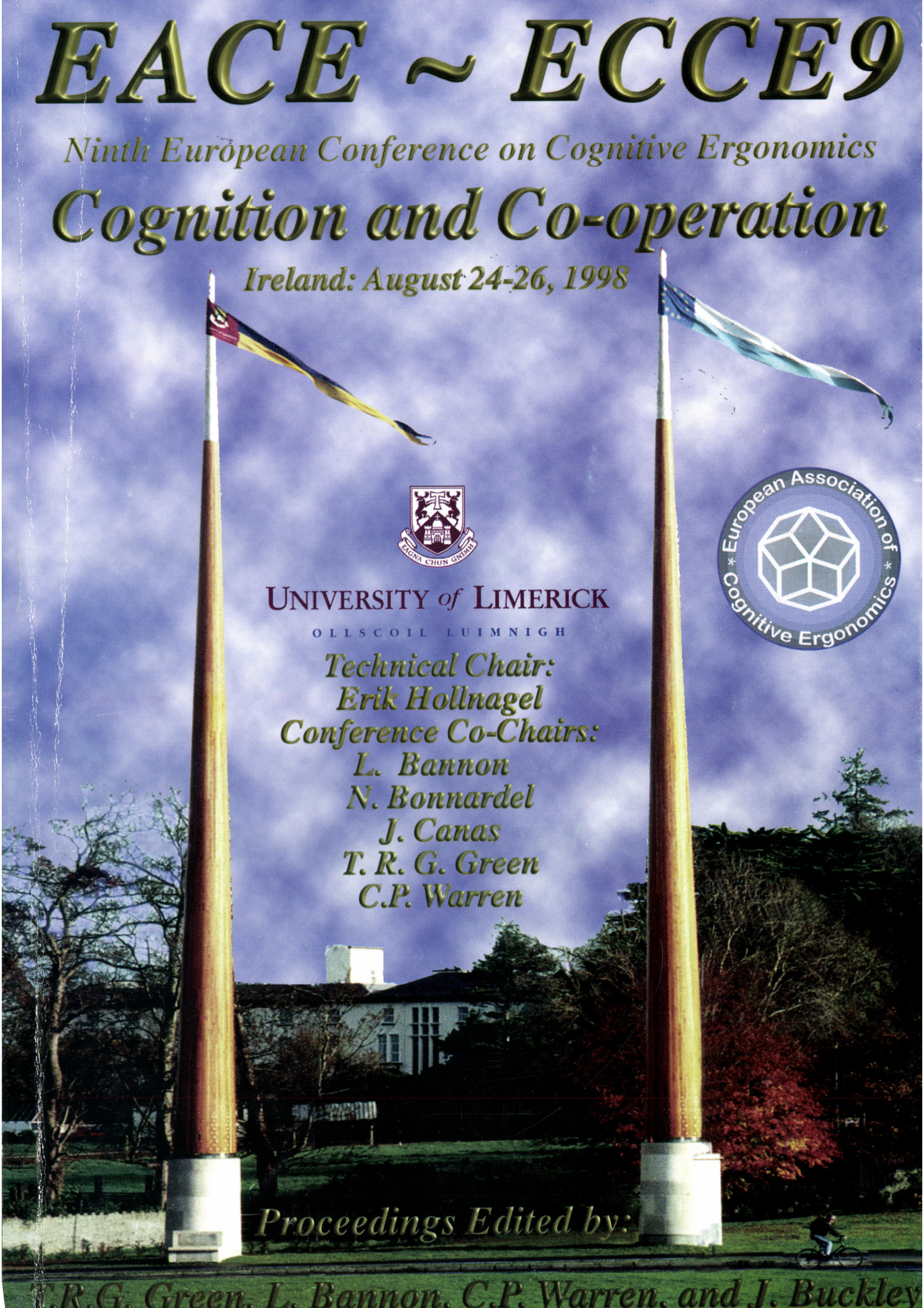
EACE ~ ECCE9

Ninth European Conference on Cognitive Ergonomics

Cognition and Co-operation

Ireland: August 24-26, 1998



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ECCE 9

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PREFACE

Welcome to ECCE-9 - the Ninth European Conference on Cognitive Ergonomics!

About ECCE-9

The main theme of ECCE-9 is "Cognition and co-operation". Cognitive ergonomics began with a concern for how people use and relate to artefacts, and how this affects the quality of work. In the past decade the growing use of information technology has, however, significantly changed the both technical and social work environment. The tasks and responsibilities are no longer confined to the local place of work, but may extend over considerable distances - indeed, around the globe or into space. Teams may furthermore exist only for a limited period of time, which makes establishing effective co-operation a primary concern. Whereas face-to-face communication is usually smooth and effortless, communication and collaboration over a distance or in a complex work environment may introduce novel tasks and demands. In cases where there is no common physical environment, co-operation becomes dependent on a establishing and sharing an understanding of tasks, resources, and constraints. Cognition and collaboration is therefore a worthy theme for cognitive ergonomics today.

The papers at ECCE-9 are grouped into a number of sessions, with the following titles: Co-operation and Communication; Designing for Co-operation; Human Performance Management; Modelling Issues; and Situation Awareness. These sessions contain papers that address both theoretical and practical issues, and in the tradition of the ECCE conferences ample time is provided for both presentations and discussions. The best papers, judged by from their contents and presentation, as well as the discussion they generate, will be considered for publication in the new journal of *Cognition, Technology & Work*. This will provide an opportunity to disseminate what happened at the conference to the larger international community of cognitive ergonomics and cognitive engineering.

About EACE

The ECCE-9 conference is organised by EACE - the European Association for Cognitive Ergonomics. The ECCE series of conferences has been organised biennially since 1984, thereby making it the oldest conference series of its kind internationally. In addition, EACE also organises a conference on Cognitive Science Approaches to Process Control (CSAPC), of which the next will take place in Lille, France, in 1999. The CSAPC series of conferences is also biennial, and the first conference was held in 1987.

The purpose of EACE is to bring together European researchers in the domain of cognitive ergonomics, which aims at bringing cognitive engineering and technical information processing system developments together to improve the design of joint, interactive systems. EACE is mainly composed of members who are confirmed researchers (i.e., who have published research related to Cognitive Ergonomics) regardless of whether they have a doctoral diploma, and probationers who are not yet researchers but registered as doctoral students and demonstrate the capacity to do research in Cognitive Ergonomics. Only members are entitled to vote in the General Assembly. The probationer status is considered as temporary; a probationer should become a member within a five-year period. Because of the European nature of the association, a member or a probationer must be a national of or domiciled in a European country. However, nationals of countries outside Europe may become corresponding members.

Membership of EACE, which currently is 40 ECU per year, is an excellent way of getting in contact with the cognitive ergonomics community in Europe. In addition, EACE members receive the regular EACE Newsletter, enjoy reduced fees to the conferences organised by EACE, as well as a number of other benefits. Anyone interested in joining EACE is encouraged to contact the membership officer: Elly Lammers at Free University, Amsterdam (email: elly@cs.vu.nl).

Welcome to Limerick and to a stimulating and enjoyable conference.

Erik Hollnagel
Chairman, EACE
Halden, Norway, July 1998

Acknowledgements and credits

Anyone who has ever been involved in organising a conference will know that it depends on the hard work of a number of volunteers. This conference is no exception, and it is only proper that full recognition is given to the following committee personnel, referees and individuals:

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ABSTRACT

When the field of cognitive ergonomics stretches out to encompass collaborative work, new issues arise, concerning for instance the research goal and methodology, the circumscription of the unit of analysis, the decomposition of the collaborative system and the role of the artifact. In this paper, collaborative work is focused as contrasted to individual work, and the unit of analysis concerns a team rather than an organization. Four possible frames for analyzing collaborative work are here compared with respect to their theoretical concepts as well as methodology. It will be shown that the frames differ in terms of to what extent they support an instrumental approach to ergonomics, the characteristics of the situations approached, how the collaborative system is decomposed and how they conceptualize the role of the artifact.

Keywords

Activity theory, control, co-operation, collaboration, co-ordination, distributed cognition, information processing.

INTRODUCTION

It has been common to talk about cognition as though this might concern only mental processes taking place within the head of one single individual. In traditional cognitive ergonomics, analyses have been performed with the aim of adapting technological systems to general characteristics of human beings as individual information processors. When new scopes for computer support are envisioned and developed, new areas for cognitive ergonomics also arise. From the point of view of cognitive ergonomics the scope of team work is fairly new. In order to approach this new scope, we have to consider what the extended domain implies in terms of theoretical concepts and empirical methodology.

New issues

The new issues which have to be approached concern how to extend the idea of "cognition" beyond the individual, the new kinds of tasks and computer systems to be considered, as well as the methodology for investigating collaborative work. The extension required to cover collaborative work may concern different units of analysis, such as a team, an organization or a society. Although researchers and studies often mix units, a simplified rendering of these units and their corresponding concepts is the following: For teams, the concepts are concerned with information processing in the team with regard to the task to be performed. For organizations, the concepts are concerned with the survival value of the organization, which relates both to its external efficiency and internal structure. Finally, for society, the issues concern history and culture, values and practices which support sense-making and future planning. These units and general concepts relate to the disciplines of social psychology, organizational theory and sociology/anthropology, respectively. The disciplines themselves are heterogeneous, and similar issues may be covered in different disciplines, but the history and culture of the disciplines are still visible in the various attempts at approaching social issues.

I will here mainly turn to the transition from the individual to the team unit of analysis. The disciplinary history and culture will be footed in psychology and social psychology. The reason for this choice is that sociologists and anthropologists have dominated the current discussions on the "turn to the social". Hereby the individual's place in the social web has been suppressed in favour of considerations of the greater unit of a social system (cf Hutchins, 1995). Since technology use still requires individual decisions and actions, a tension is created if these are not considered in the design of collaborative systems (Grudin, 1988).

FRAMES OF REFERENCE

I have found four different frames which are suitable for approaching the transition from the individual to the team in a technological setting, i.e. the group as information processor, the co-ordination/control frame, the distributed cognition approach and activity theory.

Groups as information processing units

This frame is derived from small-group research and mainly poses the question of how the information processing in groups compares to the information processing in individuals (cf Hinsz, Tindale, & Vollrath, 1997). It should be noted that the concept of "group" here may cover both groups as consisting of participants with similar tasks and roles and teams as comprising participants with different competencies and roles.

Fig. 1. A general information processing model

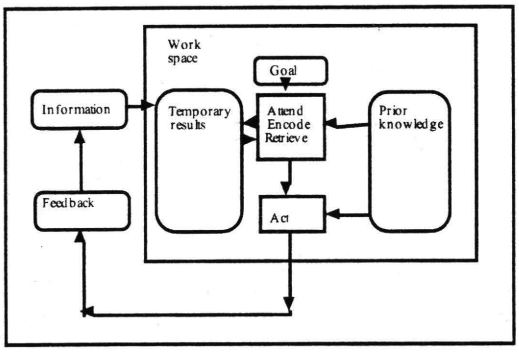


Figure 1, which is familiar to most researchers within cognitive ergonomics, shows a common way of conceptualizing information processing in general. Rounded rectangles are used to depict information repositories or a space, where information is processed. Rectangles are used to depict processes. The work space is a limited space which holds information of the objective of the current work as well as temporary information of the results of the processes. In a group, the work space may be considered as the union of what is individual and what is shared. Within the workspace, information processes are performed, which serve to interpret the information and decide upon action. The interpretation of information is dependent on the context, including the prior knowledge of the people involved. In a group, some of the prior knowledge is common, some has to be explicitly shared and some is personal. The external information is selected and transformed in the work space by attentional and encoding processes. These processes are governed by prior knowledge (top-down pocessing) as well as by the temporary results (bottom-up processing). The encoding processes and the retrieval processes from prior knowledge are controlled by the current goal, and continue until a relevant action is derived and performed. In a group, persons may negotiate their goals, communicate their encodings and selections among each other, whereby they reach a shared (which does not mean common) goal and interpretation of the situation. The actions may be joint or distributed, according to the characteristics of the task. The new information resulting from the actions is used for new rounds of processing (feedback). The frame implies a sequential information processing, where iterations of the processes are performed until the objective is reached.

As we see, the extension of the individual frame to a group setting poses a lot of new issues. What is meant by "common" and "shared", for instance? How are differences and conflicts detected and resolved? How do people know what to communicate, when and to whom to communicate in order to share information or arrive at a shared interpretation?

Within the current frame, these questions have not yet been addressed. Therefore, let us consider the concepts used, which are the same as those used for conceptualizing individual information processing as well as those used for conceptualizing computer information processing. Groups are compared to individuals in all these respects: attention, goal, prior knowledge, encoding, etc... We may ask ourselves whether these concepts are adequate for describing group cognition or cognitive ergonomics for groups. Since groups represent a more complex system, new concepts will be needed, for instance organization or co-ordination concepts or group dynamic concepts. Other important concepts refer to social interpretation or construction of goals and concepts. Interconnectivity and need for communication have also to be considered. Since the idea of the group as information processors is fairly recent, few detailed analyses as to new concepts required have been performed within this frame of reference (however, see e.g. Hinsz, (1992). A more serious objective to the frame is that the data discussed are derived from laboratory studies. The ecological validity of these studies may of course be questioned. Finally, the approach inevitably leads to comparisons between individual and group information processing, comparisons which are not at all relevant. In several circumstances it is found that groups perform less well than they might do if only the summed performance of individuals were taken into account (cf Andersson, 1996, Andersson & Rönnberg, 1995, 1996,1997, Hinsz, 1991, Janis, 1982). Such a reasoning implies that the individual's contribution to the group's result is additive (cf Steiner, 1972). In many collaborative situations, however, people complement each other with different competences, which corresponds to a product rather than a sum, i.e. without a particular competence, the result would be zero.

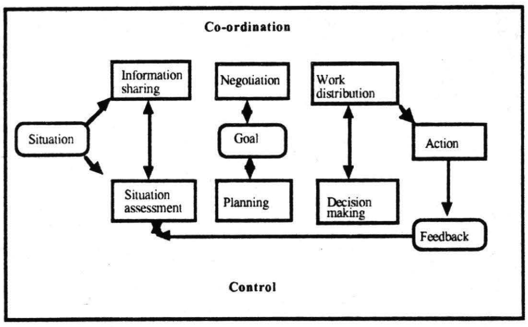
Given all these problems, it might well be considered that this approach can be neglected in any serious consideration of real life co-operation. This conclusion is too quickly drawn, however. Some field studies seem to support the laboratory findings of deficiencies in terms of group collaboration. So, for instance, some "groupthink" was evident in the

Tjernobyl accident. In some military situations, it has also been found that the group dynamics of the hierarchical organization prevent lower rank participants to question the situation assessment and decision making of higher rank officers. We can thus not dismiss the small group laboratory approach to research in co-operation, but we have to be careful about generalizing the results without looking at the situation where they were generated.

Co-ordination/Control

Next frame of reference relates co-ordination issues to control issues. This frame has been sugggested in conjunction with collaborative management of real-time dynamic systems, like forest fires, military command and control or public transport co-ordination (Waern, 1998). In these cases, people have to co-operate to handle a situation which develops autonomously, without any human intervention. The goal is either to keep the process within its normal limits (public transport co-ordination) or to act on a possible deviation and prevent as soon as possible any (further) damage to occur (emergency management). The frame integrates control theory with co-ordination aspects and is presented in fig 2.

Fig. 2. Elements of co-ordination and control



In the figure, the concepts of co-operation are found in the upper part and the concepts of control in the lower. Concepts related to processes are shown within ordinary rectangles, concepts related to information states are shown within rectangles with rounded corners. The control and co-ordination processes interact directly, as shown by the arrows between them, as well as indirectly through the entities depicted in the middle. These entities correspond to the situation, the goal and the action. The subtasks of the main task of control consist in assessing the situation, planning for achieving the goal and deciding which action to take. The action gives a result, which is fed back into the control process via the situation assessment. The co-ordination subtasks consist in sharing the information to be used in situation assessment, negotiating the goal and potential revision of it, and distributing the work with respect to the action to be taken. In contrast to the group as information processing frame, the co-ordination/control frame focuses the actions to be performed, not “spaces“, nor knowledge storage. It can be regarded as a frame concerned with the requirements of co-operation in controlling dynamic systems and can thus be used as a frame to describe current practice as well as to analyze ideas about alternative practices.

The frame has been found useful for analyzing co-operation in studying how dynamic situations are managed (Artman, 1998). The methods used include using field studies to identify relevant issues and studying these issues in detail by experimental studies in simulated environments (microworlds). Since it is proposed that the team works towards a general goal, the performance of the team as a whole may be assessed. It is not meaningful, however, as in the groups as information processors approach, to compare this performance to a pooled individual performance, since the frame is directly concerned with how individual perceptions and actions are communicated and combined.

Distributed Cognition

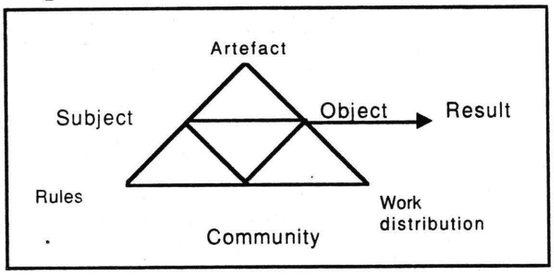
This frame approaches people and artefacts as "agents" in a joint system. These agents are equivalent, and the focus lies on the transfer of information between the agents as well as on the transformation of information, within and between agents. and focuses on the issue of how information is transformed and transferred between these agents. Within this frame, cognition is considered as a phenomenon which "emerges" from the working of the system as a whole. Co-ordination or collaborative processes are not focused per se, they are likewise considered as emerging from the working of the system (cf Hutchins, 1995, Artman & Garbis, 1998). The methodology is based on field studies with a close focus on information processing. Hutchins plays with the idea that the whole system of people and artefacts may be considered in a similar way as an individual. In an article, entitled "How a cockpit remembers its speeds" he shows how the concept of "memory" in some cases has to be attributed not only to single individuals but also to the artefacts used and the people who are responsible for keeping track of changes in the artefact as well as of the actions to be performed Hutchins, (1995). In this respect, the framework is similar to the first one, approaching groups as information processors. The difference lies in the conception of artefact, which, as already pointed out, is integrated in the same (computational) system as the human agent. It should be noted that Hutchins acknowledges the role of the individual, although he prefers analyzing the system as a whole.

The frame has hitherto only been used in a descriptive way. For cognitive ergonomics purposes, a "measurement" of performance (effort, efficiency, satisfaction, e.g.) would have to be proposed, and the instrumentality of the frame built up by searching for relationships between the outcome and observations within the system of distributed cognition.

Activity Theory

This frame (rather than "theory") is derived from the notion of "activity" as contrasted to cognition. Cognition is not focused per se, but lies within the activity system. The reason for including activity theory in this particular exposition is its current popularity among researchers within the field of computer supported cooperative work. The most interesting addition of activity theory, with respect to the other ones presented above lies in the idea of "mediation". This idea is illuminated by the activity theory triangles, shown in Figure 3.

Fig.3. The structure of activity theory



The basic structure of an activity includes three elements: the subject, the object and the community. The subject works towards an object and is related to a community. The relationship between these basic elements may be mediated in various ways. The main mediator between subject and object is the artefact, rules mediate between the subject and the community, whereas work distribution mediates between community and object. The activity gives rise to a result.

We may want to map the concepts of subject, tool and object with terms as "person" or "user" for "subject", "artefact" for "tool" and "task" for "object". However, such a mapping is to some extent misleading. By "subject" in activity theory can be meant an individual, but also a group of co-operating individuals. The concept of "object" is related to an entity which can be conceptualised or manipulated by several people in co-ordination, which is different from an individual task or the group goals talked about earlier in this chapter. The "tool" concept, finally, both enables actions and restricts the subject into actions permitted by the tool. The tool concept includes tools which are not explicitly designed, such as language. These differences between concepts in activity theory and the information processing frame of reference exist already in the original versions of activity theory (Leontev, 1978).

Activity theory is similar to distributed cognition in the respect that it is descriptive only. For cognitive ergonomics purposes, a predictive approach has to used. It may be possible to relate observations of the structural concepts of activity theory to the outcome, however, nobody has done so hitherto, according to my knowledge, at least.

Comparisons of the frames

I will now compile the comparisons of the frame with respect to some issues, i.e. the goal of the scientific approach, the specificity of the domain approached, the decomposition of the system into elements and the role of the artefact. Table 1 summarizes the comparisons.

Table 1: Comparisons of frames

	Scientific goal	*Specificity of domain*	*Decomposition of system*	*The role of artefacts*
Groups as information processing units	Prediction	Best applicable to situations of independent and additive co-operation	Individuals	No role inside the frame
Co-ord-ination/ control	Prediction	Best applicable to dynamic situations	Tasks and subtasks	No role inside the frame
Distri-buted cognit-ion	Description	Best applicable to highly regulated domains	Individuals and artefacts	Integrated in the same comput-ational system as people
Activity theory	Description	No restriction on domain	Subject/object/ society/mediator	Mediating between subject and object

The first comparison refers to the scientific goal. The goal of ergonomics is predictive, since it is concerned with adapting design to human characteristics in a way that results in efficiency, satisfactory workload and worker acceptance. Only the two first frames currently enable predictions from the system studied, by explicitly searching for relationships between internal components and the external outcome. The two last frames currently only work with descriptions, and thus are not yet suitable for ergonomic purposes.

The second comparison concerns the type of domain or situation for which the frame is most applicable. It can be seen that activity theory has got the most imperialistic claims, and the original proposal for the frame of groups as information processors does not contain any restriction as to domain either. However, the analysis of the data shows that it is most applicable to situations where people co-operate in an independent and additive way. The distributed cognition and the co-ordination and control frame have been used in particular situations, relying upon the participants' expert skills.

The third comparison concerns the decomposition of the system studied. As Simon (1996) has pointed out, many systems are at least partially decomposable, and there are several ways of decomposing a system. The differences in choice of elements reflect the research interests of the various frames. The group as information processor approach only considers individuals as elements, whereas the distributed cognitions approach considers individuals and artefacts. Activity theory uses a more complex decompositional strategy by the focus on main actors (subjects or society) working towards an object, and mediators between these main actors and the object. Finally, the co-ordination/control frame is rather simple in focusing its decomposition into tasks and subtasks: system management tasks versus co-ordination tasks.

Finally, the role of the artefact varies between frames. In the first two frames (the group and the co-ordination/control frame), the artefact is kept outside of the frame as such, whereas in the last two frames (distributed cognition and activity theory), the artefact is included in the frame. It is difficult to tell which of these theoretical approaches is most suitable for cognitive ergonomics. On the one hand, traditional cognitive ergonomics might prefer to keep the artefact separated from the human user, since a separation facilitates systematic research of design of artefacts as related to human issues. This conceptualization is most compatible with the view on human "interacting" with artefacts. On the other hand, conceptualizing artefacts as "mediating" between subject and object or as nodes in an information processing network might better reflect an expert use of the artefacts, where the artefact is as transparent that the user does not have to pay any attention to it.

The differences indicate that there are not only practical reasons (i.e. applicability for a particular problem) for choosing one frame rather than another. There are also political reasons (the frame which gets most use is the most prestigious one), comprehension reasons (the frames map differently against different researcher's prior knowledge) and goal related reasons (the frames map against different scientific goals). It might for instance be suggested that only those frames which relate outcomes to the relationships between people and artefacts (and thereby enable predictions) are useful for cognitive ergonomics purposes. However, it may also be the case that the frames which hitherto describe only, on the level of people and artefacts, may find their predictive factors with another circumscription of the system, one that includes organization, society or culture. I sincerely invite other conceptualizers to join in a creation of a theory which has the following desirable characteristics: it works with a unit of analysis which includes several subjects, it incorporates artefacts as mediators and it can predict the efficiency/effort/user satisfaction of a system comprising people and their artefacts.

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Ambiguity and Problems of Communication in Air Traffic Control

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ABSTRACT
We present the findings of a data collection exercise, based on a questionnaire, in the domain of Air Traffic Control. The key issue is the language ambiguity that can cause serious problems and may lead to accidents. Air traffic controllers have been shown to be aware of the problem and have proposed possible solutions that could be implemented in current traffic control systems.

Keywords
Communication, Team work, Air Traffic Control, ambiguity, Accident analysis

INTRODUCTION
The objective of this study is the analysis of the problems and issues derived from the communication processes in the domain of Aviation and Air Traffic Control (ATC) and, in particular, of the role played by "ambiguity" of language in the interaction between controllers and pilots. This problem has been highlighted by well-known statistics (Rankin and Krichbaum, 1998) which show that the third cause of aviation accidents can be attributed to communication problems between air traffic controllers and pilots (Figure 1). Typical examples of accidents caused by communication problems are the accidents of Tenerife (1977) and the accident of Orange County (1981). Moreover, the above mentioned statistics show that, contrary to the general trend, air traffic control together with maintenance, are the only two categories that have shown an increase over the last ten years, while causes related to other categories, like aircraft, crew, and weather condition have actually decreased.

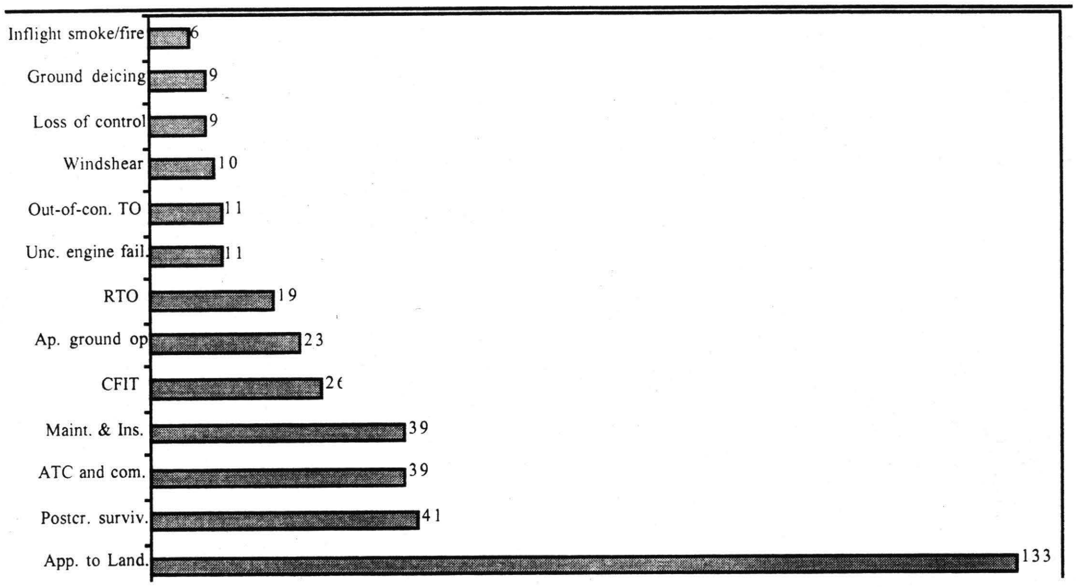
The need to improve further aviation safety and reduce the rate of accidents to avoid a critical increase in number of events by the year 2025, requires that also the ATC related accidents are carefully studied and controlled by inverting the positive trend. One of the most relevant technological means by which ATC is expected to improve is the application of "data-link" and "free flight". Data-link is one of the most important technological improvements that will allow the increase of flight density and frequency planned and expected in the next two decades. By data-link the use of verbal communication in standard language will be replaced by automatic transfer of information requiring only visual perception by the traffic controller, instead of the standard "classic" combined aural-visual and oral perception, understanding and communication.

Consequently, the question of "language" and "ambiguity", and the issue of verbal communication in general, have been somewhat disregarded and, perhaps, not sufficiently considered as a potential area of analysis and intervention for reducing further human contribution to accidents. The objective of many studies is focused on the development of means for the precise coding and presentation of information, rather than the analysis and prevention of aural-verbal communication.

However, while the introduction of advanced modern technological tools may be rather rapid and may occur in a short time scale in many countries, in others the use of verbal communication in standard language will continue to be the most common means of interaction between ground and cockpit. This issue may have an important impact in accident causation if not considered with sufficient attention and understanding.

The specific issue of ambiguity in language has been already studied and well analysed by

Figure 1. Aviation accident statistic (from Rankin and Krichbaum,1998)



Cushing (1994). who has shown how many aviation accidents contain one or more inappropriate performances derived from incomprehension or inappropriate language

This paper shows how the problem of ambiguity of language could be studied and tackled by means of some simple field study, based on data collection by a questionnaire and associated analysis (Nanetti, 1998). The aim of the questionnaire is the identification of the reasons and forms of language ambiguity and the evaluation of the degree of the awareness of air traffic controllers of this specific issue. In the following section two examples of catastrophic accidents related to the problem of language ambiguity will be briefly described. Then the questionnaire that has been developed will be presented, and, finally the results obtained in the specific application of an Italian ATC environment will be discussed.

AMBIGUITY AND ACCIDENTS

The intrinsic complexity and flexibility of natural language are the source of incomprehension in many every day situation in normal life. When the language is utilised as a means of communication in a technical domain like the air traffic control the risk of some negative consequences becomes relevant if the verbal communication are not controlled and formalised according to well-defined rules and regulations. The chance of confusion and incomprehension between controllers and pilots can result in phenomena typical of ambiguity of assumptions, uncertain references, implicit inference etc. These factors may be generating events leading to accidents. However, more frequently they are contributors to the development of accidents, in combination with other, usually marginal and per-se irrelevant, conditions that "chain" in a very unfortunate sequence leading to disaster.

The aviation accidents of Tenerife (1977) and Orange County (1981) are two typical examples of tragic events related to problems of communications between cockpit and control towers. In particular, the accident of Tenerife, is linked to a specific sentence pronounced by one of the crew members "we are at takeoff", by which he was informing that the aircraft was at the end of the runway in position and waiting for the authorisation for takeoff. However, the specific sentence was interpreted as if the crew was initiating the procedure that leads to takeoff position. This was not the only cause of the accident, but certainly the ambiguity contributed to the misunderstanding in locating the exact position of the aircraft in the airport area that was totally obscured by very heavy fog.

In the accident at the John Wayne Orange County airport on February 17th 1981, the misunderstanding between the two pilots was engendered by the significance associated with the verb "hold". In aeronautical terminology, "hold" means "stop the ongoing process", while in the every-day conversational sense it can imply to continue doing whatever actions are being carried out. The temporary transfer of the level of exchange of communications between the captain and the first officer, from a technical jargon to a more colloquial exchange of sentences, generated the misunderstanding between the two pilots that led to the catastrophic landing with retracted gear.

These two examples show clearly the need to:

- Explore in more detail the degree of awareness of pilots and traffic controllers about the need for the adoption of appropriate formal language in their communication; and
- Identify where and when appropriate training and understanding is required with respect to such issues, before critical events occur.

Moreover, in order to ascertain that the issue has to be appropriately retained by the pilots and air traffic controllers, it is necessary to convey the message in the appropriate social and cultural environment that surrounds the specific working domain under study.

THE QUESTIONNAIRE

The aim of the questionnaire is to evaluate the awareness of air traffic controllers on the use of appropriate formal language in their communications. Another aim is to define the most appropriate framework for transferring such concepts through training. An important result of such analysis is also the definition of the root causes of ambiguity and the forms that ambiguous expressions can take amongst air traffic controllers and between air traffic controllers and pilots.

The questionnaire is very simple contains only 10 questions, in addition to the general information on the respondent that allows the statistical differential analysis. The first 6 questions are oriented to generating in the respondent some form of awareness or recollection of the "ambiguity" issue in communications. Question 1 covers the knowledge about human factors in relation to accidents. Question 2 tackles the issue of communication in incidents/accidents. Question 3 contains the term "ambiguity" and explores the respondent ability in perceiving the problem. Question 4 aims at identifying what ambiguity implies for different actors. Question 5 explores the level of experience of the respondent controller. Question 6 covers the relative weights of controllers and pilots in creating ambiguity in their communications.

Questions 7 to 10 concentrate on specific issues of ambiguous communications by presenting precise situations and exploring controllers' knowledge and attitudes.

As the aim of the study was to demonstrate the applicability of a questionnaire for studying the problem of ambiguity, and not the quantitative evaluation of the issue of ambiguity of language in a specific ATC centre, a limited number of questionnaires have been distributed and analysed. In practice, only 15 questionnaires were distributed and 13 were in fact returned for the analysis. This is obviously a non-representative sampling, in statistical terms, of the population of air traffic controllers belonging to the same nation or cultural root. However, the answers received have been considered particularly representative for a stereotyped situation and national culture. This is particularly true, as the Area Control Centre where the questionnaire was distributed manages almost half a million aviation movements per year. Moreover, the 13 controllers who returned the questionnaire were very experienced and knowledgeable controllers, in terms of working time and general background education.

ANALYSIS OF RESULTS

The results of the questionnaires has been carried by reviewing the answers given to closed questions, 1-6, and by comparing the data with larger statistical information, and by analysing the answers to open questions, 7-10.

Answers to closed question

The controllers have shown a good awareness of the likely causes of accidents in aviation. In particular, the ranking resulted from the response to question 1 (Figure 2) can be compared with the statistical summary of commercial jet aeroplane accidents for the last 10 years (Rankin and Krichbaum, 1998). This statistics shows that cockpit crew is the most relevant cause of accidents, followed by maintenance, aircraft, meteo and airport/ATC.

From the analysis of the questions more related to the specific problem of language ambiguity/communications and its impact on safety, it firstly appears that the controllers are perfectly aware of the problems, which can arise both amongst controllers and between controllers and pilots (Figure 3).

The interaction between controllers and pilots is considered particularly important, while there is a very strong agreement on the sharing of responsibility between pilots and controllers with respect to the contribution to ambiguity in communication (Figure 4). Moreover, as discussed below, many controllers have clear opinions about the causes and relevant factors that may be affecting such problems.

Looking in more depth at the likely causes and factors that may influence or generate communications problems or ambiguity, it results that the change or shift from standard language to colloquial informal communication or expression is the most relevant source of ambiguity (Figure 5), both for pilots and controllers. This cause is followed by problems in reception or radio frequency.

The analysis of the working environment conditions that are more prone to generate problems of communication and ambiguity (Figure 6), shows that a condition of emergency or the night shift do not seem to represent a problem in the controllers' view, whereas the generic "workload", use of English language and the transfer of duties at shift change are the most important contributors.

Focusing on the human related aspects of communications, the major problems seems to arise in the case of novices, or young controllers, or when there is low familiarity with English or with use of standard ICAO (International Civil Aviation Organisations) language (Figure 7). It is important to note that in this case, the pilots' attitudes or experience does not seem to represent a problem for the controller, while the interaction with other very experienced controllers may give rise to misunderstanding and communication issues, due to excess of familiarity/confidence with the job.

Figure 2: Answers to question 1: According to your knowledge and experience, please rank the given list of likely causes of aviation accidents in order of importance.

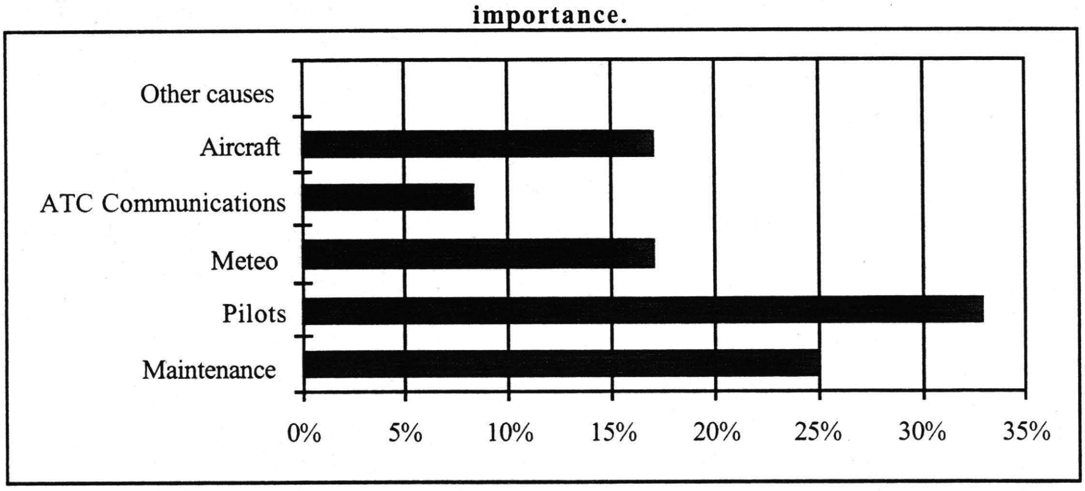
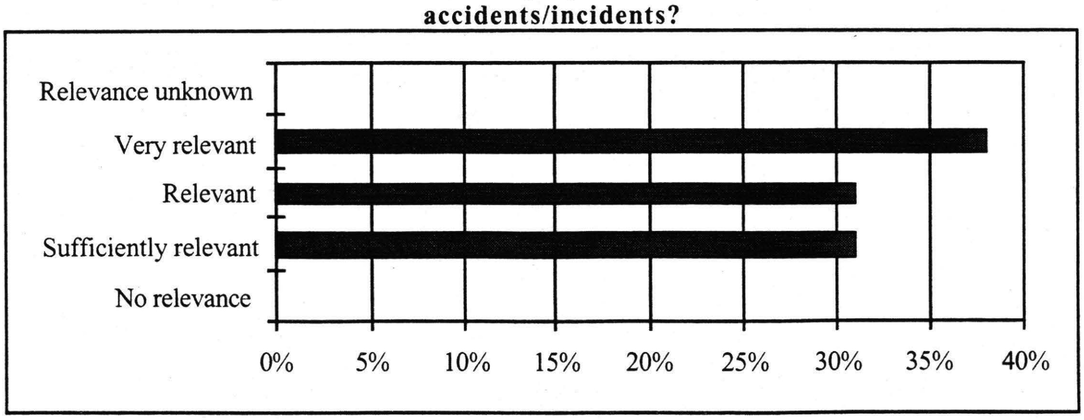


Figure 3. Answers to the question 3: According to your experience, how do you consider the problem of " ambiguity in communications" in aviation accidents/incidents?



Answers to open questions

The open questions represent a moment in the answering to a questionnaire when people can express ideas, opinions, suggestions and judgements on their working environment and condition in general.

In the case of the controllers, the problem of ambiguity was clearly recognised and many suggestions were made on how to tackle it. The need to communicate in an "as-clear-as-possible" format when specifying clearances was generally recognised as the most common event of error. In particular, the possibility to mix flight levels with radio frequencies has been given as an example of too familiar utilisation of numbers. Another important proposal focused on the need to provide and promote as strongly as possible the utilisation of standard language. While the first of these two suggestions can be promoted and performed, the second one, i.e., the adoption of a language that is free of ambiguity, seems almost a utopia, as no language can actually be developed that allows communication without possibility of misunderstanding and incomprehension.

In summary, the answers to the open questions strengthen the findings of the closed questions, as they prove the awareness of the controllers of the problem of ambiguity.

CONCLUSIONS

The research project discussed in this paper had the objective to evaluate whether the issue of communication, and, specially, ambiguity, is appropriately perceived by air traffic controllers and if the forthcoming technological innovations, like data-link, is perceived as a solution to the problem.

The question of the possibility to resolve the problem by technology has been debated. The authors' position is that, while from a purely theoretical standpoint, the use of data-link seems to resolve the issue in a complete manner, from a more practical viewpoint, the communication between ground and cockpit and within the cockpit will continue to play a critical role. Moreover, while many current problems of communications, e.g., radio frequencies, altitudes, headings etc., may be well resolved by data-link, other types of communication errors, possibly more subtle and dangerous, may be introduced.

In order to collect the opinion of controllers, the use of survey by means of questionnaire was applied. The results obtained, although quantitatively irrelevant, given the low population of controllers to whom the questionnaire was distributed, can be summarised in the following points:

- The air traffic controllers are perfectly aware of the importance of the problem of ambiguity in communication;
- The most important areas and the principal sources of misunderstanding have been highlighted and some suggestions for amelioration has been identified, even if some are not practically applicable.

Following this preliminary survey, a more extended study should be carried out in the area of ATC, so as to further evaluate and consolidate the findings of the present study. Moreover, the results of the study should be compared with the views of pilots.

In any case this preliminary study has proven that the issue of communication needs be further studied, rather than abandoned, as if the whole problem could be solved by the introduction of new advanced technology.

ACKNOWLEDGEMENTS

The authors are grateful to Professors Cristina Cacciari and Marco Depolo of the Department of Psychology of the University of Bologna for their collaboration and precious support in developing the questionnaire.

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Figure 4. Answers to question 4: Who do you think are the primary responsible/contributors for ambiguity in ATC communications?

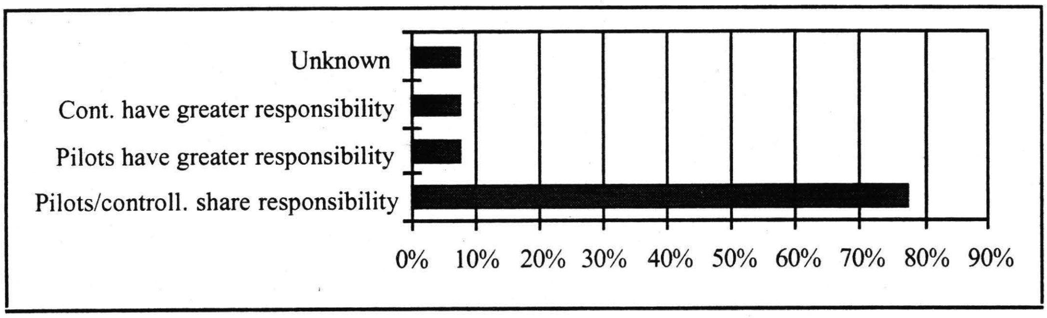


Figure 5. Answers to question 6: According to your experience when is it more likely that a communication in ATC causes problems?

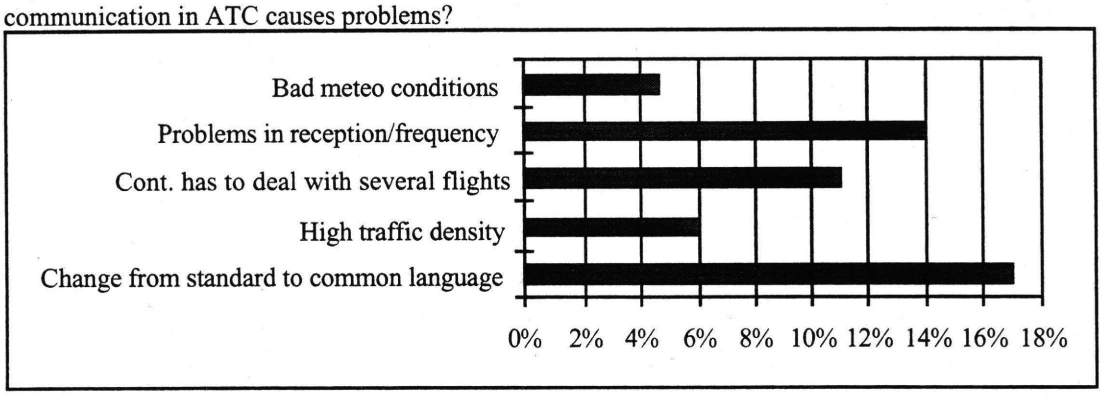


Figure. 6. Answers to question 3: according to your experience, which are the working conditions that are more likely to generate ambiguity in the communications.

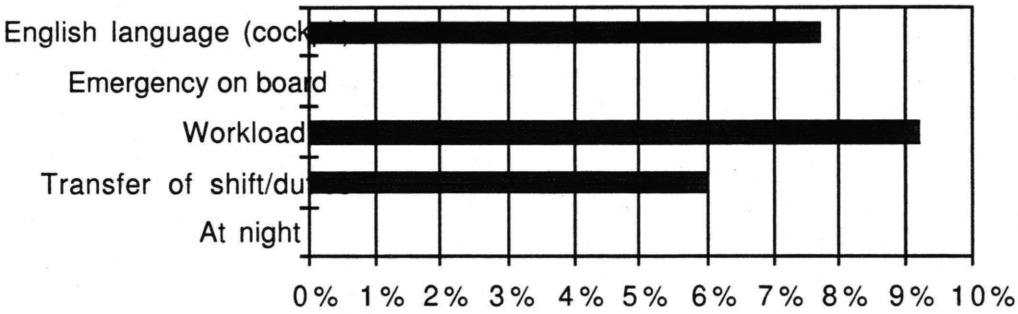
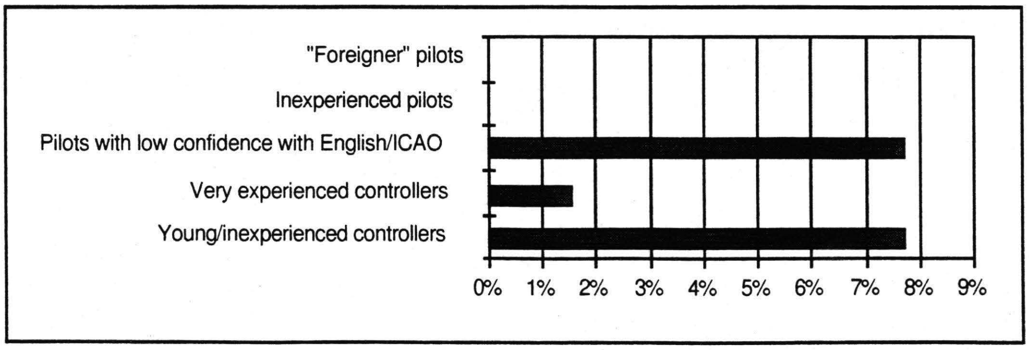


Figure 7. Answers to question 5: according to your knowledge and experience in which type of communications the problem of ambiguity occurs?



Communication of Handicapped Persons in a Telematic Environment

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ABSTRACT
Levelt's theory on speaking suggests that in communication Cognitive Effort Resource Planning (CERP) takes place. The main question that prompted the two experiments that are described in this paper concerned the CERP that takes place in handicapped persons performing communicative, language like actions. Suggestions that CERP took place came from the observed compensating strategies in the experiments. These strategies seem to be invariant with respect to channel configuration however. This suggests that persons hardly adapt to different surroundings in their cognitive styles. If this is true channel, designs should be adapted to the cognitive styles.

Keywords
Cognition, effort resource planning, communication channels, cognitive styles.

INTRODUCTION
> "... one cannot dissect the speaker's skill into components without carefully considering the tasks these components, alone and together, have to perform (Levelt, 1989, Chapter 2, 'The Speaker as Interlocutor')".

Expression of content can be treated as contextual. People generally consider this contextual aspect as a semantic feature, suggesting that one's performance expresses somehow an adaptation to the environment. But the contextual nature of expressive performance may also be of a more formal nature. It may for instance depend on the communicative format of the channels that enable the expression, thereby influencing the expressed context in unexpected ways.

The problem that gave direction to the research was rather practical. It concerned the role of communication in the social integration of handicapped people. We think that telematic environments that support co-operation, or, more specific synchronous and a-synchronous MUMM (Multi User Multi Media) systems, can be configured and designed in such a way that the control over the communication can be manipulated in favour of the handicapped person. We hope that the results of the experiments provide suggestions and a rationale for intuitions with respect to the optimal design and configuration of these kind of systems.

COMMUNICATION AND HANDICAPS
It is well known that the application of different media may cause a shift in the participant's control over communication (Clement, 1990; Kiesler & Sproul, 1992; but see Weisband, 1995). This shift is mainly accomplished through the manipulation of informal aspects of communication. These aspects are informal in the sense that their presence has no explicit representation in the formal part of the communication. Informal aspects of communication consist for instance of task related performances like back-channelling, perception and generation of co-messages and interruptions, prosodic aspects and all kind of gestures. A consequence of their informality is, amongst others, that they are as such not present in the communication and can therefore not be used in the argumentative structure. However, the informal aspects, when in fact processed, have an implicit influence on the formal contents of communication.

For the current discussion it is fruitful to make a distinction between personal and channel constraints on communication. Furthermore we suppose that both types of constraints can be interrelated. For instance, a person that suffers from hemi-paresis, (one sided spasticity) and that has correlational articulatory problems may experience difficulties in face to face communication. A problem may be that he[1] has problems to finish his contribution within appropriate time constraints. A sympathetic partner in the conversation may then try to help the speaker to finish his utterance. Unfortunately the control over the communication is now transferred to this "helping" partner.

A medial constraint is for instance interruptability. Interruptability or "barge-in", the possibility of two communicators to interrupt one another, is for

[1] Everywhere where "he" is written "she or he " is meant.

instance present in normal human-human telephone conversations but not in the interaction of a human with most interactive spoken language systems. In that respect these systems resemble e-mail, where a packet-parcel approach is adopted towards communication. One only publishes one's utterance once it is finished and approved of.

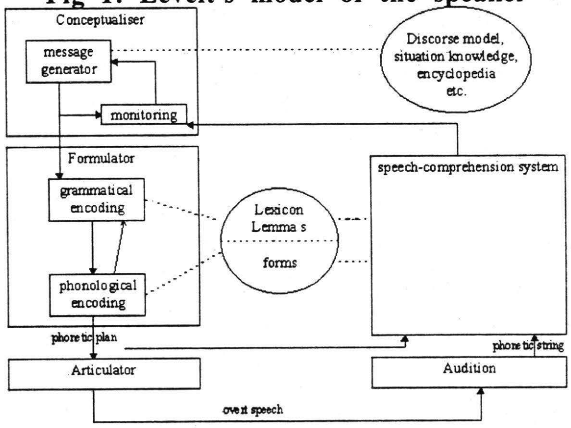
A spastic person with an articulatory handicap, which most spastic persons have, has a problem with interruptability in face to face communications. It needs effort to barge-in at a specific point in the conversation. This suggests packet-parcel communication above barge-in telephone communication. On the other hand badly sighted persons prefer in some situations telephone barge-in communication above face to face communication. In these telephone communications the disadvantage that is caused by the inability to cope with visual co-messages and back-channelling is removed. These casual observations suggested that different handicaps lead in different degrees to a social handicap and furthermore that environments can probably be designed to (partly) overcome these handicaps.

Interacting constraints

In the current experiments we focus on those aspects of communication that have to do with controlling an ongoing conversation. In doing so we hope to understand in a more fundamental way the casual observations that were described above. The aspects we focus on are for instance temporal constraints, both with respect to channel and personal limitations. Channel constraints are for instance interruptability and co-visibility. Personal constraints may, as suggested, be comparable to channel constraints. Perceptual disabilities are for instance comparable to limitations of the receiver channels of communication. Both represent problems to decipher or interpret a signal. Motor constraints are on the other hand comparable to the limitation of sender channels of communication. Both represent problems to encode a message into a decipherable or interpretable message.

In analysing the influence of the handicaps and the manipulation of media dimensions on communicative performance we oriented ourselves with Levelt's theory about the generation of spoken language (1989, see figure 1). And although this theory primarily concerns itself with cognitive constraints on the (human) generation of speech his model and the inherent principles can easily be generalised to the analysis of the influence of perceptual and even mental handicaps on communicative performance in general.

Fig 1: Levelt's model of the speaker



Levelt's model is an abstract informationprocessing model. It does not specify the exact nature of the processes that are responsible for the articulation of a certain content (but see Levelt and Roelofs, 1999). An important aspect of Levelt's model is however that constraints are supposed to be modular. Furthermore, although the modular processes may in some sense be treated as encapsulated and parallel, there is a restricted cost allocation of attention within but also between the modules.

This feature predicts for instance that more attention for the formulation of an utterance restricts the amount of attention that can be allocated to other aspects of an utterance like conceptualisation or prosody in the articulation. It also explains that time pressure on articulation may lead to less attention for the prevention of articulation errors.

Levelt's theory thus suggests that when a certain module draws heavily on resources other modules have to suffer. From a rational, cognitive point of view this means a kind of cognitive effort resource planning (CERP). The model therefore predicts that specific handicaps because of different cost-benefit profiles have specific repercussions for the conversational process. In the following alinea's I hope to show that these repercussions are relevant in the sense that they explain and predict some aspects of the influence of a handicap on communication.

There is empirical evidence for adaptive CERP in the case of some handicaps. For instance, some people suffer from an aphasia in which their ability to plan a single grammatical utterance is limited to a certain maximal complexity (Kolk, 1995). People suffering from this kind of deficiency tend to economise by planning a relatively large number of relatively short utterances, thus allocating attention to the conceptual module.

For persons with an articulatory handicap the theory would on the other hand predict that in conceptualising, formulating and planning an utterance, the high articulation costs are minimised by another strategy. For instance, articulation costs are minimised by a more abstract language use. This is supposed to be an effect at the textual and not at the sentence level. While the actual and predicted impairments described above are supposed to have an influence on the construction of meaningful communication, interpretation problems may be caused through impairment of the receptive abilities.

For instance, a deficit in the audition module may lead to excessive attention allocation to speech-comprehension modules, while a retinal deficit may in a communicative situation necessitate more verbal co-messaging and thus to allocation of effort to the planning module of the speech system.

Besides CERP Levelt's model also suggests that channel restrictions may imply different cost allocation profiles. For instance, if articulation of content needs relatively more effort, as in writing, this may lead to a more a more abstract and concise use of language (Clark and Brennan, 1991) and thus to a heavier burden on the higher cognitive modules.

We suppose furthermore that these repercussions imply suggestions for the use and design of MUMM environments because, as mentioned, the constraints on communication due to handicaps and those due to channel constraints interact. For instance, if, thanks to retinal damage or another visual handicap, someone fails to interpret co-messages of his partner, this is a disadvantage. It may be remedied through a manipulation in which the other partner also misses the visual information so that they are on an equal footing. For an articulatory handicap on the other hand the disabled person may benefit from limiting the speaking channel, for instance by completely shutting it down or by limiting interruptability. In an IRC [Inter Relay Chat] like situation for example the handicapped person is allowed to finish his utterance before somebody in the larger chat community is allowed to publicise his own utterance.

It may also be that specially designed interfaces and intelligent agents may aid the handicapped in communicative situations. For instance, it has been shown that presenting the basic grammatical structures of a sentence to the speaker can alleviate some of the cognitive planning problems that were involved in the previously discussed aphasia.

HYPOTHESIS

Our general hypothesis is that communication relevant handicaps, on the coding or the interpretation side of communication, lead to a certain type of adaptive economising which we have called CERP, cognitive effort resource planning, leaving its traces in communicative performance.

The general hypothesis should of course be interpreted according to the situation at hand. Cognitive economising is for instance in the case of acticulatory problems not sentence- but text oriented. That is, a person suffering from an articulation deficiency would try to formulate a text that may comprise any number of utterances, in the smallest amount of morphemes, thus delimiting his articulation costs. It may furthermore be directed at the construction of short sentences because it reduces the amount of relatively costly prosodic devices.

Because of the general nature of the hypothesis it is not possible to test the general hypothesis in a single experiment. As a first effort we investigated the influence of different degrees of visual impairment on the communication process. And although the main reason was the availability of research facilities at the moment, it was also inspired by the wish to validate some casual observations made in clinical literature. In a second research effort we tested the influence of different media conditions on the performance of youngsters with an articulatory handicap. We tested among other things the hypothesis that CERP takes place at the sentence level by an investigation under different personal and media conditions.

THE EXPERIMENTS

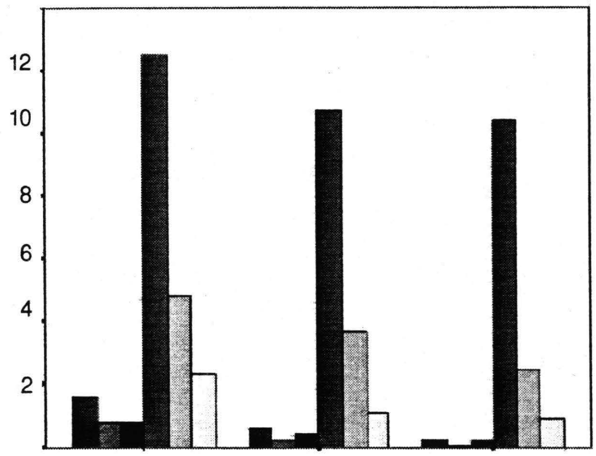
In two experiments, one in the area of sensory and one in the area of motor handicaps, we investigated some of the ramifications of the above described theoretical and intuitive notions. In both experiments we used a linearisation task where one subject instructs another subject. In a linearisation task abstract spatial configurations with different complexity profiles have to be described.

Although the configuration is abstract it is supposed to be possible to generalise the performance of describing such configurations to all kinds of realistic tasks that imply the notion of describing a spatial structure. Examples of such tasks are for instance describing an interface, a layout on a motherboard, a seating arrangement at a table or a route through a city. The main advantage of the Levelt task or a similar one is that it not only allows us to use competence metrics, metrics with respect to result characteristics (time taken and number- and types of errors) but also performance metrics, metrics with respect to process characteristics. Such a performance metric for abstractness is, for instance, the amount of chunking, "now three to the left", while a more concrete and listener friendly strategy is expressed by a procedural "to the left, once again to the left and one more". There are thus clear normative models for the task execution available that can even be expressed as computational models in the format of ATN's, Augmented Transition Networks or Contextual Grammars.

Experiment 1

In the first experiment we investigated how VIP's (visually impaired persons) communicate with well-sighted people as compared to people without a visual impairment. The experimental subjects were arranged in pairs where one of the subjects, the describer of the spatial configuration, was without a visual impairment. The decoding and handicapped partner had to copy the described arrangement on a draughtboard for visually handicapped people. The experimental manipulation consisted of varying the visual ability of the partner, the "maker" of the descriptions. Three levels were distinguished, well sighted (N=8), severely impaired (N=5) and blind (N=3). The distinction between the severely impaired and blind people was made after the experiment was executed because in the analysis of the data we became aware that it seems that severely impaired and blind subjects do not belong to the same experimental population. This is exemplified by the results of the experiment (fig. 2).

Fig. 2: Effects of visual handicaps - mean conversational units per session



three sets of five columns:
three sets: blind, badly sighted, normal.
six columns: overlap total, overlap informal, overlap formal, units describer, units maker, units informal maker

It was our first hypothesis that if the maker had a visual impairment, and thus was less able to make use of visual co-messages, he and the describer would compensate by verbalising more. A second hypothesis was that more overlap would occur because co-messages regulate turn-taking.

In the figure blind, disabled and normal persons are compared on six dimensions. From the figure it can be seen that blind people exhibit more overlap, which was expected and confirmed the second hypotheses about the role of visual clues in turn taking. Blind people seem to have difficulty knowing when their partner has finished or wants to start an utterance. The group with badly sighted makers had considerably less problems but still significantly more then the well sighted. Furthermore it is informative to notice that informal overlap decreases steeper with increasing visual competence then formal overlap. This suggests that formal overlap is often purposive, while informal overlap may be more accidental.

In the casual literature it is furthermore suggested that blind persons tend to control the conversation through talking more. However, from the figures it seems that, in accordance with the first hypotheses, the (non impaired) describer also talks more in the blind condition. This suggests that it seems to take more conversational units to describe a configuration to a blind person, probably also because visual co-messages such as pointing could not be used. It is furthermore noteworthy that the total number of speech units of the describer in the badly sighted and in the good sighted condition was not significantly different. Badly sighted makers seem to be able to use the communicative efforts of the describer as well as the well sighted makers.

The differences between blind and badly sighted are in general larger then the differences between the badly sighted and the people with no visual problems. This is illustrated by the amount of overlap between utterances.

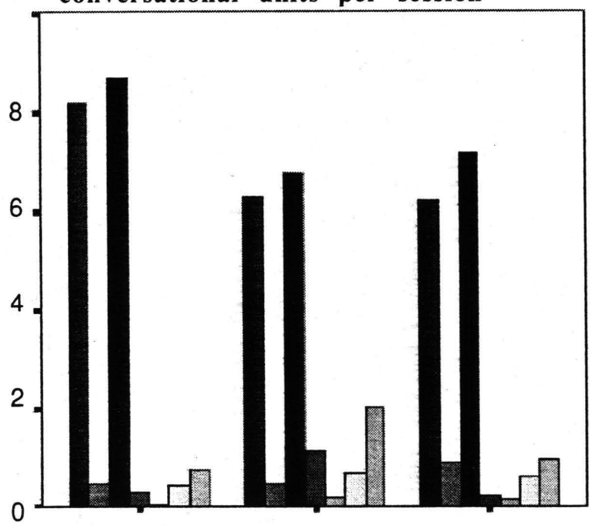
Experiment 2

In the second experiment we studied the influence of physical handicaps on communicative performance. In preliminary research it was experimentally established that if persons are restricted to IRC chatlike communication they tend to use, in comparison to normal face to face situations, fewer words, almost no "informal" words and more abstract words. Abstractness was amongst others measured by the imagibility values of the words. In the follow up investigation we wondered whether this relationship also holds when differences in articulatory competence are present. In this study we again used the linearisation task in the testing of our current hypotheses.

There were three groups of subjects, now in the role of describer. The maker was a trained researcher who was instructed and trained to respond with a more or less constant attitude towards the partner who had to describe the figures. The first hypotheses and the main one was that spastic describers used fewer units then the other two groups. Another hypothesis can be derived from the first one. The more abstract speech units are made, the less the maker has to say, especially with respect to the formal, task oriented aspects of the communication.

While the main experimental variable in the former experiment was ordinal (no-bad-well sighted), our current variables are categorical. The first one is of course the type of handicap of the maker; the second is the type of communication channel. The type of handicap variable has three values. Besides the spastic experimental group we used the spina bifida group as a control group. However, because it is thought that persons with spina bifida are excessive in their use of language we also used a control group of non-handicapped persons. The channel variable had two values. The first channel condition was a face to face condition, while in the second condition the maker was hidden behind a screen. We actually also had a third condition as a kind of baseline where there was no maker at all but just a taperecorder.

Fig. 3: Effects of motor handicaps - mean conversational units per session

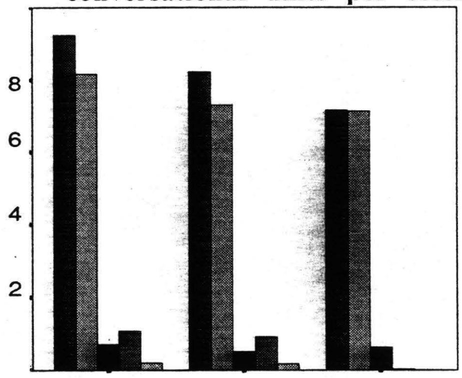


three sets of seven columns:
three sets: spina bifida, spastic, normal.
seven columns, formal units describer, informal units describer, total describer, formal units maker, informal units maker, yes maker, total maker.

The main results with respect to the variable "type of handicap" seem clear cut and are significant. The talkativeness of spina bifida is confirmed while the spastic describers tend to economise. Surprisingly, there is no significant difference between spina bifida describers and spastic describers for informal units. The normal controls on the other hand generate significantly more informal units. This suggests that the talkativeness of the spina bifida describers arises from the fact that they make bad formal task oriented descriptions. They do not easily come to the point.

Another clear distinction is that the maker of the configurations needs more units, probably in back channelling. This is for instance suggested by the increased number of "yes"'s by the maker in the spastic situation.

Fig 4: Effects of channels - mean conversational units per session



three sets of five columns:
three sets: visual channel, non-visual channel, recorder,
five units: total units, units describer, informal units describer, units maker, informal units maker (the last two missing in the recorder condition of course)

The main result with respect to the variable "channel" was not as expected (fig. 4). Some observations can be made. In the visual condition significantly more units were uttered by the describer while the utterances of the maker remained relatively constant over both visual and non-visual conditions. This suggests that in some way the visual channel stimulated less optimal performance and that this can only for a small part be contributed to a visual stimulation of informal communication. It is also interesting to notice that the describers behaviour was not significantly different in the non-visual and the recorder condition, even where it concerns informal communication. The last observation confirms a casual observation that informal communication occurs also if there is no real partner present but only a recorder.

A result that cannot be read off from the above picture is that there seems to be no interaction between the variable type of handicap and the variable channel. This may of course be due to the relatively small number of persons within the categorical variable type of handicap (N=6 for all levels). If the observation is valid however this may point to the existence of special cognitive styles for (handicapped) persons, styles that proliferate across communication channels. In some sense this provides a nuance for the casual observations mentioned in the introduction of the paper that a special configuration of communication channels helps handicapped persons in controlling the communication. The best strategy seems to be to try to adopt to the existing personal style in designing communication channel configurations.

DISCUSSION

The main question that prompted the experiments reported on in this paper concerned, first, the cognitive effort resource planning that takes place in persons performing communicative, e.g. language actions. It seems that the severity of a visual handicap predicts some variance with respect to CERP. If the severity of the handicap increases more overlap errors are observed while also more information units are exchanged, probably in an attempt to compensate for visual feedback. It seems however that this relation is non linear because persons with a severe visual handicap who are not blind resemble normal persons in their communicative efforts. Furthermore we did not investigate the effects of learning because the experimental sessions were relatively short and no significant change in the performance was registered.

CERP was also observed in the communicative efforts of people with motor handicaps. On the one hand spastics tend to economise in the number of their formal utterances while their communicative partners spend a lot more on the construction of formal and informal units. This may be because of the less partner friendly communicative strategies but also because of difficulty in the auditory aspect of the speech of the handicapped speaker.

With respect to the influence of channels on communication it was observed that visual communication stimulates the describers language performance. This was contrary to the idea that removal of the visual channel would increase the number of language units to compensate for the loss of visual feedback. Interesting to note was also that it did not matter much if the describer talked to a person or if the describer talked to a tape recorder.

Even more interesting is the finding that different types of handicaps showed no interaction with different channels. This may mean that the number of persons in the group was to small to measure an effect or that different handicaps are characterised by cognitive styles, irrespective of channels configurations. The consequence could be that different channel configuration do not lead to different communication styles but that channel configurations should be adopted to the communication style. Finally it should be remarked that these observations with respect to cognitive styles are beyond the Levelt model. This model cannot explicitly model cognitive styles as such because it is just a formal model of processing constraints. However, it is able to explain why such styles do arise and what their consequences may be.

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Cooperation, Interactions and Socio-Technical Reliability in Air-Traffic Control: Comparing French and Irish settings

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ABSTRACT

In complex work settings, collaborative activities do not only enable activities to be performed, but also contribute to the reliability of the socio-technical system. We describe cooperative activities observed in the domain of Air-Traffic Control, in two different countries. French and Irish controllers, despite differences in terms of organisation and resources, implement similar cognitive processes in order to ensure the efficiency of their activities and the reliability of the whole system. We illustrate the role of multimodal communications, mutual monitoring and mutual awareness in the system reliability, before addressing design-related issues.

Keywords

Cooperative Work, Communication, Air-Traffic Control, Reliability, Mutual awareness, Mutual Monitoring.

INTRODUCTION

Cooperative activities in complex work settings have been the focus of various studies along the past decade, interested either in people's use of technology, people's interactions and modes of cooperation and lately relations between human activities and so-called global reliability. Some of these studies highlight the importance and the impact of naturalistic and ethnographically-based analyses upon the design of CSCW systems and the reorganization of work (Filippi and Theureau, 1995; Heath et al., 1995).

Within this framework, this paper address the problem of system reliability through the analysis of the cooperative aspect of air traffic controller's activities in each location. More precisely, we analyse the impact of each working environment on a set of processes that are related to cooperation and that organized our looking at the sites: *Mutual Awareness, Mutual Monitoring and Communication.* From a reliability perspective, our assumption here is that, by contributing to cooperation, these processes contribute also to the reliability of the systems.

The domain of Air-Traffic control (ATC) is one of the most widely analysed in this context (see for example Bressolle et al., 1995; Hughes et al., 1992, Salembier, 1994). Indeed it combines the features of safety-criticality, cooperative environment and high technologies. In this domain, people (air-traffic controllers) are performing cooperative activities while using various computer-based systems and "human-machine" interfaces.

Despite the presence of local failures (both human and technical), the system is globally reliable, as very few accident occurred these past years.

Field studies of air-traffic control have been performed in two different countries (France and Ireland). The comparison between our observations leads us to underline the presence of similar processes, in spite of organisational and technical differences. The aim of this comparative analysis is first to identify generic mechanisms observed in collaborative work settings and second to understand how these are implemented in specific situations.

First, the working situations are presented, in describing both the similarities and the differences between the work settings. In the second part, underlying processes such as mutual awareness, mutual monitoring and communication are illustrated with examples issued from the field studies. In the last part, we discuss the presence of similar processes, despite the local organisational and technical specificities and and highlight how these processes contribute to the global reliability of ATC systems.

THE AIR-TRAFFIC CONTROL ACTIVITY

Field studies have been performed in air-traffic control centres both in France (Athis-Mons) and in Ireland (Shannon). The data collection first consisted in task description, through visits and interviews with the management. Later, video-recordings of the actual activities were performed during peak hours.

The activity of controlling the Air-Traffic differs according to the geographic area concerned as well as the location of planes in the air space. Three main sectors of control are usually identified, the en-route, the approach and the tower. The control of high level traffic is called "en-route control" and is the focus of the present studies.

Description of the work settings

The purpose of this paper is to show how different controllers in different work settings perform similar activities, implementing similar mechanisms in order to achieve the same general goal, i.e. ensure the process and the safety of ATC, despite differences in the two control centres.

In both situations, the main actors involved in en-route control a planning controller (PC) and a radar controller (RC). In both settings, the two controllers are seated side by side, and thus have the opportunity to monitor each other's actions, to use complementary modality of communication (verbal / gestural, visual / auditive). Communication media are also similar (telephone and radio), and similar artefacts are used: radar screens, flight strips and strip progress board.

Yet, as we are now going to see, there are some differences between the two sites (see figure 1). In this paper we restrict the comparison to aspects we identified as relevant regarding our research objectives, i-e the task distribution, the available artefacts and the audio resources.

Task distribution

In the Irish case, the RC focuses on monitoring the current traffic on the radar and takes in charge the communications with the pilots, as well as with other radar controllers in charge of adjacent sectors. He/she handles real-time operations. The PC is in charge of anticipating (hence planning) the expected traffic, and thus handles the strips, i-e organises them on the strip board according to the status of the various planes. As we will see later on, this organisation of the strip is meaningful to the RC. Even if this latter radar controller is the main interlocutor in charge of the planes currently in the sector, it is important to underline that both controllers are able to use the radio and thus talk with the pilots or hear current communications. This is mainly enabled through the use of a micro-equipped headset.

In the French case, the RC monitors the current traffic on the radar and takes in charge the communications with the pilots. He/she also uses the strips on which he/she annotates instructions given to pilots and organises them (the strips) to represent information about flights (location, destination, etc.) particular aspects of the traffic (conflict between flights, abnormal aircraft, etc.). The PC takes in charge the communications with planning controllers from adjacent sectors. Sometimes, she/he helps the RC in the handling of strips and in the traffic management (conflict detection and resolution).

Artefacts

(1) Radar screen: In Ireland, only one radar screen is available on each position and located in front of the RC. In France, in complement to this radar screen (also located in front of the RC), a second one is located in front of the PC. This second screen offers a wider image of the situation, presenting the foreseen traffic.

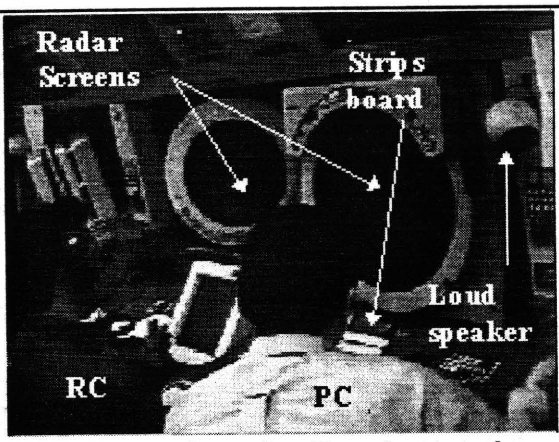
(2) Strip progress board: In Ireland, the strip progress board, handled by the PC is located in front of this latter. The controller puts on the left part strips expected within the next 20 minutes, while planes entering the sector or already within the sector are organised on the right part of the board. In the French site, the strip board is located in front of the RC and can be seen and accessed by the PC.

Audio Communications: As stated before, in Ireland, the controllers use headsets which enables them to communicate with the pilots through the radio. These headset also enables telephone communication usually between controllers from adjacent sectors to be directly supported (in combination with the use of a telecommunication keyboard). Yet, in this case, as opposed to the radio communication, only the controller using the telephone is able to hear it in his/her headset. The information are not broadcast on both headsets.

In the French control site, radio communications between pilots and radar controllers can not be heard through the headset; yet a loud-speaker can be used by the PC to hear communications between pilots and the RC.

AWARENESS, MUTUAL MONITORING AND COMMUNICATION IN COMPLEX COOPERATIVE WORK SETTINGS

As shown by several empirical studies of complex cooperative work settings performed within different domains of research (ethnomethodology, anthropology, cognitive ergonomics, CSCW), the efficient coordination of distributed activities and the reliability of work depend on a set of key processes that are combined dynamically and which lie at the intersection of cognitive and social activities (Martin et al., 1997; Morvan et al. 1996).



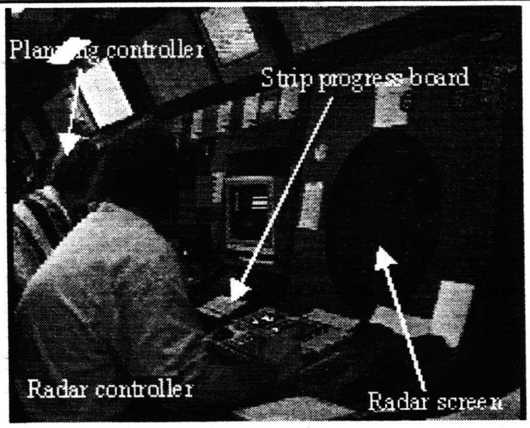


Figure 2a. A view of a French control position. 2b: A view of an Irish control position.

Among these various processes, we identified as relevant and crucial Mutual Awareness which is closely related to mutual monitoring and communication.

Mutual Awareness (MA) is a CSCW notion referring to the awareness that individuals of a cooperative ensemble have of each other's activities, intentions, and so on. It accounts for the fact that in cooperative work situations, participants track and attend to the activities of their colleagues through overhearing and/or overseeing processes. In other words, they distribute dynamically their attention on the basis of what they have to do at a given time in a given situation and of the relevance of events they perceive contingently or in a planned way. MA is also made possible by communication in the sense that it allows individuals to maintain their awareness of each other's activities and so forth. The public availability of artefacts or tools and of their use also support MA by allowing participants to understand and make sense of other's actions and to recognisetheir intentions. More generally, it was observed that people use information provided by artefacts in combination with what they hear or see and with what they know about the situation to make inferences that allow them to attribute intentional states (beliefs, wants, intentions, and so on).

MA is close to the notion of Team Situation Awareness (TSA) which is an extension of the notion of Situation Awareness (SA). TSA aims at taking account for the nature and cognitive properties of teamwork (Salas et al., 1995). In order to understand the relation between TSA and MA, note that the "situation" may include member's tasks, actions, and so on. TSA have been defined in different ways. For example, Endsley (1995) referred to TSA as both the SA required for each team member and the overlap in situation awareness that is necessary among team members, particularly for coordination. In this view, MA can be considered as an overlap of team member's SA including information about others.

MA is also close to what Bratman (1992) call *mutual responsiveness* which is considered by this author as an important characteristic of Shared Cooperative Activity (SCA). Mutual responsiveness refers to the fact that in SCA, each agent attempts to be responsive to the intentions and actions of the other, knowing that the other is attempting to be similarly responsive.

Mutual monitoring refers to the fact that in cooperative work settings individuals monitor each others' actions. This monitoring allows the coordination of actions and contribute to the robustness of the system despite the occurrence of local problems (Rognin et al., 1997) by enabling the detection and repairing of errors. Mutual monitoring is enabled by the the possibility for individuals to see or hear each others' actions. In other words, mutual monitoring is tightly connected to MA.

In collaborative work settings, **communication** allows agents to broadcast information about their activities, their intentional states and also about other events. Thus, communication contributes to the maintaining of mutual awareness among the cooperators. Communication also enables them directing or drawing the attention of the other participants to relevant events, possible problems and disturbances, etc.

COMPARATIVE ANALYSIS

Mutual Awareness and Monitoring

In both sites we observed that controllers often look at and listen to their colleague and track their actions in order to keep themselves informed of the activities of the other. Also, controllers often behave consciously or unconsciously in such a way that colleagues can perceive their actions and infer their intentional states. In other words, controllers often render their activities publicly visible. It is important to note that this process of rendering one's activity visible to others is afforded and facilitated by the physical co-presence of controllers.

Let us describe how, both in Ireland and in France, controllers use visual and audio monitoring in the course of their collaborative activities.

Visual monitoring

The two main artefacts providing shared visual external representation of the on-going process are the strips progress board and the radar screens. They can be described by virtue of their own functional properties: a strip for example can be shown, annotated, given, shifted, ... All these provide cues to identify/reconstruct the state of the environment (traffic) and/or the course of action the controller is engaged in.

In Ireland, the visual control loop between the PC and RC makes it possible for the RC to monitor the strips updating performed by the PC: the RC sees peripherally his/her colleague writing on the strips, and then infers from that the action performed. Examples of explicit requests following an absence of updating have been observed.

In France, the flight progress board located in front of the RC is actually managed by both controllers. It plays the role of an external memory and supports the collective decision-making process by giving cues to past, present and forthcoming actions. This aspect enables the controllers to refer to an "on going shared context" when needed and to mutually check each other's actions. E.g., if the controllers during a collective conflict solving step decide to give a flight a heading, and if the RC forgot to do so, this can be detected by the PC by looking at the strip without any explicit request at a first time.

Audio monitoring

As described above, the Irish controllers are both able to hear the communications with pilots on the radio frequency. This opportunity is extensively used by the PC in order to monitor the instructions given by his/her colleague as well as the feedback received from the pilots. Not only this information is essential for the elaboration and updating of a shared representation of the situation, but it is also used by the PC to perform his/her task. Indeed, every time a pilot acknowledges and accepts an instruction, the PC annotates the associated strip with up to date information. The access to audio information avoids explicit feedback from the RC to the PC. As described above, the visual monitoring, in combination with this audio one, increases the reliability of cooperation in enabling controllers to implicitly cross-check their activities.

In France, the RC is in charge of both monitoring the planes and updating the strips. This explains why the PC has not access to the radio communications. Yet, as we observed, it is usual for the controllers to switch on the available loud-speaker. Why would controllers add complementary sources of annoyances? It appears that this information provides a knowledge of the current situation and gives to the PC the possibility to monitor both the instructions and their acceptance.

This leads us to stress the role played by the PC in the reliability of the control, in contributing to the error detection and recovery.

Mutual awareness is based on the possibility given to each participant to monitor the activities of the others. By allowing the detection and repairing of troubles and errors, this process of monitoring plays an important role in the robustness of the global system despite the occurrence of local problems. As illustrated in Rognin et al. (1997), mutual monitoring is one of the processes enabling the emergence and continuous use of control loops directly contributing to the reliability of the socio-technical system.

Multimodal communication

In Air-Traffic Control, various modes and types of communication are observed. Besides direct face-to-face communications between the planning and the radar controllers, many verbal communications are mediated, by radio with the pilots and by telephone with controllers from other sectors.

Yet, non-verbal communications play an important role in the activity of Air-Traffic controllers. Due to their closeness and the existence of shared artefacts such as the radar and the strips, the co-located controllers are able to use gestures and actions in order to exchange information. For example (Figure 2) it is usual for controllers to point at the radar screen to draw attention to a specific event. Similarly, one controller might look ostentatiously and with insistence to his/her colleague in order to stress a need for attention.

So, in both French and Irish work settings, controllers combine verbal acts and gestures in order to communicate with each other.

Here we contend that the combination of gestures and oral communicative acts plays an important role in the reliability of understanding process: providing redundancy gestures helps to reduce the potential ambiguity of speech-based communicative acts. Thus multimodal communication may prevent miscommunication problems (misunderstanding, misinterpretation, etc.) and improve the intent recognition process.

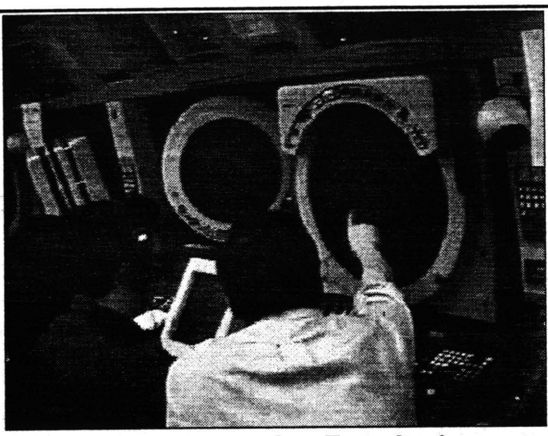


Figure 3a: French site

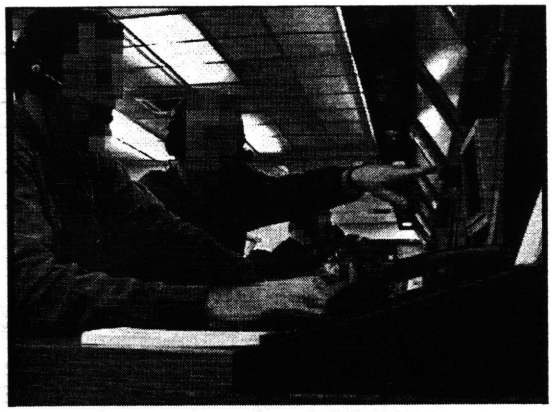


Figure 3b: Irish site

Multimodal communication, combining verbal and gestural information (pointing at the screen)

DISCUSSION: DESIGN ISSUES

The results of these comparative field studies not only confirm the emergence and efficiency of processes such as mutual awareness and mutual monitoring, but also illustrate how, despite different working environments, similar cooperative processes are observed. These organisational and environmental characteristics also support the reliability of controllers' cognitive activities.

Besides the similarities in their objectives, the controllers from both sites share one major feature, which is the performance of their task within a shared work space, in which they are able to access information of diverse nature. As we described, controllers use these information not only to perform their individual task, but also to ensure the reliability of the whole system.

In both locations the controllers base their activities and the implementation of various cognitive processes on the open nature of the work space. The public nature of both visual and audio information enables them to monitor the current state of affair and infer how to collaborate with their colleagues.

We saw in our examples that these intertwined processes of mutual monitoring and mutual awareness are essential for reliability in the sense that they provide a safety net, making the best of the presence of two controllers on the positions. These processes also enable people to anticipate potential needs and thus may reduce the costs associated explicit communication.

As illustrated in this paper, the controllers use similar mechanisms and behave similarly, despite differences in the work settings and in the organisation. This seems to indicate that human cooperative mechanisms are inherent to human nature rather than dependent on the work arrangement (for example, task allocation).

The comparison shows that in the presence of different organisations (work settings and task distribution), controllers still manage to implement similar processes such as the audio and the visual monitoring, or the use of multimodal communication. The point here is not to look for the best setting, but rather to understand how people get round systems limits and implement useful and reliable collaborative processes. Once these processes are identified then settings which will not endanger or prevent their occurrence (rather than actively support them) will be possibly suggested.

Our analysis of cooperative work activities in different sites imply that if one wants to re-organise (for example, by the introduction of new technology) these work environments, then one needs to take into account the cooperative processes described in this paper. In this context, it is important to be able to assess the potential impact of a modification on these processes.

An important step toward this goal will be the development of a framework for conceptualizing and reasoning about these processes. In this context, although MA is often mentionned as a central element in cooperative activities (Bellotti and Rogers, 1997, Schmidt, 1994), it is still fuzzy and not well understood. Its use is still based on intuitive understanding and there is no commonly accepted definition. For these reasons, there is a lack of models that allow us to understand the relations between work environments and MA. Yet, the SIM'COOP environment (Salembier et al. 1997) for example, constitutes an attempt to fill this gap by providing a conceptual and methodological framework that enables us to analyse the impact of new work environments on MA in cooperative work settings.

CONCLUSION

Two work settings have been compared to examine the impact of the organisation of work and the artefactual environment of each site on the collaborative processes we have identified as crucial for cooperative work and system's global reliability (mutual awareness, mutual monitoring and communication).

The examples from the field studies show how, despite diversity in organisations and in environmental resources, the controllers implement similar processes in order to handle efficiency their work. The next step of this joint project will be to provide a formal description of the two work settings (task allocation, relevant artefacts, MA processes,...) using a single conceptual framework (SIM'COOP) in order to perform simulation with similar samples of traffic. The objective is to identify what would be the potential consequences of introducing modifications in each settings on mutual awareness.

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Euterpe: Tool Support For Analyzing Cooperative Environments

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ABSTRACT
This paper describes EUTERPE, a support tool for analyzing cooperative environments. The support is based on a formal analysis of the task model and can be done both on a logical and a visual level. An analysis of a cooperative environment requires a model that can formally describe the task world and that allows meaningful analysis to be done. Euterpe uses a logical model that is based on Groupware Task Analysis which describes the task world including cooperative aspects. By modeling the task world in logic and deriving graphical representations from it, several ways of analysis become possible.

Keywords
Tools, Cooperation, Task Analysis

INTRODUCTION
Task analysis is a useful way to get better insight into cooperative environments. However, it is often also a very unstructured and time-consuming activity. Many methods exist, but thoughts on task models and what they describe exactly have not been stabilized yet. Furthermore, task analysis methods usually only deal with task *modeling* and not really with task *analysis*. After the task world has been modeled it is up to the analysts to interpret the task model and find out where causes of problems can be found or where there is room for optimization of the work. These may be one of the reasons that cause task analysis to be both ineffective and inefficient.

A task model that can describe the task world including cooperative aspects and that allows some form of analysis could improve the task analysis process and outcome. Preferably the analysis of the task model should be done at least semi-automatically, thereby reducing the required effort of the analysts. D'Ausburg et al. (1998) describe a formal approach based on model checking techniques for analyzing user interfaces. A similar approach can also be applied to analyzing task models. However performing a formal analysis of a task model requires a formal representation of the task model that is suitable for doing an analysis, especially for analyzing cooperation. The task model therefore needs to be based on a task analysis theory that recognizes the cooperative aspects of the task world.

Although a formal analysis can be the basis for analysis it is not on the level analysts prefer to work. Hence representation tools can effectively hide the formalism and provide means to assist in analyzing the environment that is being studied. In addition, a tool can also provide more structured ways of doing task analysis. The next sections describe such a tool - EUTERPE - based on Groupware Task Analysis that supports formal analysis both on a logical and a visual level. Both the used models and the analysis primitives will be described in the next sections.

ANALYSIS TOOLS
In the area of task analysis or requirement engineering (Loucopoulos et al., 1994) there are many techniques and to some extent tools that can be used. Especially in the first phase of collecting information and representing structures not many tools turn out to be useful or available for actual use. An interesting tool however is for instance U-TEL (Chung-Man et al., 1998) which is a tool that assists in elicitation of user task models from domain experts by natural language processing and wizards. It is part of the model-based user interface development environment MOBI-D (Puerta, 1997). However, the task models that can be specified are rather simple and do not allow roles and responsibilities to be specified nor are any analyzing primitives provided. In fact they are not intended for describing cooperative aspects of the task world. Some commercial software tools also exist. WinCREW is a tool for analyzing the behavior of small tank crews and the Observer (Noldus, 1991) is for human behaviour analysis based on video analysis. Although they were intended for analyzing cooperative environments they use mostly statistical methods. However for analyzing a cooperative environment a formalism is needed that explicitly recognizes and describes the cooperative aspects of the task world. Such a formalism would consequently allow more deeper analysis than just statistical evaluation.

GROUPWARE TASK ANALYSIS

In the past task analysis has focussed mainly on analyzing a single user and his/her tasks. Groupware Task Analysis (Veer et al. 1996) expands task analysis by looking at a task world from the perspectives of work, agents, and situation. It regards the task world as an organization where many people do tasks, work together and interact with both people and objects. From the perspective of **work** GTA looks at tasks, goals, actions and procedures within an organization, while from the perspective of **agents** GTA looks at the persons and machines that perform the work, their role is the organization and the allocation of responsibilities. When looking from the perspective of **situation**, the static and dynamic aspects of the task environment are studied, including the objects that are present and events that happen internally or externally.

In Veer et al. (1996b) we present a field study where GTA was used to analyze a cooperative environment, in this case the social security administration. These perspectives have been elaborated formally into an ontology (van Welie et al., 1998) for describing a task world. The ontology describes how GTA looks at the task world independently of graphical representations, by describing the concepts and the relationships between them.

EUTERPE

Our task analysis tool, EUTERPE, named after the muse presiding over the arts and sciences, is a graphical tool for entering and analyzing task analysis data. It uses the ontology as the basis for generating representations. The ontology is operationalized using DLP (Eliëns, 1992) an object oriented variant of Prolog. The ontology is specified in terms of concepts such as task, object, role, agent, event and relationships between them, represented internally using a logical programming language. The logical representation is on an abstract level and it does not imply any graphical representation. However, it is rich enough to accommodate the extraction of the information necessary to generate commonly used representations such as tree structures, process flow graphs or templates. The task world ontology is a model that describes a way of looking at a task world. We look at the task world in terms of a number of concepts that are related to each other. The following section will briefly explain the concepts and their relationships. A more detailed description can be found in van Welie et al. (1998).

Concepts and Attributes

This section will define the concepts and the next section will define their relationships in detail.

Object. An object refers to a physical or non-physical entity. A non-physical entity could be anything ranging from messages, passwords or addresses to gestures and stories. Objects have attributes consisting of attribute-name and value pairs. What can be done with an object is specified by actions, for instance *move*, *change*, *turn off* etc. Furthermore, objects may be in a type hierarchy and can also be contained in other objects.

Agent. An agent is an entity that is considered active. Usually agents are humans but groups of humans or software components may also be considered agents. Agents are not specific individuals (like Chris) but always indicate classes of individuals with certain characteristics.

Role. A role is a meaningful collection of tasks performed by one or more agents. A meaningful role is *responsible* for the tasks that it encompasses and roles can be hierarchically composed.

Task. A task is an activity performed by agents to reach a certain goal. A task typically changes something in the task world and requires some period of time to complete. Complex tasks can be decomposed into smaller subtasks. Tasks are executed in a certain order and the completion of one task can *trigger* the execution of one or more other tasks. A task could also be started because of an event that has occurred in the task world.

There is an important distinction between unit tasks and basic tasks; ideally a unit task should only be executed by performing one or more basic tasks. The relationship between the unit task and basic task is interesting because it can indicate the problems that an agent may have in reaching his goals.

A unit task, as in GOMS, is defined as the simplest task that a user really wants to perform. A basic task is a task for which a system provides a single function. Usually basic tasks are further decomposed into user actions and system operations. A user action is an action done by the human users that is only meaningful in the context of its basic task (e.g. a key press). A system operation is an action done by a system; it is not a typical task because it, as such, serves no goal for the user.

Event. An event is a change in the state of the task world at a point in time. The change may reflect changes of attribute values of internal concepts such as Object, Task, Agent or Role or could reflect changes of external concepts such as the weather or electricity supply. Events influence the task execution sequence by *triggering* tasks. This model does not specify how the event is created or by whom.

Relationships

The concepts defined in the previous section are related in specific ways. In this section we sketch the relationships. For each relationship the first-order predicate definition is given and explained. Figure 1 shows all the concepts and relationships.

Uses. The uses(Task,Object,Action) relationship specifies which object is used in executing the task and how it is used. The Action specifies what is being done with the object. It typically changes the state of the object.

Triggers. The triggers(Task/Event, triggeredTask, triggerType) relationship is the basis for specifying task flow. It specifies that a task is triggered (started) by an event or a task and the type of the trigger. Several triggertypes are possible such as OR, AND, NEXT to express choice, parallelism or sequences of tasks.

Plays. Every agent should play one or more roles. The plays(Agent, Role, Appointment) relationship also indicates how this role was obtained. Currently, the Appointment parameter can be ASSIGNED, DELEGATED, MANDATED or SOCIAL.

Performed_by. The performed_by(Task, Agent/Role) relationship specifies that a task is performed by an agent. Whether the agent is also the one who is responsible for the task depends on his role and the way it was obtained. When it is not relevant to specify the agent that performs the task, a *role* can also be specified as the performing entity.

Subtask. The subtask(Task, SubTask) relationship describes the task decomposition.

Subrole. The subrole(Role, SubRole) relationship brings roles into a hierarchical structure. The subrole relationship states that a role includes other roles including the responsibility for the task that encompass the role. When a role has subroles the task responsibilities are added up for the role.

Responsible. The relationship responsible(Role, Task) specifies a task for which the role is responsible.

Used_by. The used_by(Object, Agent/Role, Right) relationship indicates who used which object and what the agent or role can do with it. The agents' rights regarding objects can be of existential nature (CREATE and DESTROY), indicate ownership (OWNER), or indicate daily handling of objects (USE, CHANGE).

The relationships of this model form a minimal set of relationships that exist. However, there are also other relationships that can be of interest. Consider for instance a relationship *involved_role* that indicates which roles are involved in a task. Such a relationship could be defined as the roles of the agents involved in the task and all the involved roles of the subtasks. The *involved_role* relationship is not part of the ontology because it can be defined using only the relationships of the ontology.

Deriving Graphical Representations

EUTERPE offers several representations, all generated from the same data to guarantee consistency,. including task trees, object hierarchies, templates with detailed information about entities such as tasks and objects, entity lists and process graphs. Kaindl (1993) discussed the importance of availability of task analysis documentation to clients or project members, and suggests the use of hypertext documentation. EUTERPE can therefore generate HTML documentation that shows all the data including links between entities. In order to incorporate ethnographic data it is also possible to attach video fragments, images or sounds to any of the entities.

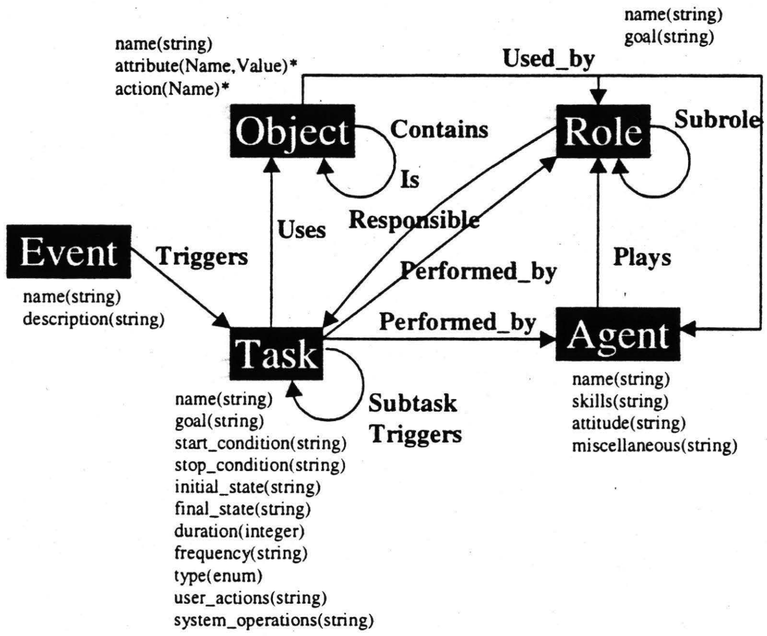

Figure 1 Concepts and relationships

FLEXIBLE REPRESENTATIONS

When designers using EUTERPE needed to explain the problems they found in their analysis, they often colored certain nodes in task trees to indicate problem areas. Reasons for coloring were often closely related to attributes of entities such as tasks and objects. Common remarks were that certain tasks take too much time or happen too often, or that certain people do things that they officially are not allowed to do or that they do things with objects for which they officially did not have the appropriate rights. We found out that exceptions to the "official way of working" gave interesting information about the task world. Most remarks were things that could be "detected" by logic expression on our model. This led to the addition of analysis primitives to EUTERPE.

ANALYZING COOPERATION

The basis of EUTERPE is that the theory of GTA is formalized into the ontology and that the ontology is represented as a first order predicate logic. The representation of an ontology in logic allows us to analyze the task world in all its facets, the people with their work and the organization they are part of. One criticisms on task analysis has always been the fact that it remained unclear what exactly to do with the data. What should be next is an analysis of the data, finding problem areas and designing a "New World" that relieves these problems. The analysis usually has an informal character and is based on insight. However, we found that some problem areas have a more general nature which are domain independent.

- **Problems in individual task structures.** The task structure is sub-optimal because too many subtasks need to be done or certain tasks are too time-consuming or too frequent.
- **Differences between the formal and actual task performance.** In cooperative environments, usually regulations and work practices exist which are documented, for instance as part of ISO9000 compliance. In reality tasks are mostly not performed exactly as is described on paper and that "one way" of how the tasks are done does not exist. When persons in a cooperative environment think differently about what needs to be done, problems arise.
- **Inefficient interaction in the organization.** Complex tasks usually involve many people who need to communicate and interact for various reasons, such as knowledge about tasks or responsibility for tasks. This can be the cause for time-consuming tasks but also for irritation between interacting people.
- **Inconsistencies in tasks.** Tasks are defined but not performed by anyone or tasks are executed in contradictory order.
- **People are doing things they are not allowed to do**. In complex environments often people have to do tasks without official permission or they are using/changing objects they are not allowed to change.

Of course not all of these problems can be automatically detected. However our model can detect many problems semi-automatically by providing the analyst with a set of analysis primitives. Analyzing a cooperative environment can be done when the data present in the model is transformed into qualitative information about the task world. EUTERPE basically has two primitives of qualitative analysis. First of all visually in graphical presentations. When the data has certain features, these can lead to modifications of the graphical representations. The second primitive is to analyze the data on a logic level by putting some constraints on the model. Constraints that cannot hold may show interesting features of the task world. These two primitives allow several ways of analyzing a task model. We distinguish four ways: *inspection*, *analysis*, *verification* and *validation*. In the next sections these ways of analysis will be elaborated and clarified with examples.

Inspection

Inspection means browsing through your data. A task model based on the ontology is a complex model. In projects done by designers the task models typically consists of about 100 tasks, 20 object, 15 roles, 10 events and 10 agents. This a lot of information that needs to be understood. Graphical representations in general show specific aspects of the data, for instance a tree shows the hierarchical structure of tasks. Other useful representations include flow graphs, interaction diagrams, templates and hyperlinked structures. Euterpe offers several of these representations and provides a coherent and consistent view on the data.

Additionally a coloring mechanism can be using to tune the graphical representations e.g., the coloring of nodes in a tree can be used to analyze task/agent allocation. The user can specify a condition for coloring of a node, for instance "all tasks performed by Chris". The user can choose from a range of predefined conditions of specify the condition in logic. Conditions can be arbitrarily complicated and range from showing task/agent allocation to showing instances of delegation of task responsibility. Figure 2 shows an example of a task tree with colored nodes. Another possibility is browsing through the concepts and seeing their details and relationships for instance by following links in the HTML representation or viewing templates.

Analysis

Whereas inspection is merely "looking at" analysis is "finding out what is going on". Here the goal is to gain understanding of the task world and to find the nature and causes of problems. This can be achieved by using several different representations like those used in inspection and by using certain derived characteristics. For instance, coloring all tasks in which a certain role is involved may help to gain insight in the involvement of a role in the task structures. Euterpe has built-in characteristics that can be checked on request but the advanced analyst is also allowed to specify additional characteristics. Some examples of predefined characteristics are:

- agent X:
  all tasks performed by agent X
- cooperative task:
  all tasks where more than 3 agents are involved
- boring_task:
  all tasks that are performed more than 20 times per hour
- complex_task:
  all tasks that have more than 3 levels of sub-tasks

In DLP syntax a boring task could be defined:

```
boring_tasks(T) :-
    gta_task <- is_instance(T),
    T <- frequency(Freq, Unit),
    Freq > 20,
    Unit = hour.
```

Cooperation can be seen as a dependency or interaction between certain tasks performed by different agents. Using that definition it is possible to define an expression that shows the frequency of interaction or how tight the cooperation is, for instance by counting the number of agents involved in a number of tasks. Because GTA looks at an organization of people and tasks instead of looking at one person, tasks are explicitly related to agents, objects and roles. All these relationships are established when the data is entered in EUTERPE.

Verification

This kind of analysis is on a more logical level. Verification concerns only the model as it has been specified. Only a limited degree of verification of a task model can be supported due to the inherent lack of formal foundations for task models. There is no model to verify the task models with. However it is possible to see if the task model satisfies certain domain independent constraints. The task world ontology merely defines the concepts and relationships without any constraints. This was done deliberately to give the analyst as much freedom as possible to specify what they find during data gathering. There are however constraints that we would like to have satisfied independently of the specify domain that is being studied. For example we would like that for each task there is at least one responsible role and that each task is really being performed by an agent. These constraints can be specified as logical predicates and can be checked automatically. Examples are:

- unauthorized task performance:
  a task that is performed by an agent whose role does not encompass the responsibility for the task.
- unperformed tasks:
  a task where no performing agent has been specified.
- unhandled event:
  an event where no task is being triggered.
- occurrence of delegation:
  a task that is being performed by an agent other than one that is responsible for the task.
- impossible task sequence:
  a sequence A followed by B followed by C and the sequence A followed by C followed by B

In DLP syntax delegation is expressed as:

```
delegation(Src, Dest) :-
    gta_task <- is_instance(T),
    gta_role <- is_instance(Src),
    gta_role <- is_instance(Dst),
    Src <- responsible(T),
    not(Dest <- responsible(T)),
    T <- performed_by(Dest).
```

These constraints are similar to the characteristics used in analysis. However, they have been defined irrespectively to the specific study being done. They should hold in any domain. A task model where all

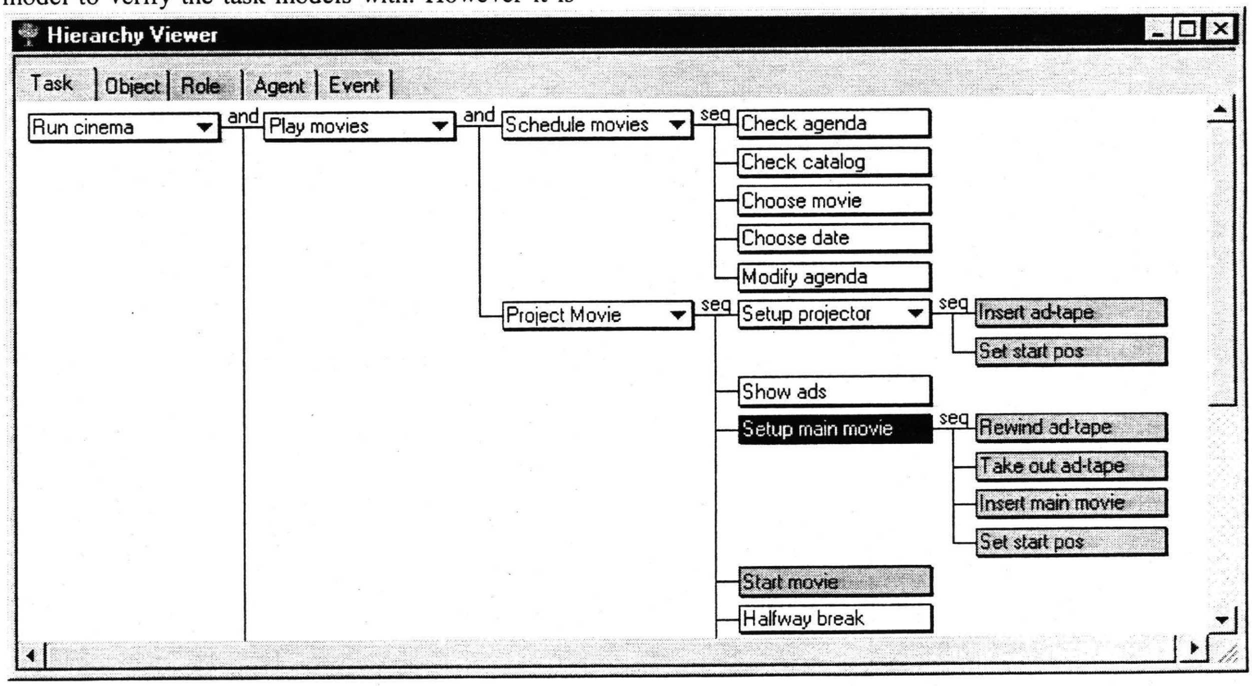

Figure 2 Task tree with coloured nodes

constraints are obeyed may be considered "better" than one that does not obey all the constraints. In other words the constraints allow us to denote classes of model which may have an order of preference.

Validation

Validation of task models means checking whether the model correspond with the task world they describe. In the process of validation one may find that certain tasks are missing or there are more conditions that are involved in executing a task. Often one finds that there are exceptions that had not been found in earlier knowledge elicitation. Consequently validation needs to be done in cooperation with persons from the task world and is not directly automatable by any tool. However it is possible to assist in the validation process for instance by generating scenarios automatically that can be used to confront the person from the task world. Such generated scenarios are in fact simulations of pieces of the task model. Generating simulations has not been implemented in Euterpe but recent work on early task model simulations (Bomsdorf et al., 1997) has shown promising examples of early simulations based on task models.

MANAGING CONFLICTS

When doing an analysis irrespectively of the kind of analysis, problems or conflicts may arise. By conflicts we mean situations that need to be handled by the analyst. Examples of conflicts are contradictory data gathered from different persons describing the same task. In this case one of the persons may have made a mistake or forgotten something. Another possibility is that different persons really do the task in a different way in which case it is very interesting to note this fact. Conflicts do not always need to be "solved" but they certainly require attention and should be seen as a hint for possible interesting aspect of the task world. The ontology we use allows inconsistencies and others causes of conflicts to be specified because we found in practice that it is often very important to be aware of these conflicts. Many analysts or designers develop models of a task world with the goal of finding *one* model that captures how the task world works. When modeling complex cooperative environments this is almost never the case and the analysts should not have this one model as the most important goal.

CONCLUSIONS

EUTERPE can be a useful tool for analyzing cooperative environments. Because it is based on the theory of Groupware Task Analysis it has a well founded theoretical background and it offers a structured approach to task analysis. Furthermore, it offers primitives to analyze the captured data in several ways. Analysis primitives are specified logically and can be modified or added. EUTERPE allows cooperation analysis and enables experimentation with analysis primitives, which is also part of our future research.

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Integration and Dis-integration: Situated Practice and the Structure of Hospital Information

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ABSTRACT

In this paper, we discuss part of a study of the organisational context of information use and distribution in a large hospital which was about to introduce a centralised, integrated hospital information system with a view to enhancing patient care. Our approach was to examine the relationship between information and cooperation in this hospital by eliciting, from 16 members of staff, evaluations of information from different sources. The results highlight the relationship between meaningful information and meaningful activity, a theme which we discuss in terms of the development of the hospital information system.

Keywords

Information systems, integration, personal construct psychology, situated, activity.

INTRODUCTION

This project started with a hospital information system which had been installed for about 12 years, which had been expensive, but which had never been used to any great effect. Management were on the verge of introducing another system when they asked us to 'find out' what had gone wrong with implementation of the older system and whether there existed any obstacles to implementing the new system. After some discussion with a variety of stakeholders in the hospital, it seemed that, although uncertainty about the implications of technology on jobs, inadequate training, and lack of concern for the interface between technology and the organisation of work played a part, there was a more basic issue at work which had to do with the perceived relevance, usefulness and meaningfulness of the information system. With this in mind, we agreed with the stakeholders to look at the relationship between information and work practices in their organisation.

Information systems and situated practice

Our hospital was not the only place where an information system (IS) had failed. Lyytinen and Hirschheim (1987) suggest that the level of IS failure is about 75%. With particular reference to hospital systems, Bywater (1994), having reviewed major computer projects in British National Health Service Hospitals, pointed to the failure of information systems to deliver expected improvements. Grudin (1988) had earlier provided a range of reasons for the failure of information systems which included issues of ownership, social and motivational issues, and the salience of non-routine work. Grudin's intervention can be seen as part of a growing concern in IS research with the soft side of organisation (Checkland and Scholes, 1990; Vidgen, 1997), with processes such as interpretation and trust, and with plurality.

A number of assumptions are made in mainstream IS development. It is assumed that information can be abstracted from activities and represented in a manner which will be useful to people in the organisation, many of whom will not have been party to the activity. Moreover, the notion of a single system supporting information-related activities in an organisation suggests a unitary understanding of organisation, where members of the organisation are assumed to have shared goals, values, and interests. Such an assumption can lead to the development of ISs which cut across structures, practices, and formal and informal groupings. Soft systems proponents have recognised this dilemma and have promoted methodologies for taking into account different subcultures, values and interests in an organisation. However, re-marrying the soft and the hard, the culture and the information, has not been unproblematic. It may be that starting with a disjunction between hard and soft systems is not the best way to deal with plurality.

An alternative is to treat information and context as integrated from the outset. Greeno (1998) tries to do this by studying interactive systems larger than the behaviour and cognitive processes of an individual: "by investigating activity in intact multi-person, human-technology systems, asking how such systems function" (p.7). The aim of Greeno's strategy is to analyse information structures in socially organised activity. However, Greeno's situative perspective is not unproblematic either. Greeno points out that while cognitive science analyses structures of the information content of activity with little attention to interactions or social or technological resources supporting activity, situated interactional studies analyse patterns of coordination of activity but have little to say about information content. An attempt to integrate the two would be timely for both theoretical and practical purposes. But what Greeno seems to offer here is an exhortation that each should work hard to meet the other. Although we are sympathetic with Greeno's objectives and much of his characterisation of the problem, we find his road to integration unsatisfactory.

George Kelly's (Kelly, 1955) Personal Construct Psychology (PCP) claims that the 'hard' and 'soft', information and context, cognition and culture can only be integrated by appeal to a superordinate category. Kelly posited the 'construing individual' as such a category, an active organism which creates information structures in context. Our objective, in this paper, is to explore the value of PCP and the associated methodology of Repertory Grids in developing conceptualisations of the relationship between information and work practices for use in information system design.

Using PCP in requirements analysis

In practical terms, this work can be seen as part of requirements analysis. Others have already suggested the relevance of personal construct psychology to this process (e.g. Jones and Brooks, 1994). However we would add a caveat that, in this context, requirements are seen as socially constructed through a process of negotiation, created rather than actual and captured (Harker, Eason and Dobson, 1993).

Personal Construct Psychology and Repertory Grids can play a part in Requirements Analysis by providing access to local conceptual resources at work in activity management (Harre, 1993). By local conceptual resources, we mean the ways of seeing, the patterns of understanding that characterise a person's interpretation of information. The argument is that people do not passively receive information, we interpret information in the light of theories (or interpretations) actively constructed from our past experience. The unity of information structures and socially organised activity is through personal experience and related processes of construction

With respect to the specific question motivating this research, the value of a hospital information system in terms of work practices in the hospital, PCP points to the folly of assuming that a unitary information system will support the activities of the range of people working in a hospital. In using repertory grids, as part of a requirements analysis process, we are trying to learn about the ways in which people doing different kinds of work in this particular hospital construct information. The broader theoretical claim is that a focus on individual's constructions of information will help elucidate the relationship between information structure and socially organised activity.

METHOD

A Repertory Grid has two main components: elements and constructs. Elements tend to be specified by the investigator to reflect the concerns of the research. They are, however, often specified only after some form of dialogue (e.g. formal or informal interview) in which the investigator engages the participants in conversation about the subject matter. As one of the major methodological concerns of Grids is to elicit participants' own conceptual resources, the greater the role participants have in specifying the elements, the better. Constructs are an attempt to represent participants' abstractions of their experiences of the events, people, situations or whatever is represented in the set of elements. Constructs are elicited from participants by asking them to take a set of three elements and specify how two are alike and the third different from those two. Each construct is a bipolar discrimination, a basic dimension of appraisal for that person. Analysis of each grid describes the individual's conceptual resources for classification and appraisal in that domain.

In this study, elements were specified by the researchers following a meeting between one researcher and the Information Services Manager in the hospital. The manager described the way in which information flowed through the hospital and specified what he considered to be the different functions in the hospital who contributed to and used the information. The researchers specified elements based on the functions identified in this meeting. As the goal of the research was to investigate appraisals of information from different sources or functions in the hospital, elements were specified as 'Information from Function' where the 'Functions' were those identified in the meeting with the manager. The specific elements used in the grids were:

information from medical staff
information from paramedical staff
information from administration
information from management
information from laboratory staff
information from nursing staff

In order to provide a polar contrast in the grid and to get participants to focus on the people who provide most meaningful and least meaningful information, two further elements were added to the grid:

information from someone who usually provides meaningful information
information from someone who usually provides unmeaningful information

Sixteen participants from 22 canvassed to represent the functions listed above, completed the grids. One researcher met each participant twice, once for an interview to discuss details of their role in the organisation and the information that they use and a second time to complete the grid. Eight constructs were elicited from each participant using the standard triad elicitation procedure. Each construct was laddered, a technique much like a structured interview designed to ask participants which pole of a construct they prefer and why. They are asked 'why' questions about their accounts of preferences until they are unwilling or unable to go any further. This generates more general constructs. They are also asked a series of 'what' questions about their preferences, designed to produce the physical characteristics of constructs. Finally, the grids were rated on a five point scale.

ANALYSIS

The analysis presented below consists of a detailed idiographic case, to exemplify the process and the outcomes available from analysis of an individual's constructions of information from sources in the hospital, followed by a thematic analysis which cuts across a number of individual analyses.

Consultant's Grid

We decided to use one of the medical consultants as an example here because of his experience in the organisation, being in his 50s and having spent much of his career in hospitals in this Health Authority. He also has an interest in information systems in general and in his own speciality. On top of this, as a consultant, he occupies a pivotal position in an organisation striving to engage consultants as resource managers as well as medical specialists.

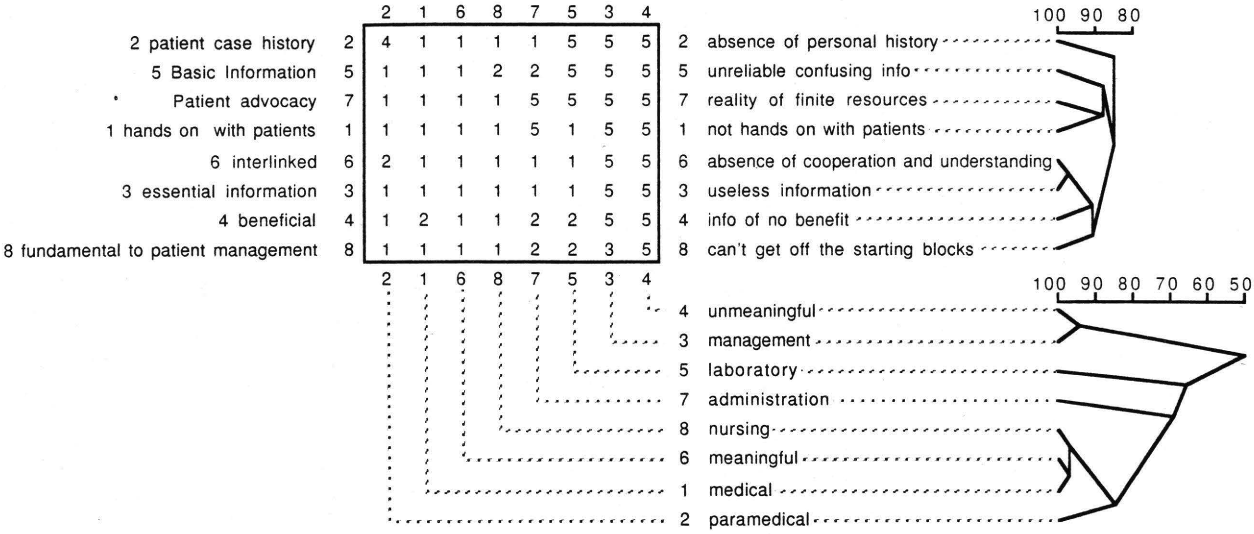
Figure 1 is a focus grid produced using RepGrid (Shaw, 1993). The labels below the matrix represent the elements. Those to either side are the constructs generated by the consultant when engaged in triadic elicitation using these elements. The numbers in the matrix are the consultant's ratings of all elements on each construct, the higher numbers tending towards the negative pole of the construct. For example, when rating construct 2 (patient case history - absence of personal history), the consultant rated the element 'medical' as 1 and the element 'unmeaningful' as 5. That is to say that he construes 'information from medical staff' as concerned with patient case history and he construes 'information from someone who normally provides unmeaningful information' as lacking personal history. The ratings on the far right are similarity ratings which is one of the indices used to show how elements and constructs cluster together.

As can be seen from figure 1, there are two clusters of elements. Cluster 1 contains four elements; meaningful, medical, nursing and paramedical. Cluster 2 has the elements unmeaningful and management. Laboratory and administration are independent of the other elements. The most striking feature in this structure is the strong correlation between management information and unmeaningful information and medical and meaningful information. This medical aspect was elaborated in laddering when the consultant said (at different stages):

> Dealing with patients is central to my work. Doctors deal with the functional state of the patient. Nurses deal with nursing requirements. They are both hands on so the information they use is hands on information. .... Doctors and nurses information is based on interaction with the individual. .... Doctors can't manage patients without nursing involvement. They are interlinked because they are both managing patients.

Although constructs cluster quite tightly overall, two clusters are still discernible. Cluster 1 contains: 'interlinked - absence of co-operation', 'understanding essential information - useless information', 'beneficial - of no benefit' and 'fundamental to patient management -can't get off the starting blocks'. There are 3 constructs in cluster 2: 'basic information - unreliable confusing information', 'patient advocacy - reality of finite resources', 'hands on with patients - not hands on with patients'. Cluster 1 indicates the dimensions the consultant uses in evaluating information in the hospital. From his perspective, quality information is interlinked, essential, beneficial and fundamental to patient care. The constructs in cluster 2 are solely concerned with patient information.

Figure 1: Focus grid for the medical consultant



Focus grid re-presents the original grid, used be the consultant, reorganised by the similarity of constructs and elements. Similarity is calculated using a distance-based hierarchical cluster analysis technique.

Looking at elements and constructs together, there is a conceptual space occupied by 'meaningful' sources of information directly involved in patient care (nursing, medical and paramedical) and appraisals related to patient advocacy, essential, beneficial and interlinked. Information from these sources forms part of a nexus relating patient care activities and meaningful information. In contrast, 'unmeaningful' management information is seen as useless, lacking understanding and cooperation and concerned with finite resources possibly at a cost to patient care. There is ambiguity about information from laboratory and administrative, which seems to occupy a middle ground.

The key themes from analysis of this quantitative and discursive data are the contrast between the co-operative relationship amongst those directly involved in patient care and the overall absence of co-operation and understanding across the organisation.

Thematic Analysis

A number of themes introduced in the analysis of the doctor's grid recur in analyses of other grids. The most salient are: the relationship between the meaningfulness of information and its association with activity; the relationship between meaningfulness of information and identifying the source as engaged in a communal activity or practice with the recipient; the institutionalisation of separation.

Meaningfulness and activity

In response to the triad of elements 'unmeaningful, paramedical, and administration', the Information Systems Manager produced a construct: expectation of action - no expectation of action. In laddering he stated that:

> There is no expectation of action with unmeaningful information. It has no value. No one expects you to do anything with it. Paramedical and administration information is expected to be followed by some action.

He also gave some indication of what he meant by action, and how it and related information might be structured in his particular organisation, when he produced the construct 'patient specific information - non patient information'. One of the nurses produced a related construct: 'personally relevant to the patient - clinical about patient (facts) always written'.

> Administration information is meaningful because it is relevant to patients. It is verbal. Laboratory information is non-verbal. Administration information gives you more of the patients story. It helps you to get an overall picture - more holistic. Administration information affects other services. It caters for peoples' needs. Personal information helps people. Personal information puts more value on the relevant information. It allows you to take a holistic approach. It helps you to set up a rapport with patients. It's more real.

Regardless of any perceived disjunction between the values and interest of groupings involved in patient care and those involved in hospital management, most participants indicated that they considered information which was closely related to the activities in which they are engaged and with which they identified themselves to be most meaningful. The activities, and the meaningful information related to them, could reasonably be categorised as either patient specific and personal or management related and concerned with trends.

Shared meaningfulness and community membership

The information systems manager posited appraisal of trust as a central conceptual resource in structuring information in hospital activity with his construct 'trust of source - lack of trust of source'.

> It is important to trust your source. When the source has more credibility you act better, more positively. I don't trust laboratory staff. They are a very blinkered group. I don't accept information from them at face value. I would look for independent verification.

In doing so, he makes very general claims about the trustworthiness of a whole function. The point we are making here is that this is part of the conceptual apparatus deployed by him when using information in the hospital.

The general manager appraised in terms of whether information was strategic or short term, which, in part, depended on the source and whether that source shared his own concerns and interests with the future organisation of services. The general manager treats administration information and management information as from distinct groups of people engaged in different activities and probably with different values. In contrast, shared meaning and community was pivotal in analysis of the consultants grid presented earlier. His discourse goes to the heart of the matter:

> Nurses, paramedics and doctors are part of a team. Rapport is very important with paramedics and nurses. The labs are not part of that team. ...... Nurses and doctors cannot get on without each other. It is important to have close dialogue and understanding between doctors and nurses.

Institutionalisation of separation

The final theme identified is institutionalisation of separation. By this we mean reliance on institutional badges, professional status, and so on in appraising information and sources. This theme is articulated most clearly by the general manager, whose background is administration. Laddering his construct 'professional - routine administrative', he said:

> Doctors and nurses have particular professions. Administration staff do not. Their work is routine. Professional - is more likely to do with clinical performance, quality of patient service, individual performance.

It was also articulated by a nurse but, in this case, more at the level of the institution getting in the way of her doing her work.

> Management information is useful but it's run by budgets. It makes my job harder because it is information that is against patient care. It clogs up wards. It's about budgets and cost expenditure. It is usually negative, about overspending. Financial restraint is not my issue. Services must be provided without restraints on the care I want to provide.

DISCUSSION

The work reported in this paper is motivated by two concerns: the practical problems experienced by our hospital in implementing an information system and the difficulty of describing information structures in socially organised activity. We have explored the value of PCP in requirements analysis as a means of addressing both problems.

It is clear from our analysis that people working in the hospital see themselves as members of different communities of practice (Lave, 1988). They may all express an interest in patient care, but their day to day practices give qualitatively different meanings to that expression. Within the various communities, activities are interlinked and coordinated, and judgements and values shared. Without thinking much about it, participants in a community of practice seem to share practical, gut responses to situations, which are not so readily shared between communities. People from different communities are likely to check the credibility, value, and implications of information from a member of another community rather than 'unquestioningly' act on it. This is not necessarily a bad thing, conflicting views can be fruitful, though it does have implications for how we think about collaboration and particularly about information provision and use in such a 'dis-integrated' organisation.

Our use of repertory grids addressed the receptive side specifically. But there is evidence that much the same can be said of contribution. Symon, Long, and Ellis (1996), suggest that medical and medical-related staff in hospitals tend not to complete the administrative and accounting parts of forms and, when they do, they resent having to do so. This speaks to the centrality to information system design of the 'concerns' of workers, suggesting that system design needs to be aware of practical concerns as well as information processing capacities.

Our data suggests that, in a hospital setting, working cooperatively involves intimately related practices mediated by shared concerns and activities. The meaningfulness of information and its use differs depending on whether the people sharing the information share a sense of community or not. When they do, information sharing comes naturally and is used as a stimulus to action. When they don't it is treated as something alien and often as something troublesome. In practice, information is not separable from source, activity, and identity.

It follows from this that information and particularly an information system should not be treated as some neutral resource. As far as they are concerned hospital staff are engaged in different activities and they feel strongly that others do not share their concerns. This is not pluralism as suggested by Vidgen, but dis-integration. The salience of conflicting appraisals in the hospital suggests a more radical approach to IS design than simply offering a plurality of views on the same information.

The key to understanding information in this organisational context and to appreciating the requirements for IS design is in the activities which bind communities together. The IS should be viewed as a tool to support functional work systems at different levels of the organisation. Following Schneider and Wagner's analysis of integration and fragmentation in IS design in French hospitals (1993), we suggest that it is counter-productive to expect all workers to share the same perspective and to contribute to what may be a system for business or management requirement. Instead, a system which supports specialised functions where appropriate and which offers multiple perspectives and overviews where appropriate - which treats information structures as emergent from personal construction in socially organised activity - is more likely to encourage dialogue and change. As one of the major concerns of participants in this study related to a sense of not being understood, perhaps a more interesting approach to the technology might just help to bring about a more integrated approach to the organisation.

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The Prescription and Practice of Work on the Flight Deck

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ABSTRACT
Technological change has led to the proceduralisation of flight deck work. Yet accidents attributable to pilot error still occur. CSCW studies of work suggest work as prescribed does not always reflect work as practised. While one might expect this to be less true of safety critical settings like the flight deck, the case studies we present provide support for this distinction. We present two re-framings which better capture the status of procedures on the flight deck. One case study illustrates what else is required in order to make procedures work. The second illustrates how procedures are customised. Instead of seeing them as prescriptions of work we view them as resources for action and boundary objects. We discuss design implications of this re-framing

Keywords
Pilot error, CSCW, procedures, practices, resources for action, boundary object, due process.

INTRODUCTION
There have been many technological advances in the commercial aviation industry. A modern aircraft is now capable of automatic flight practically from take off to landing. For the humans on the flight deck, this technological advance has been associated with dramatic changes in the nature of their work and in particular an increasing proceduralisation of their work practice. Much of the human work on a flight deck is prescribed by so called *standard operating procedures* (SOPs), which are typically defined by aircraft manufacturers or operators. On all flight decks SOPs are represented in printed form in a so-called *quick reference handbook* (QRH) and in the more modern aircraft, they are also represented as pages on an electronic display. A QRH will include procedures for carrying out tasks conceived by the designers including both normal procedures such as landing checklists and procedures especially designed for dealing with emergencies. Viewed from *outside the cockpit* SOPs are understood as prescriptions of work and pilots are expected to follow them whenever possible. Yet, *pilot error* is still one of the most often cited contributing factors to aircraft accidents. In a recent CAA study of 447 global fatal accidents, 76% involved a crew primary causal factor. (CAA 1998). Such statistics raise the question why human error still occurs when the work is so well prescribed.

Researchers engaged in field studies of other work domains, have been quick to point out that there is very often a significant difference between work as prescribed and work as practised- work when viewed *from the inside*. Button and Harper (1993) describe a case study in which the normal accounting procedures associated with a manufacturing process were often ignored by workers in order to meet the contingencies presented by rush orders. Button and Sharrock (1994) observed how methodologies enforced on design teams are 'made to work' in practice by those using them. Such *making work* involved short cutting steps in the sequential process and patching up the product afterwards. Symon, Long and Ellis (1996) describe the dilemma faced by staff in a radiography department who have concern both for proper procedure and for the care of their patients. Their analysis demonstrates a subtle decision process in which at times procedures are followed and at others *workarounds* are used to avoid procedures and get the work done. Rather than interpret these behaviours as bad practice, these authors argue that responses to local contingencies are in the nature of human work and it is in the detail of this process of engagement with methods, procedures and other formal artefacts of work that the intelligence of human work resides.

In this paper we present two case studies relating to the meaning and use of SOPs on the flight deck. The SOPs we have focused on here are SOPs for dealing with emergency situations. These case studies are our attempt to assemble a view of SOPs from *inside the cockpit* and to explore the status of SOPs informed by the research perspectives reviewed above. In the first case study, we interviewed crew (pilots and flight engineers) and cockpit designers to discuss the impact of the proposed introduction of electronic representations of SOPs onto a flight deck. In the second case study, we interviewed a line pilot and analysed the annotations he had made to a quick reference handbook. As we present these *views from inside* we will develop an argument for re-framing the status of SOPs in relation to work practice and discuss the design implications of this re-framing and also the implications for our understanding of pilot error.

CASE STUDY 1: PROCEDURE FOLLOWING IN COMPLEX SITUATIONS

Interviews were carried out with aircrew and designers currently involved in a development project. The discussion centred on a number of safety critical scenarios where flight crew would be required to carry out several concurrent tasks. The design issue in this case study was the possible reduction in crew complement and consequently the automation of much of the power plant health monitoring function. As part of this move SOPs, which on previous versions of the aircraft had been represented in paper form in the QRH would be moved to an electronic format. Health monitoring systems would diagnose problems and relevant electronic pages of the SOPs would be presented to the pilots. As a consequence, the scenarios that were explored were those that the crew believed would involve a high workload for the flight engineer in the existing aircraft. The scenario we focus on here is one in which the aircraft suffers a bird strike while close to the ground. The participants discussed how they envisioned the scenario might unfold, and where they thought the problems might be for the envisioned flight deck. Three main themes emerged from the discussions.

One problem involves many tasks

An over-simplistic characterisation of the work of fault management in complex systems is that a single problem (e.g. engine failure) is associated with a single recovery procedure (e.g. shut down failed engine). In fact, complex systems are complex because they are constituted of many tightly coupled sub-systems. Failure in one system has knock-on effects in others (See Perrow 1984 for a discussion). The interviews for case study 1 revealed a complex relation between the problem, the relevant SOPs and the work that was required of the crew. The SOPs used for dealing with the emergency scenario are themselves fairly simple but to deal with the problem effectively requires the use of a number of different procedures concurrently for example, engine 2 fire drill, engine 3 re-start, generator failure, blue hydraulics failure and so on.

Prioritisation is essential

The scenario requires fast action and a key skill of the crew is to decide how to prioritise relevant procedures associated with a number of different and conflicting goals distributed amongst the crew. For example, dealing with engine fires by idling engines and maintaining power in order to gain height. Such prioritisation decisions need to be informed by contingencies of the particular occasion of use such as weight of the aircraft and height above ground. Because the information is distributed among crew members this activity may require significant communication.

Prioritisation leads to fragmentation

Partly because of the prioritisation issue, procedure following is fragmented. Part of one SOP will be executed and then put on hold while another is partially executed or perhaps completed. This interleaving means that the crew need some way of remembering where they are in a complex, multithreaded activity sequence. The aircrew we interviewed talked of the QRH as "a good system, because you can flick from one drill to another, you can do as much of one drill as you want then go to another". But in order to use the QRH in this way, they additionally need a deep knowledge of the physical systems they are interacting with in order to judge where in a procedure it is safe to break off.

SOPS AS RESOURCES FOR ACTION

The complex nature of procedure following illustrated by this case study reveals that putting procedures into practice is more than just mechanically following SOPs. It illustrates how SOPs are 'made to work', by intelligent practitioners. The ability of the crew to prioritise the execution of the procedures to produce a satisfactory solution to a complex problem is as much a part of the practice as the procedures themselves. Star (1989), has used the term 'due process' to refer to the often tacit knowledge that is required to make formal representations work in open systems such as offices. Aircraft flight decks are open systems in Star's sense and the due process in making SOPs work hinges on the human ability to gather information about local contingencies in order to determine how to use the SOPs. The knowledge required to do this transcends the knowledge encapsulated in the SOPs and is more concerned with the deep knowledge of systems, environments and particularities of the situation at hand.

Case study 1 provides our first re-framing of the meaning of SOPs in the work practice of flight crews. Rather than being viewed as a prescription of what ought to happen and a mechanism for controlling what does happen in practice, SOPs might be more usefully viewed as *resources for action* (Suchman 1987). Central to the idea of resources for action is that they are not control mechanisms, internalised and executed unthinkingly and unwaveringly. Rather they are objects of cognition that can be reasoned about and used as an input to a decision making process about action. Wright, Fields and Harrison (1996) characterise a number of information types that can serve as resources for action. They take many forms and one particular form is that of a plan - a sequence of actions to achieve a goal. In resource terms, SOPs are examples of such plans.

In our first re-framing then, SOPs are viewed as resources not prescriptions for action. The work setting which SOPs inhabit is an open system where due process mediates between formal procedures embodied in SOPs and the practice of flight crew. The intelligent work we observe is an integration of the resources provided by SOPs with the expert decision making of practitioners. In this reframing SOPs are not viewed as a formal abstraction of work practice which removes the detail of work to achieve an ideal solution to a problem. Rather they are one of possibly several sources of information which is used to decide upon a reasonable and justifiable course of action given the particulars of the case at hand. There may be entirely unproblematic cases in which a problem can be solved by simply following procedures, but these may be the exception rather than the rule.

Table 1: Analysis of annotations to a quick reference handbook

Type of annotation	Frequency	Percentage
1. clarifying the reason for procedure	63	19.5
2. addition of extra actions or procedure	61	18.9
3. additional relevant background systems information	48	14.9
4. alternative procedure/ uncertainty about effectiveness of current procedure	38	11.8
5. consequence of taking an action	32	9.9
6. delimiting the scope of a condition or procedure	26	8.0
7. cause of warning or condition	21	6.5
8. consequence of warning or condition	20	6.2
9. highlighting importance of particular steps	14	4.3
total	323	100

Table 2: Examples of the four most frequent annotation types

Type of annotation	Example
Why the procedure is the way it is	
1. Clarifying the reason for procedure	*"De-energises DC fuel pump"* [following procedure 'APU selector .... Off' position]
3. Additional relevant background systems information	*"Deploys automatically when both engines fail"* [referring to ram air turbine in loss of engine thrust section]
Modifications to actions of the procedure	
2. Addition of extra actions or procedure	*"Try another autopilot"* [when procedure calls for autopilot disengage if inoperative]
4. Alternative procedure/ uncertainty about effectiveness of current procedure	*"No mention of using APU at low level to start engines"* [when attempting engine restart after loss of thrust]

CASE STUDY 2: CUSTOMISING THE PILOT'S QUICK REFERENCE HANDBOOK

The second case study focuses on the QRH. Information for the case study was obtained from interviews with a line pilot. A key finding from our interviews was that pilots annotate a *personal copy* of the QRH which they may carry on to the flight deck and use in their day-to-day work in preference to the *flight deck copy*. The flight deck copy must not be interfered with since in day-to-day operation, the aircraft is used by different crews. Questioning pilots from different airlines and flying different aircraft revealed that annotating personal copies of checklist documentation is not uncommon. Some pilots produce their own more comprehensive versions for personal use based on experience gained from line operations and simulator sessions.

An analysis of a total of 323 annotations present in the pilot's QRH was carried out. Segments of the QRH were used to generate a classification scheme, which was then validated against the remainder of the QRH. The pilot was subsequently asked to comment on the classification scheme which he confirmed as being an accurate representation of the intent behind his annotations. The classification scheme was then further validated by asking a volunteer researcher knowledgeable in the field to perform a similar classification exercise based on a sample set of just over 12% of all QRH annotations. Full agreement was reached in 62.5% of cases, while partial agreement occurred in 27.5% of cases, yielding a combined full or partial agreement rate of 90%. Table 1 shows an analysis applied to pilot annotations of QRH procedures.

As can be seen from table 1, the modifications to the written procedures take a number of different forms reflecting different purposes and concerns. Although there are 9 categories in total, the 4 highest scoring categories cover over 65% of the annotations. Categories 1 and 3 cover over 38% of annotations and are concerned with providing a rationale for *why the procedure is the way it is*. Categories 2 and 4, covering 26% of the annotations can be seen as concerned with *modifications to the actions in the procedure*. Examples of these are provided in table 2.

SOPS AS RESOURCES FOR ACTION AND BOUNDARY OBJECTS

The existence of annotations to the QRH substantiate and extend our claim in case study 1 that SOPs might be more usefully viewed as resources for action. The annotations support the view that SOPs are objects of cognition, they are reasoned about and evaluated by pilots in the light of their collective experiences of practice. SOPs are given a meaning against a backdrop of systems experience and culturally constituted knowledge. The SOPs receive a new meaning within the community of practice adding both rationale (categories 1 and 3) and detail (categories 2 and 4) to that which is found in the QRH. But this meaning is not worked out on an occasion of use, it is worked out it before it and it is recorded in the pilot's annotated QRH for just such an occasion. Such customisation extends our understanding of resources for action beyond case study 1 and beyond that found in the literature (Suchman 1987, Hutchins 1995). It is not just that sequences of actions represented in the QRH have to be intelligently modified to take account of local contingencies. It is that the actions are given a different meaning even before they are used as resources. The annotations literally represent the pilot's evaluation of the SOPs as resources. Extending our analysis of SOPs in this way leads to a second, additional re-framing.

In her studies of distributed work in scientific communities, Star (1989) uses the term *boundary object* to refer to representational artefacts that are used to co-ordinate the work of different communities involved in joint projects. A boundary object is both plastic enough to be adapted to the local needs and constraints of each of the several communities using it but robust enough to maintain a common identity across sites. She argues that boundary objects are essential to articulation work between communities of practice. In studies of the Berkeley Museum of Zoology (Star and Griesemer 1989) she identifies several such objects. For example, forms filled in by field workers and used by museum staff to classify exhibits are designed in such a way that they can be interpreted differently by both communities but the essential information required by both can be extracted.

Framing SOPs as boundary objects as well as resources for action provides a further layer of insight into their status. There are at least four communities who come into contact with SOPS; (1) the pilots, who constitute the end users, (2) the aircraft designers who often enough, design the SOPs and embody them in the QRH (3) the operating companies who sometimes elaborate the SOPs or re-embody their own 'in-house' QRH and who are responsible for enforcing their use by crew whom they employ, and (4) the regulatory authorities who may investigate the actions of individuals and companies in the event of accidents and incidents.

SOPs are boundary objects because they are used by all of these communities. They have a common identity which is their representation in the QRH. But in each community they have flexible interpretation as resources for very different kinds of action. For the pilots the meaning of SOPs is as a resource for action in specific contexts of use. This involves understanding the relevance of SOPs in solving a particular problem and the consequences of carrying out the actions associated with it. For designers of SOPs and the QRH, their meaning is an abstraction of a class of problems (e.g. engine failures). They have a meaning as the correct course of action specified at some level of abstraction and as a designed response to carefully circumscribed failure modes. For operators and designers, SOPs have a meaning as objects aimed at establishing a pattern of habitual behaviour which can be carried over from one aircraft to another and which avoids the necessity of each individual having to develop his/her own work practices or be re-trained. For all of the communities *outside the cockpit*, SOPS have a meaning in terms of *what ought to have been done* in order to avoid an accident or incident. That is to say they are *artefacts of accountability* (Button and Sharrock 1994; McCarthy, Healey, Wright and Harrison 1997).

SOPs do not always pass unproblematically across the boundaries of these different communities. In terms of the flow between pilots and designers, the printed form of the QRH provides a plastic medium upon which pilots can adapt and tailor the SOPs presented to them, but designers receive no feedback about how their SOPs are modified and used. Part of the reason for this may be product liability. A company may not wish to be in possession of information regarding suggested modifications relating to safety. In terms of the flow between pilots on the one hand and operating companies and regulatory authorities on the other, the meaning of SOPs as artefacts of accountability is inconsistent both metaphorically and literally with two versions of the same object. Pilots are not allowed to modify the cockpit QRH, which is why pilots may carry *personal copies.* At an organisational level this conflict of interpretations creates what we have referred to elsewhere as a context for collusion (McCarthy et al op cit.).

DESIGN ISSUES AND CONCLUSIONS

The case studies raise some obvious design issues. Case study 1 suggests, for example, that electronic checklists should be designed to assist in the prioritisation problem and in keeping track of actions already completed. Early attempts include the Electronic Centralised Aircraft Monitoring (ECAM) computers employed in the Airbus A-320. Screen real estate is major issue for electronic displays and keeping track of a number of relevant procedures could potentially involve clumsy navigation. Boeing's Electronic Checklist (ECL), in use on the B-777, is an attempt to address these, and other, difficulties. An alternative would be to prioritise and fragment the actions associated with the separate procedures, but this implies that enough can be known before hand about local contingencies. There is also a risk of the activity losing coherence for the crew.

Case study 2 identified a number of shortcomings of existing SOPs that could be reasonably described as bad design. For example, the structure of nested procedures is not always clear, and many of the annotations which elaborate and extend procedures could be included in a re-design.

But while these design implications are valid enough, they miss the substantive conclusion raised by our re-framings of the meaning of SOPs. Flying aircraft has become more complex due to technological change and demands on the crew for safe, economic and legal flight. One response is to represent the work in SOPs the aim of which is to prescribe how the work will be done. In this view, SOPs are a representation of work of one community with the intention of making it visible to another. By making the work visible, an opportunity is also afforded for making it organisationally accountable, which is of interest to regulatory authorities and others who may be concerned with evaluating work practice. The problem is that SOPs are abstractions that under-specify the work practice they are meant to make visible. As has been concluded elsewhere (Suchman 1995), it is the artfulness of the intelligent worker that fills the gap between abstractions of work and its practice. This is the due process required to make formal representations work in open systems.

McCarthy, Monk, Watts and Wright (1998) discuss *clinical guidelines* as one example of a more effective boundary object. As the name implies, these are recommendations rather than stipulations and it is expected that practitioners will exercise clinical judgement in their use. Clinical guidelines are customised by local committees with a consequence that users of such artefacts have some sense of ownership and control rather than just responsibility. They also make explicit the concerns of different communities that use them and provide a rationale for their existence. This is not an argument for a radically different representational artefact - clinical guidelines have a number similarities to aircraft SOPs. Rather it is an argument for a radical re-framing of the meaning of these representations by the communities of practice that use them.

Finally, to return to a question raised in the introduction. Why does human error still occur when work on the flight deck is so well prescribed? The re-framings of SOPs offered in this paper lead us to one possible answer. When failures lead to accidents, hindsight bias (Woods et al. 1994) seduces us into concluding that a contributing factor was failure to follow recommended procedures (NTSB 1996, for example). But when such violations lead to successful avoidance of an accident, the contributing factor is good airmanship, as typified by the recent accident involving Emerald Airways flight JEM 1532 at Stanstead airport. The pilot in this incident is accredited as having made a correct decision despite not following standard procedure (Daily Express 1998). In both cases what is observed is due process at work but the ambiguity of SOPs as prescriptions on the one hand and resources for action on the other, leave the observer with the freedom to judge the pilots as culprits or heroes.

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The Second Line Operator: a Crucial Location in Large Distributed Critical Systems

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ABSTRACT

Concerned with sociotechnical reliability issues, we are interested in *second line* activities such as those of on-line technical maintenance in Air Traffic Control. Organisationally contiguous to *the first line*, but not directly involved in the process control, second line operators are accountable for part of the the conditions of these activities of control. In this paper, we develop the conceptual and methodological framework elaborated in order to tackle the question of role of the second line and more generally organisational dimensions of safety management during operation. We illustrate our approach with a case from the ATC technical on-line maintenance domain. It appears that the second line operator from his/her specific position and competencies within the system, makes use of the structural properties of that system and create contexts which are less vulnerable to errors.

Keywords

Sociotechnical reliability, fault management, tolerance mechanisms, organisation, human cooperation, Air Traffic Control.

INTRODUCTION

Human Reliability has long focused on assessing front line activities, such as those of control room operators, pilots, air traffic controllers, etc. The recognition that root causes of accidents are widely distributed within the system as a whole, appears through the recent interest in assessing conception or maintenance activities.

Both in research and application domains, focusing either on the technical or the human factor, the evolution of ideas converges towards the need for developing a global and integrative approach (Laprie et al., 1995). The challenge facing those concerned with understanding human work in hazardous settings as well as those who design technical mechanisms is to develop a common conceptual framework that can be applied meaningfully and proactively to socio-technical systems (Reason, 1990).

The concepts of dependability (rather than reliability which has a more restricted meaning) and especially of fault tolerance provide the necessary unifying basis for this interdisciplinary perspective.

Fault tolerant design reduces consequences of system errors, as has been widely demonstrated in the technical domain over many years. Design of fault tolerant interfaces is also influenced by cognitive models of human error such as Reason's (1990). Nevertheless, such interfaces are still of limited use in complex work settings probably because they are constructed on an abstract view of the working conditions. Design of fault tolerant systems is influenced by underlying assumptions on how people work and how organisations function. Those assumptions are usually rooted in a rationalist perspective of human work despite many years of reasoned criticism (de Terssac and Maggi, 1996).

Moreover, several major accidents result from complex error mechanisms that are apparently organisational or social in origin. We now need to move beyond purely technologically or cognitively inspired design and develop organisational models in order to design fault tolerant systems (McCarthy et al, 1997).

As faults are unavoidable and somehow not predictable events, dependability in a fault tolerant system is supported by an appropriate combination of various means distributed within the system. Tolerance of faults (either human or technical) not only is a matter of designing technical means but also has to do with the organisation of system operations and maintenance. Organisationally, human operators play a significant role in this complex context of fault management during operation. Human reliability at work must thus be replaced in both an organisational context and a technical context.

One way to collect relevant information about these suspected human work processes that make the system work efficiently is to examine and analyse a particular domain that successfully manages high hazard operations on a regular basis (Rochlin, 1989).

We focused our attention on an Air Traffic Control ground centre and more particularly on a sociotechnical subsystem located on what we call a *second line*: the operational (on-line) maintenance of the computing systems. Indeed, if we consider the control as a front line position in the context of ATC, operational maintenance appears as a second line position, both in terms of spatial locations and organisational functions. The second line appears as a crucial position in the sociotechnical system: contiguous to the first line, but not directly involved in the process control, it still is accountable for the preconditions of these activities of control. From their specific position and competencies in the system, they make use of the structural properties of the system and create contexts which are less vulnerable to errors.

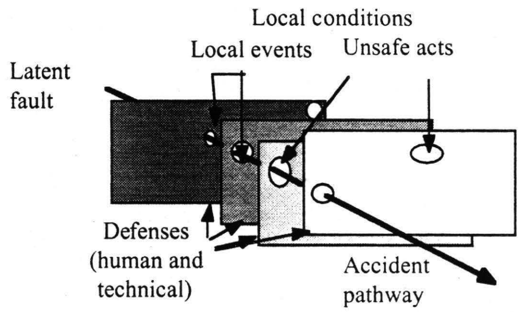
This paper is composed of three parts. Firstly, we introduce our framework of analysis combining dependability and ergonomics concepts, adding several forays into the organisational research domain. In the second part, we describe the situation of operational maintenance in Air Traffic Control. After a basic review of the work settings, we describe the task field of operational maintenance operators (division of work and coordination means). In the third section, we present a case study with some details concerning the relations between structural context (both technical and organisational) and the continuous changes observed in the activity field while the operator manages technical events. We identify various organisational informal processes, such as: (i) reorganisation of the field of work according to modifications of the causal field, (ii) anticipation of potential events and conditions and (iii) cooperative mechanisms within an extended sociotechnical net. We discuss the results according to our model in order to explain how this rapidly changing sociotechnical system maintain successfully dependability.

CONCEPTUAL FRAMEWORK: DEPENDABILITY AND ERGONOMICS

Resulting from gradual evolution within the Fault Tolerant Computing community, dependability stresses the way our society is becoming more and more dependent on computing systems. A unified conceptual framework that allows the integration of a number of approaches, methods and techniques during the design and development process is now emerging. The more recent challenge concerns the contribution of human agents in fault tolerant critical systems (Laprie et al., 1995).

On the basis of the sociotechnical approach developed by Reason (1990) and Rasmussen (1991) in the context of large scale critical systems, we adopt a structural vision of dependability, seen as supported by numerous lines of technical and organisational defenses. We call a *defense* any entity of the system that can detect errors and/or can serve to terminate causal chains of events before serious loss and damage can occur. Accidents in well defended systems result from the combination of latent fault, local conditions and failed defenses (fig.1). Defenses work as barriers and protective functions implemented in addition to operational functions (for example, an automatic switch to a back up technical component). They are designed prior to the system operation according to a fault model of the system (dependability requirements). Human operators are widely involved in fault management during operation, thus we consider lines of defenses as including human work activities.

Fig.1 : A dynamic model of accident causation, adapted from Reason (1990)



Cognitive ergonomics provides a complementary framework for understanding not only how human activities work as defenses in an operational context, but also how operators actually make use of some safety related properties of systems.

Human work is structured by the organisation, through the division of work, the ordering of the functional processes, the operating procedures. Following McCarthy et al.'s (1997) suggestion, if we aim at organisational informed design in the context of fault management, we first need to consider the fundamental issues involved, as well as the concepts and models at hand. A neglected issue concerns the operational life of a system, in particular the actual management of unavoidable sociotechnical changes without endangering the current dependability (Rasmussen, 1991). Thus, a framework is needed in order to help design and management to predict the evolution of organisational structure from a perspective of dependability.

To this end, Reason (1990) proposes a macroscopic version of the model outlined above (Fig. 1). He highlights how organisational processes can support the propagation of latent faults from management and design to the front line through various functional entities such as training or technical maintenance. The limitation of this macroscopic approach relies in its predominantly static view of organisation (for a critical review see McCarthy et al., 1997). Changes in organisational rules[1] will not directly result in the desired changes in the organisational context of work. These relations are likely to be mediated by dynamic social and organisational processes. A very important one is related to how operators interpret the underlying intentions within the new rules.

From an ergonomic methodological point of view, organisational conditions are also often described as externally imposed, standardised and rather static prescriptions to which the actual work can be contrasted. Activity analysis stresses by contrast the active, variable, and situated changing nature of real work (de Terssac and Maggi, 1996). The classic reference to the prescribed task does not operate since in open and rapidly changing systems, tasks are *discretionary*. Clearly, the human operator is expected to define and organise his/her activity according to the context. We need a dynamic approach of organisation in sociotechnical systems that takes " the nature of organising less for granted " (McCarthy et al. 1997). We adopt here a sociological approach of human work as an *action process* (de Terssac and Maggi, 1996). The working situation results from the regulation between two kind of processes one of which is partially predetermined and the other is constructed in the situation.

For our purpose of developing an organisational approach of fault management in complex systems, we need a model of the working situation, that combines both a causal model of faults and a dynamic model of work organisation. In large scale and especially in rapidly changing systems, unpredictability of combination of both faults in design (either organisational or technical) and operational conditions creates the dimensions of complexity and uncertainty of the real work situation. As a consequence, fault management human tasks can neither be fully predefined nor considered as strictly individually achieved. We considere fault management as made of *situated* and *distributed action processes* (de Terssac and Maggi, 1996). The notion of *situated* action (Suchman, 1987) draws attention to the way human operators define the decisions to make, the goals to achieve and the resources to use according to their understanding of the situation at hand. By *distributed*, we refer to a characteristic of organisation of real work related to a particular event as made up of many action processes and subprocesses done over time and divided up among operators and machines either locally in the unit, in other units, in departments or other organisational units (Strauss, 1985). The author uses the term *articulation work* for the activities in which operators have to engage in order to achieve coordination.

Reason suggests that the more distant from the front line the latent faults are, the more dangerous they may be. We propose here a complementary assumption : the closer to the front line the defenses are, the more crucial they must be considered. But too close is probably not the best choice, because it might generate high coupling and reduce the protecting effects. The second line is close to the first line, with enough time and resources to allow the human operator to develop a local as well as a more global point of view of the technical conditions in first line. In the present study, we focus on these dynamic processes in second line where latent faults (technical and organisational) are effectively managed by *defenses* before combining with dangerous conditions in first line.

In the next section, after a description of the case study, we discuss the interest of the model in order to accounting for human contribution to dependability on an every day basis.

ON LINE MAINTENANCE OF A DISTRIBUTED COMPUTING SYSTEM IN AIR TRAFFIC CONTROL

Five Air Traffic Control (ATC) centres are geographically distributed on the French territory. The public service of Air Traffic Control is ensured for aircrafts flying through controlled airspaces. It aims at avoiding collisions between planes, managing the daily traffic flow and initiating the rescue process for aircraft in distress. The controlled airspace is divided into volumes called sectors. Each sector is managed by two controllers who are accountable for all the traffic crossing their sector. Considering the division of work in ATC, we locate the controllers in what we call the *first line*, directly involved in the operation of the system composed of aircrafts and pilots.

In order to achieve their task, these *first line* operators crucially depend on various technical devices displaying information and enabling communication with pilots and with other ATC centres (e.g. radar display, flight plan information on strips, radio, telephone). Sociotechnical subsystems, located on a *second line,* are in charge of maintaining the availability of these technical devices and the large technical subsystems that supply them. Controllers within the same geographical center are the principal customers of maintenance operators. The tight coupling in first line and the nature of

[1] Organisation rules are for example prescriptions.

control activities (decisions of control and communications) require an organisation so as the controllers are able to immediately offload technical disturbances onto available technical specialists. *Operational Maintenance* (OM) is performed by a team of technicians, each of them specialised in one particular subsystem, and explicitly accountable for its functioning. OM is performed on a basis of 24 hours a day, 7 days a week and aims first at restoring the system in case of failure. OM function is clearly in the *second line* and accountable for the technical working conditions of the *first line*. Operators alternate OM with *Specialised Maintenance* (SM) that is carried out during office hours and mainly consists in installing and testing new components, in configuring data, and in managing repairs of faulty components.

Our focus is on the Operational Maintenance of the CAUTRA[2] local subsystem which primary function is to provide the controllers within the centre and the regional area with processed data issued from radars and flight plans. A team of nine technicians alternate the two functions (three weeks of OM, six weeks of SM).

The CAUTRA local subsystem is connected with a number of local (within the centre) and external (distant) similar subsystems and terminals. Within the centre, division of work according to technical domain and subsystem is quite complicated. OM operators of different specialities have to collectively manage situations emerging from local interdependencies. Concerning external technical interdependencies, respectively used and maintained by remote controllers and maintenance operators, they make up a socio-organisational network in which any change at some particular location may have consequences at a distant place. In the context of OM, dependability mechanisms must thus be understood within a sociotechnical extended and heterogenous network. Coordination relies mostly on oral (face to face, mediated by telephone) or written communication between operators.

OM of the CAUTRA subsystem is first closely related with the downstream function and at the same time decoupled from it and, secondly intrinsically a part of the upstream network. The OM point of view on the system is very specifically structured. According to our framework, the macroscopic analysis revealed that MO works as a sociotechnical defense located in a strategic place. The structure enables partial awareness of conditions for operation in first line and technical conditions emerging from a complex and extended network of local defenses and operational functions of the subsystem.

[2] "Coordinateur Automatique du Trafic Aérien"

Within this organisational and technical context, OM also is of great interest because the analysis also highlights two important features of vulnerability: (i) the rapid evolution of the technical system and (ii) the turnover of the technical staff. As a result, the operator in charge of Operational Maintenance (on-line) may lack experiential knowledge, essential when facing infrequent and novel situations, whose resolution requires knowledge based reasoning.

In this complex situation, the operator has clearly to build up his/her activity field and articulate it with those of other operators within a technical and organisational context. Thus, we focus on the organisation of the activity field of the OM operator when he/she is involved in fault management contexts.

THE SECOND LINE ACTIVITY FIELD

This study is part of a larger research project conducted by the French ATC research centre, the CENA[3]. The project aims at preparing future evolution of maintenance working environments. It is therefore important to understand precisely how work is presently done. Over a period of two years, an ergonomic analysis was performed in the ATC center, through an iterative process, consisting in observations and tape recording of real activities, data analysis and interviews of the operators. Concerned by fault tolerance issues, we analyse how technical events are currently managed, from the maintenance operator point of view. The following example from our data indicates first how the operator in second line defines the situation according to an uncertain context and second how he constructs a temporary solution for handling it. Third the technical problem is handled within an informal distributed network. Finally, we point out how such cases provide opportunity for learning.

In addition to fault management, the CAUTRA OM operator has to perform some repetitive tasks such as saving processed Radar Data of the day before on a guard band (for possible legal purpose). While discovering that saving operation is impossible, the operator detects a probable failure of the local net between calculators and stations.

The operator interprets the present state of the subsystem as probably causally linked with a past error of the same local net (occurred on the day before), despite his colleague's oral and written conclusion that the error has been successfully treated. He elaborates a likely causal link of that event to a temporary change of the configuration of

[3] Centre d'Etudes de la Navigation Aérienne

the CAUTRA subsystem in order to create a temporary extension of a demonstration device for the " Salon du Bourget ". Those changes were undertaken by operators from an external organisational entity.

The OM operator also considers that although the failed function is clearly an off-line one and that OM is under an obligation only for on-line functions, he thinks that he has to find at least a temporary solution. The reason of this extension of his accountability field is that the unavailability of the local net *could have safety consequences in case of crash*. Indeed, in this kind of situation, the control function needs to identify the last geographical coordinates of the plane to start the procedure for rescue. The off-line application for revisualising and specifying the location clearly requires the functioning of the local net. So his primary goal is defined in terms of compensation according to an anticipation of a possible local event (in the first line) that would combine with this latent technical condition (in second line). He still has no real plan for problem solving but is trying to set the problem.

This Saturday morning, the OM operator copes with a complex and uncertain situation without clear evidence about what happened on the day before and what kind of actions were previously intended. The past event is untraceable in detail. His knowledge of this part of the system is limited especially concerning the recent change and he knows that Specialised Maintenance colleagues are off until Tuesday (Monday is a holiday). The span of time appears to him too long to just wait in this deteriorated situation. After several unsuccessful attempts at compensating the problem by simple and safe ways, he decides to call a CAUTRA colleague at home in order to collect historical information.

The dimensions of the paper do not allow us to detail the different points of the conversation. Nevertheless, we want to underline that the point of view of OM operator on the possible indirect consequences of the problem is rapidly adopted by his colleague. The gaps between their respective representations of the causal context were progressively reduced as they interactively reconstructed the likely development of the dynamic relations between event, actions and actors. The remote CAUTRA operator at home enrichs his experience by learning what kind of errors he made the day before (an omission during execution of a procedure and a failure in assessing the actual extension of the technical error). In return, he suggests two approaches for planning an indirect way of cirrecting the fault.

Then, the OM operator calls his hierarchical superior to explain the technical situation to him (the engineer in charge for the technical subsystem is not necessarily in the center). The point of view of the superior appears in this case to be less extended than the OM maintenance operator's one. It is more formal, adhering to the formal accountability field of OM. While understanding the point of view of the OM operator, he leaves the decision to be made up to the operator's knowledge of the situation.

The OM operator in the center can then manage one of the two suggestions successfully. The way adopted was clearly unspecified during design, but it worked. The possible operational problem is solved. The last phase of the problem concerns the treatment of the technical error and is accomplished in the afternoon with the assistance of two other CAUTRA maintenance operators (off duty). They not only interact with the operator in the centre by phone, but on one occasion they come to the centre to enable easier discussion.

Since these results are also found in very different cases, we suggest some features and implications of this extension of the activity field in comparison with the accountability formal field. The observed dimensions are (i) causal, (ii) temporal, (iii) spatial and (iv) organisational. Indeed, they are strongly related with each other. The causal dimension stresses the active (and interactive) orientation of the data collection toward a better understanding of the causal chain that lead to the actual state of the technical system. Yet the operator knows that he inherited two errors made by his colleagues the day before. So there could be more of them. The operator clearly accounts for the possibility of combination of errors while trying to explain a complex situation. The temporal dimension concerns different time spans. In short term, the operator handles this case while monitoring the evolution of the traffic load (how many flights presently processed). Anticipation of potential events such as a possible request from the first line is in middle term and on the job training in long term. Spatial dimension in this situation is small since the operator remains mostly in the technical room, close to the essential technical subsystemt. Theorganisational dimension refers here to the nature of the accountability field. Only operational functions are under obligations. The organisational dimension also involves the cooperative nature of activities. The informal local network of CAUTRA operators provide efficient assistance to the OM operator in unspecified ways. It is clearly motivated by the shared feeling of their individual lack of experience. Actually, alternanation is likely to be an external structural factor that supports the social relations and common knowledge elaboration as well as articulation within the centre, providing them with complementary perspectives on the components they deal with.

CONCLUSION

The vulnerabilities in defenses pointed above are reconsidered within this results. Extension and restructuring of the activity field appears as resistance means that are organisational in nature. They reflect the successive points of view the operator adopts to deal with a situation and his/her ways for stabilising the situation for the first line while at the same time the sociotechnical subsystem is reproducing itself (technologically and in terms of competences). In addition to these results, from a methodological point of view it is argued that an ergonomic approach which allows consideration of the dynamic interplay between human activities and technological and organisational context is essential for such an analysis.

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Cooperating with Computers: Abstracting from Action to Situated Acts

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ABSTRACT

For the design of computer interfaces, interaction can be represented as situated acts that abstract up from situated action. The situated-act representation specifies interaction independent of interface modalities, enabling specialization of interfaces based into particular modalities. The approach is illustrated through interfaces in two domains: an aircraft navigation system and a multimodal VR viewer.

Keywords

Situated action, situated acts, modality, multimodal interfaces

INTRODUCTION

It is generally accepted that when humans and machines interact cooperatively, they rely on communicative actions to carry out their intentions. A problem with this view, though, is that the concept of action is typically linked to the physical affordances of the interface or the transmissive characteristics of the medium of communication. As a result, accounts of interaction—even situated interaction—tend to be expressed in terms of actions: "Push button B" or "Move levers forward to position P." We suggest that interaction can be more fruitfully represented at a higher level of abstraction, situated acts, which can represent the force of the communication in terms of the domain task instead of in terms of the interface: "Go to navigation fix F" or "Accelerate to speed S." In this paper, then, we develop a theory of situated acts, show how this approach can be applied to interaction in a variety of domains, including (a) aircraft navigation systems and (b) multimodal navigation interfaces. We discuss the theory's implications for design methodology and explain how the situated act approach offers the promise of designing cooperative systems at high level, independent of interface modality.

Actions vs. Acts

The distinction between action and act can be seen in the photocopier interface studied by Suchman (1987). For example in Display 4 (p. 173), the machine's instruction reads "Press the Start button (to produce a copy in the output tray)." The action is pressing the start button; the goal is producing a copy in the output tray; and the act is a command to copy a page. In contrast, in Display 3 (p. 173), the machine's instruction reads "Place your original face down on the glass, centered over the registration guide (to position it for the copier lens)." Here the action is to place the original face down on the glass, centered over the registration guide; the goal is positioning the original for the copier lens; but there is no act because this is the user's action. It has no communicative value for the copier and the user has no expected outcome other than the direct product of their own action.

The kinds of acts we suggest are taking place in cases such as the photocopier example are like classical speech acts (Austin, 1962; Searle, 1969) but are broader in their definition. These situated acts, like speech acts, have intended effects, symbolic force, form of expression, and actual effects. Unlike speech acts, situated acts do more than "do things with words:" they include the kinds of direct actions that speech cannot usually carry out, such as direct manipulation of objects in the interface or in the real world. In a graphical user interface, direct manipulation has symbolic content: the action of moving a document icon to a location depicting a folder might mean to move or to copy the document into the folder. Symbolic content constituting an act could also be ascribed to physical actions in the world. These actions could be subtle and overtly para-linguistic, such as a casting a quizzical glance, or hugely physical, not obviously linguistic but no less symbolically communicative, such as punching someone in the nose.

Task-action grammars (Payne & Green, 1989) related user behaviors to task accomplishment; they provided means of expressing interactions in detail at the level of action. Here, we are attempting to abstract up from actions to acts; our problem is to produce accounts of interaction that make sense—especially to the human actors—at the act level and then to develop appropriate means of expressing these acts as actions in an interface.

A version of abstraction from action can be found in activity theory (Nardi, 1996), which describes interaction at an "activity" level and pays particular attention to social context. Activity theory, however, has some characteristics that limit its usefulness for the analysis and reformulation of interfaces of the kind we consider here. In particular, it lacks formalisms for dealing with communicative intent and multiple agents. More generally, it has not been operationalized in terms of techniques that offer specific analyses of particular interfaces and their contexts. Consequently, our notion of situated acts tries to embody some of the spirit of activity theory while providing a more concrete basis for development and reformulation of interfaces in communicative, multi-agent settings.

Beyond Speech Acts

There are a number of fairly well-known problems with speech-act models of interaction (cf., Levinson, S., 1981). The most serious of these is the problem of knowing the complete range of intended and actual effects (Marcu, 1997). This is especially the case for interactions among human agents, which reflect a wide variety of social needs and goals. For machine agents (at least agents with no social goals, which is all we are likely to encounter for the foreseeable future), these objections to speech acts are less critical. More troublesome, for our purposes, is that classical speech acts necessarily involve speech, so that they tend to be ill-suited for representing acts expressed more broadly. The theory of classical speech acts includes categories of acts such as requests, informs and promises. These have been broadened to include meta-acts such as turn-taking (Novick, 1988) and topic control (Traum & Hinkelman, 1992). Conversely, one can extend act models in the other direction—toward domain-level acts that have meaning in the particular context of an interface, the interface's underlying application, and the application's situation of use.

Some results have been achieved in creating increasingly complex models of what might be generally termed dialogue acts, including domain-independent conversational exchanges (Winograd & Flores, 1987) and grounding (Clark, 1996). Novick (1988) proposed a set of "conversation levels" that included both domain and meta-acts. Traum and Hinkelman (1992) proposed a related approach, which they called "conversation acts". However, neither of these models explicitly abstracted communicative action to a level independent of modality. In fact, it is possible to change the modality while keeping the commonality of the user expectations of interaction (Pérez-Quiñones & Sibert, 1996). Similarly, an abstract set of communicative acts has been used to generate text or graphical expressions for referring expressions (Green *et al.*, 1997; Kerpedjiev *et al.*, 1997).

SITUATED ACTS IN DIALOGUE

We now turn to our theory of situated acts, which are a kind of dialogue act expressed largely in domain, rather than domain-independent, terms. The intended perlocutionary effects of situated acts tend to be the accomplishment of domain, rather than interface, goals. The illocutionary force of such acts are thus linked to domain concepts (e.g., climb), rather than putatively universal meanings (e.g., request). The acts are situated in the sense that they do not have meaning outside the context of the interaction itself; they are the logical thing for the user to do under the circumstances. Indeed, one of the purposes of expressing interaction at the act level is that the salience of the situation is increased. That is, the state of the interface may be observable at the action level (e.g., a new prompt appears), but the state of the underlying system is a higher-level construct that provides a deeper level of understanding. This is why the title of the paper is from "actions to situated acts:" while every action is—by definition—situated, the salience or meaning of the situation at that level may not be optimal. So our idea here is to "lift" the actions into acts that have a higher degree of situational meaning.

What we have, then, is a two-tier approach. At the more abstract level, we have a representation of situated acts that serve as communication goals, independent of specific interface style or even dialogue style. At the more concrete level, we have the interface itself, where design decisions help give shape to the interface. This level is specific to each interface design. An important consequence of our situated-act approach is that for each "application" there might be more than one design that enables the situated acts to take place.

APPLICATION OF THE MODEL

Having defined our theory of situated acts, we now show how it can be applied to complex interfaces. First, we show how a widely used command-line interface for aircraft navigation can be abstracted to an act-based representation that (a) accounts for interaction among the human and machine agents in the cockpit and (b) can be specialized to produce new kinds of interfaces for the same task. Second, we apply the situated-act approach to the problem of integrating a 3D viewer of a navy battle simulation with a speech system.

Cockpit Interface

The navigation of modern-generation aircraft such as the Airbus A340 is controlled by a flight management and guidance system (FMGS). The interface to this system is called the multifunction control and display unit (MCDU). Some of the functions handled by the system include navigation, lateral and vertical flight planning, performance calculations, and guidance. Within the navigation subsystem, functions include alignment of the inertial navigation system, computation of position, assessment of accuracy level, selection of radio navigation aids, and polar navigation.

The interface embodied in the MCDU has different displays, pages, modes, input items that correspond to the aspects of the system functions. For example, the MCDU for the A340 contains pages that cover everything from initializing a flight plan to performance on approach. The pages can be slewed vertically or horizontally on the display. The name of the page is normally indicated at the top of the display, typically in abbreviated form. The crew using the MCDU receive messages from the flight management system and type in entries using a "scratch-pad" line at the bottom of the display. An entry from the scratch pad is inserted into a field by pushing a selector key adjacent to the field. It is important to note that the MCDU is an interface used by sophisticated users in a safety-critical environment; it is about as far removed from a walk-up-and-use kiosk as one can get. But the task of following of instructions—understanding how to do things and to how to interpret the results—remains at issue even for these sophisticated users. Anecdotal evidence (Glasgow, 1997) suggests that even experienced crews of Boeing 747 aircraft differ widely in their knowledge of the interface for the aircraft's flight-management system, and that the complexity of the interface design makes it difficult to carry out foreseeable tasks under conditions of high cognitive load, such as during a flight's approach phase.

The aircraft's crew is, by definition, in a situation. Unlike the Micronesian navigators cited by Suchman (1987), who do not give evidence of a pre-conceived plan and who use purely local, observable phenomena to guide their craft, commercial aircrews have explicit flight plans and a variety of long-distance navigational aids. But the presence of an explicit plan makes the aircrew's actions no less "situated" than the Micronesians': the plan is part of the context. An element of a "situation" is no less authentic because it was created by the actor; presumably the Micronesians' situation included elements such as the trim of their sails and their intentions to journey to a particular destination. It is appropriate simply to accept that aircrews plan their flights and that these plans thus become a factor in their interactions with the flight management system through the MCDU.

The point of this analysis is (a) to show the action-level interaction of the interface and its associated procedures as presented in the flight crew operating manual, and (b) to demonstrate that these actions can be abstracted into situated acts. Please bear in mind that this account is able to present the analysis for a tiny fraction of the MCDU, and that many links to other parts of the interface and its underlying system will have to go unexplained because they are of limited relevance for present purposes. Also, some of the acronyms used in the manual have been expanded or clarified to make the account of the interaction more comprehensible (e.g., "direct-to" for the manual's "DIR TO").

One of the things that the MCDU permits the flight crew to do is to define a leg from the aircraft's present position to any waypoint; this "direct-to" waypoint may be either already in the active flight plan or otherwise designated by the pilot. In fact, there are two other distinct direct-to functions: the direct-to/abeam function defines waypoints that are projected along a leg of the initial flightplan; the direct-to/intercept function defines a means of intercepting a course defined by navigational signal at a specified waypoint. Each of these three functions has its own procedure, although there are similarities among the procedures. This example presents the simplest case, direct-to-waypoint; the analyses for the other cases are similar. As published in the Flight Crew Operating Manual for the Airbus A340, the first part of the direct-to-waypoint procedure comprises the following *actions*:

1. Push the "DIR" key on the MCDU panel.
2. (a) Slew pages until the desired waypoint is found in the current flight plan and push the key next to the display line containing the waypoint; or
   (b) Type the waypoint into the scratchpad, which is the bottom line of the display.
3. Push the top-left display key ("1L"), which enters the selected or scratch-pad item in the 1L field, "DIR TO."
4. Push the top-left display key ("1L") again, to confirm the selection and return to the MCDU's flight-plan page.

The effect of the crew's action is to tell the flight management and guidance system to travel directly to the indicated waypoint instead of continuing the current leg of the flight plan. If the new waypoint was already in the flight plan, the revised flight plan is already complete. Otherwise, if the new waypoint was not in the flight plan, then the direct-to waypoint creates what is called a flight-plan discontinuity, where the system does not have sufficient knowledge to link the new waypoint into the flight plan. The manual instructs the crew to adjust the flight plan to get the most probable flight plan beyond the new direct-to waypoint.

These actions, then, can be abstracted into *situated acts* along the following lines:

1. Specify a waypoint (either from the current flight plan or not).
2. Command the aircraft to head directly to this waypoint,

Or, even more generally, the actions could be abstracted into the following single act:

1. Command the aircraft to head directly to a specified waypoint.

Clearly either account of these acts could be realized through a large range of interface design alternatives. An assumption underlying the situated-act view is that a better design will track more closely the "natural" lines of the abstract acts. In point of fact, the MCDU's interface is relatively good in this example, as pushing the "DIR" button initiates the command, the system then offers the crew the choice of available waypoints, and the crew then selects the waypoint and confirms and action. An alternate design might involve first selecting a waypoint and then pushing the "DIR" button to take the action; this would semantically link the "DIR" button with the domain action of the command rather than the interface action of displaying the page of waypoints.

Navy VR Battle Simulation

The second example that we will discuss is a design analysis after a project was completed that shows how our act-based model could have been used to solve some design decisions for the integration of a speech interface to a virtual reality (VR) project.[1]

The VR system was a Navy battle simulator that enabled viewing a pre-scripted scenario either as a 3D graphics on a computer monitor or on an overhead display (similar to a head-mounted display except that the display was mounted on a device and the user just looks into it, like a set of binoculars). The system had few basic commands, mostly dealing with controlling the playback of the simulation and moving the user's position in the simulation. Most of the commands were implemented using either a keyboard or a mouse. There were no advanced 3D pointing devices used in this program. To integrate a speech input and natural language processing system into the viewer, we defined the different user-level acts available in the system. From these, we defined the set of verbs and objects needed for the grammar in the domain.

Domain Acts

The application domain in this example is very simple. There are six basic domain commands (acts). These are

Go to [<location> | <platform>]: Move the user to a specified location or to a named platform (boat, airplane, helicopter, etc.)

Set view to [top-view | out-of-window]: Change the view from birds-eye-view to out-of-window view. The out-of-window view uses the user's current location as point of view.

Set simulation time to <time>: Change the simulation clock to a new time, thus moving the simulation player forward or backward to a specific time.

[Play | Stop | Start | Reset] Simulation: Control the playback of the simulation.

Show information for <platform>: Opens up a window with information on platform, such as location, name, speed, types of weapons, etc.

[Show | Hide] <platform>: Shows or hide the platform indicated.

Interface Actions

Each act is paired with one or more interface actions. The original interface had two forms of interaction: a 3D display on a monitor and an overhead display. A third interface style, using speech input and natural language processing, was added. This section discusses how each act was paired with one or more interface actions. The discussion is organized by interface style.

3D Graphical Display. The graphical display included the use of the mouse to select small windows that allowed access to the application domain acts. Most of the acts described above were implemented in windows that floated above the 3D view of the world. Also, the two different views of the world allowed some different commands that were specific for each view. For example, the top-of-the world view allowed the user to select the platform for the out-of-window view by simply clicking on the

[1] Work performed by second author (Perez-Quiñones) while working at the Naval Research Laboratory, Washington, DC.

platform icon. The out-of-window view did not allow changing the platform. For each domain act, we present the interface action in 3D-monitor style:

Go to<platform>
 Change view to top-of-world view
 Click on platform of choice
 Change view to out-of-window view
Go to <location>
 Change view to out-of-window view
 Open rotation angle dialogue box
 Change angle of rotation
 Click OK
 Click mouse to move forward in direction of viewing
Set view to top-view
 Click button at bottom of display
Set view to out-of-window
 Click button at bottom of display
Set simulation time to <time>
 Open simulation control dialogue box
 Move slider to desired location
 Close dialogue box
[Play | Stop | Start | Reset] Simulation
 Open simulation control dialogue box
 Click desired button
 Close dialogue box
Show information for <platform>
 Change view to top-of-world view
 Click on platform of choice
 Click on Info button
Hide <platform>
 Change view to top-of-world view
 Click on platform of choice
 Click on Hide button
Show
 Change view to top-of-world view
 Click on Show all button

Overhead Display. The overhead display interface was designed to work as an extension of the 3D style. Therefore not all controls were implemented in this style. The list below shows only those acts that were implemented with the overhead display, and the rest were taken from the list above. The overhead display provided not only angle of view but also direction of viewing, so the system could track the user's head and use it to change the viewing area accordingly. The overhead display had a small button that was used for movement. For each domain act, we present the interface action in overhead style:

Go to <location>
 Move head
 Press button to fly in that direction

While there was only one new interface action added for this style of interface, this proves to be a considerable one. The user can "move" more freely around the simulation using the overhead display than with the 3D monitor style. The limitation of this style, much like the limitation of many VR systems, is how to interact with the world. Removing this limitation is what led us to integrate a speech interface style with the application.

Speech and Natural Language Processing. The speech interface was added to the application primarily to enhance the use of the overhead display. We were also interested in studying the use of voice commands for a hands-busy interface. The next list presents the interface actions implemented. As before, the list shows only those acts that were mapped to the speech interface; all previously mentioned interface actions are still available. The set of new acts is as follows:

Go to <platform>
 Take me to platform <x>
Go to <location>
 Take me to location latitude, long.
Set view to top-view
 Change the view to top of the world.
 Show me the world view.
Set view to out-of-window
 Change the view to out of the window.
[Play | Stop | Start | Reset] Simulation
 Play simulation
 Stop simulation
 Start simulation
 Reset simulation
Hide <platform>
 Hide platform<platform>
Show<platform>
 Show platform <platform>
Show all hidden
 Show all platforms
 Show all hidden platforms

Acts as Guide for Actions

The acts in this domain should have served as guidelines for implementing interface actions in the system. Because this system was not designed with an NLP front-end in mind, many other domain acts were not considered because the equivalent interface actions would have been cumbersome in the other styles. One example was the only query on the system: a window that displayed information on the platform specifics. With the NLP addition it becomes feasible to implement new interface actions that did not have a mapping in the domain acts. For example, a new set of queries was implemented to show/hide platforms that meet certain criteria:

Hide <platform>
 With a query, process this as follows:
 Hide all platforms that carry weapon <x>
 Hide all hostile platforms

Hide all neutral platforms
Hide all neutral platforms that have weapon<x>
Etc.

In this example, a single domain act mapped to many new actions in the interface afforded by natural language expressiveness. The result was new functionality that should have been available in the act level but was not included. The new act should have been:

Add to set <platform>
Comment: Adds the identified platform to the set
Clear set
Comment: Removes all platforms from the set
Hide <set-of-platforms>
Comment: Hide all platforms in the set

Actions in Multi Modal Interface

The addition of the natural language front end to the application improved the usability of the system significantly. The overhead display, for example, now had more uses because the user did not have to switch back and forth to the 3D view to manipulate the simulation. Also, the use of a natural language processor with some simple queries allowed the user to learn about items such as the domain and platforms much more quickly than clicking on each platform independently.

But what is important for our model about these new multimodal interactions in the domain is that the act-level representation did not have to change. The act-level representation, if expressed completely, should afford new interactions and interaction styles without changing that representation, consonant with our point that the act-level representation is specific to the domain and the action-level representation is specific to the interface style. The adaptation of styles through different actions can produce better usability but the act level remains unchanged. Open questions include whether it is possible or advantageous to provide act-level interface entities or descriptions to users, and whether action- and act-level elements should or should not be combined within an interface or procedure.

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The Role of Direct Engagement in Text-based Cognitive Tools

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ABSTRACT

The essence of hypertext is the application of the direct manipulation paradigm to information retrieval; clicking on a hypertext link invokes the display of related material. An often-repeated claim about hypertext is the close match between this basic interface style and the intricate, associative nature of our central cognitive activities of memory and thought.

This paper firstly examines the notion that this current, and rather limited, experience of direct interaction with text should be seen not as an end in itself, but more as a first step towards the fuller realisation of a new breed of information tools with richly interactive interfaces.

The paper then describes the application of some of these ideas in the development of a novel language learning prototype, the interface of which illustrates the key concept of extreme directness, termed direct engagement, in textual manipulation and interaction. The paper concludes with a reflection on the work still to be done in producing tools that better bridge the gap between the essential fluidity of mental processes and ideas and their external representations.

Keywords

Hypertext, cognitive tools, user interface design, language learning.

INTRODUCTION

The concept of direct manipulation has become central to the design of modern interactive software tools. The essence of hypertext is the application of the direct manipulation paradigm to information retrieval; clicking on a hypertext link invokes the display of related material. An often-repeated claim about hypertext is the close match between this basic interface style and the intricate, associative nature of our central cognitive activities of memory and thought. This paper reviews the origins of the hypertext idea, and contrasts some of the early hopes for hypertext with the current state of practical hypertext implementations. In the process, the issue of flexibility and directness in interface design is looked at from an unusual perspective: the gender-based psychological interpretation of certain important cultural trends provided by the controversial author and academic Camille Paglia.

The paper then explores the notion that the current, and rather limited, experience of direct interaction with text should be seen not as an end in itself, but more as a first step towards the fuller realisation of a new breed of information tools with richly interactive interfaces. One area in which an interactive approach to manipulating displayed text might be expected to bring dividends is in language learning. The paper goes on to describe the application of some of these ideas in the development of a novel language learning prototype, the interface of which illustrates the key concept of extreme directness, termed direct engagement, in textual manipulation and interaction.

HYPERTEXT: DREAM VS. PRACTICE

Hypertext has entered its third age. After a long period as an interesting backwater of research activity, hypertext enjoyed a mini-boom from the late eighties to the early nineties, with increasingly successful conferences, and even some commercial exploitation. Then along came the World Wide Web (WWW) with its simple but network-transparent model of hypertext and now only five years or so since its birth it has become a major new platform for all kinds of information, management and entertainment applications.

It is instructive to remind ourselves of the origins of the idea of hypertext. The two pioneers most often cited are of course Vannevar Bush and Ted Nelson (our apologies to the third - Douglas Engelbart - who is omitted purely for reasons of space, from this short paper). It is interesting how two such different personalities became linked in this way through a common dream of building tools which would enable the physical manifestation of the rich inter-connectedness of the world of information and ideas.

Bush was the war scientist, a highly organised man, but one who could foresee the growth in information outstripping anybody's ability to cope unaided. In a pre-computing era, he envisaged a Heath Robinson-ish contraption with cameras, levers, photocells combining to enable the mechanical linkage of related items in a personal library. In stark contrast, Nelson is a product of the 1960's, highly individual, whose urge to build his "Xanadu" of seamless, non-duplicatory, literary inter-connectedness grew out of a deep-seated fear (with, it now appears, some medical basis) of his "hummingbird mind" being unable to hold onto and control the myriad of thoughts and associations jostling for attention.

Bush's vision, though hugely imaginative for his time, focuses on the construction, maintenance and retrieval of relatively straightforward linkages between documents (or images) or clearly defined locations within documents. The simple linking mechanism available within Hypertext Mark-up Language (HTML) has made the construction of "webs" of documents inter-linked in this way possible for a huge population of content providers and readers. Bush's idea of "trails" is possible in a crude fashion even in standard browsers, with bookmarks and history lists.

It is clear Nelson envisages a more richly intertwined "docuverse", with documents inter-related not merely by link pointers but by the dynamic inclusion of parts of one document in another ("transclusion"). Even Nelson's choice of the term "hypertext" suggests something more than a desire for the simple inter-linking of documents, something that goes well beyond the limitations of traditional texts.

There has, in fact, been a strand in hypertext research which has tried to focus attention on the possibility of much richer inter-linking of textual items both within and between documents. In a paper which has received less attention than it deserved, Van Dyke Parunak (1991) attempts a detailed classification of possible link types, and is one of the few authors to tackle the relationship between structural linkage and semantic, associative linkage. In an even earlier and less widely read paper, Smolensky et al. (1988) describe a system (EUCLID) in which the internal semantic structure of a document, in the form of interlinked keywords and text segments, is viewed and accessed in parallel with the source text.

One of the few modern hypertext systems which addresses this issue of the granularity of the inter-linked items, and their visual display, is Aquanet (Marshall et al. 1991, and Marshall et al. 1994) in which small-scale relational constructs can be produced, and displayed graphically in a large workspace.

Our work is driven by a belief that the essential nature of the hypertext concept - direct manipulation of text - has far more potential than has yet been exploited. The next section draws on an unusual source to give a novel perspective on this issue.

A PSYCHO-CULTURAL PERSPECTIVE

An insight into this central issue of the nature of hypertext systems comes from perhaps the most unlikely of sources. Camille Paglia has become renowned, if not notorious, for her popular writings on the role of gender and sexuality in art and culture. In her book *Sexual Personae: Art and Decadence from Nefertiti to Emily Dickenson*, Paglia (1992) attempts to explain male dominance in art and culture in terms of deep psychological differences between the sexes which are, ultimately, rooted in physiology and reflected in mythology.

Although there is insufficient space here, and it would be inappropriate anyway, to discuss Paglia's thesis in any depth, one of her central themes, the tension between the Apollonian and the Dionysian (or, as she prefers, the chthonian) strands of the human condition and cultural development, does seem to offer an insight into the struggle to define what hypertext is, and what it might be. Paglia describes the chthonian as all that is natural, fluid, continuous, undivided, dissolute. In contrast, she equates the Apollonian with the construction of form and shape, the recognition and naming of objects, separation, individuation, the marking off of boundaries, objectification; in other words, the Apollonian is the dominant (and generally male-dominated) strand in the development of Western culture.

A central argument of this section of the paper is that the origins and development of the hypertext idea, and its exploitation in cognitive tools such as web browsers and concept mappers, can be usefully interpreted as an unfinished series of attempts to control the "chthonian", and potentially chaotic, flux of information and ideas which results from the "information explosion" of the past fifty years. Furthermore, that the nature of those attempts, and those to come, can be usefully characterised by the degree to which they risk compromising the essentially fluid nature of their raw material by imposing an overly discrete, Apollonian-style rigidity in the structure and control mechanisms used.

We will return for a moment to one of our pioneers of hypertext. In a revealing section in a recent interview (Wolf, 1995), Nelson reminisces about a moment in his youth, in a boat with his hand trailing in the water "And I remember thinking about the particles in the water ... this constant separation and reconnection and perpetual change into new arrangements ... you couldn't really visualise or express the myriad of relationships."

Bush and the WWW offer a vision and an implementation of "macro" hypertext. This vision fails to recognise that almost any significant chunk of text contains detailed, self-referential inter-relationships or linkages that are undoubtedly more important to the overall understanding of a set of documents than the high-level links between the documents which are supported so well by current Web browsers (Callaghan and Hand, 1996). Nelson's writings, and some of the other authors cited above, seem to hint at a belief that hypertext could, and should, be a lot more than simple inter-document links for rapid retrieval in some kind of 'automated library'. Engelbart's phrase "the augmentation of the human intellect" also suggests more than tools to retrieve documents faster from electronic bookshelves. This spectrum of beliefs reflects, to some extent, the Apollonian-chthonian dichotomy presented by Paglia.

It is perhaps not too surprising to find more evidence of a commitment to recognising the fluid nature of textual information coming from work in the humanities. Authors such as Jay David Bolter (1991) and George Landow (1992) speak of a convergence of technology and theories of textual interpretation. In a chapter in the book *Cultures of Computing* (Leigh, 1995), Jones and Spiro give an interesting overview of the relevance of hypertext to the important aspect of critical theory known as contextualisation, and the role of new theories of cognitive psychology (they name theirs cognitive flexibility theory) in supporting the development of hypertext tools which emphasise the utilisation of multiple representations, massive inter-connectedness, and knowledge assembly rather than intact knowledge retrieval. It ought to be said that although Jones and Spiro's paper appears in a sociology textbook, they have applied their ideas (in education) not only in literary interpretation but also in biology and military strategy.

One of the few modern hypertext systems which addresses this issue of the granularity of the inter-linked items, and the nature of the display and interaction, is Aquanet (Marshall et al. 1991, and Marshall et al. 1994) in which small-scale relational constructs can be produced, displayed and freely manipulated in a large graphical workspace. However, we are in fact on the threshold of a huge expansion in the range of possible hypertext applications (hypertext's fourth age, perhaps), with varying degrees of granularity of inter-linked components and rich visualisation options. This is due to the recent emergence of the Extensible Markup Language (XML) a powerful meta-language for defining new types of hypertext document, and its associated display language XSL.

DIRECT ENGAGEMENT

Shneiderman (1982) coined the term "direct manipulation" and defined it in terms of continuous representation of the objects of interest, and rapid feedback *in situ* of the effects of user interaction. Laurel (1986) uses the term "direct engagement" to imply the quality that good theatre and good interfaces have in common: the "interface" becomes transparent and the audience feels themselves to be intimately involved with the (artificial) world portrayed. This quality is often sought and sometimes found in games and other multimedia products. Even state of the art painting programs can achieve a degree of illusion (at least for the amateur) that one is handling something like real oils or watercolours.

It is our belief that the basic hypertext interaction in World Wide Web browsers, clicking on a text or graphic "anchor" and causing the display of associated information to replace the current window contents, or occupy a new window, is an obvious example of simple direct manipulation applied to information (Callaghan and Arion, 1997). Bush, for example, would have been overjoyed to see such a faithful implementation of his main idea. However, we also believe that this is not the end of the story with regard to the power of software and computer displays to enhance the way we work with text. If we were to characterise this interface style from the perspective introduced in the previous section, it would certainly fall somewhere near the Apollonian end of the spectrum. The next section of the paper describes a cognitive tool for language learning in which we attempt to embody a greater degree of engagement with text. This tool aims to support a more fluid style of interaction and display appropriate to the early stages of learning a new language.

THE LANGUAGE NOTEBOOK: DIRECT ENGAGEMENT FOR LANGUAGE LEARNING

The ideas discussed above have been implemented by the authors in a prototype language learning tool.

In contrast to most existing "computer-aided language learning" (CALL) products, (and hypertext systems), the Language Notebook is not based around a standard "window and dialogue box" interface environment where the primary input from the user is to type into specific textfields or click on buttons or other standard user interface controls. Instead, the user works with a free-ranging spatial area (similar to large sheet of paper) on which words and phrases can be typed freely, dragged around, and manipulated. This process mimics the common informal language learning strategy of making a note of words learned, together with reminders of their conjugations and declensions, in a real notebook - along the lines of compiling a personal dictionary, arranged and grouped in whatever manner best aids retention and recall.

In the Language Notebook, any valid words and phrases displayed on the screen in the target language can be manipulated with simple mouse operations. For example, clicking on a pronoun in a simple phrase cycles through the alternative pronouns, and the verb part changes accordingly. Similarly, clicking on a verb word cycles through the tenses. All of this happens through direct engagement with the textual elements, *in situ*, wherever on the "page" they may be - having been arranged and possibly grouped for personal preference by the user.

The Language Notebook "page" becomes a visualisation arena, a form of externalised memory, where groups of related words, syntactic sets, and simple phrase constructs can be viewed and changed *in situ*, moved around and otherwise manipulated. The overall effect is an illusion of "electronic paper" which "understands" French (or whatever target language is loaded).

Enhancements under consideration include the use of "semantic gradients" - support for the automatic, customisable visualisation of groups of semantically related words in spatial orientations which reinforce their inter-relationships e.g. words to do with the past, present and future arranged from left to right, and adjectives such as tiny, small, large, gigantic arranged either horizontally or vertically. This display would be invoked by the user from one key word, and would again appear *in situ*, and be fully manipulable by the user.

The prototype is implemented in Java, and so can made accessible as an applet to enable feedback from potential users across the Internet. It includes an object-oriented model of a few basic language constructs (pronouns, adjectives and verbs so far) with a parallel set of display classes for the actual vocabulary terms. It is being developed in Java 1.1, and work will start soon on a move to Java 1.2, which offers much more sophisticated support for text display and manipulation. The new graphics features in Java 1.2 include rotation of text to any angle, and also better support for handling user interaction with displayed text.

RELATIONSHIP TO OTHER WORK

The use of free spatial layout in an esentially text-based tool, rather than the more common window/dialogue box/textfield approach takes its inspiration from two sources. On the one hand, there have been a small number of hypertext tools (notably Aquanet, as cited above) which have enabled the user to exploit the kind of spatial freedom of organisation normally associated with drawing packages. The second source is the highly interactive approach taken to supporting mathematical calculations in packages such as MathCAD and Mathematica. MathCAD in particular employs a "Live Document Interface" which enables equations and descriptive text to be positioned anywhere on a "page", and for the equations to be edited *in situ*, with results being automatically updated in other parts of the screen.

As far as language learning tools are concerned, there appears to be no previous work which combines spatial layout/visualisation and a high degree of user interaction. In fact, in the opening address at a recent major conference on the topic, there was an explicit plea (Borchardt, 1997) for work on new forms of screen layout, and for a move away from the passive display of text. We are also involved in applying these principles to other areas, including visual programming and novel approaches to the visualisation of electronic communications (Popolov and Callaghan, 1998).

SUMMARY AND CONCLUSIONS

This paper has explored the relationship between the essential concept of hypertext, direct interaction with text, and the possible extension and exploitation of this concept in other forms of cognitive tool. In conclusion, the current benefits being derived from the use of the World Wide Web version of hypertext are a testament to the power of the Apollonian mind and its scientific method to devise controls which give at least some power over the chaos of nature; in this instance the hugely-interconnected flux of information and ideas which resides partly in our minds and partly in our information artefacts. However, there is much that remains to be done in producing tools which better bridge the gap between the essential fluidity of mental processes and ideas and their inevitably impoverished external representations. This paper describes a prototype language learning tool which illustrates the concepts of direct engagement with and flexible visualisation of textual representations.

The authors are aware that this paper continues a tradition in human-computer interaction identified by Newman (1994). In a survey of HCI papers published at a series of major conferences, he identified those which reported improved techniques, solutions or tools and those which appeared to describe what he called *radical solutions* and experience and/or heuristics gained mostly from the study of radical solutions. Most papers seemed to fall into the latter categories (i.e. not clear improvements to existing theory/practice supported by evaluations/results). He contrasted this with the situation in engineering research, where the reverse was true. The Language Notebook can certainly be described as an unproven radical solution. Although its design is based on extending the application of well-accepted interface design principles to a new area, an essential next step is to develop the prototype to a stage where some careful evaluation of its practical utility can be performed.

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Interface Ergonomy and Authoring Tools System : the case of a radiologic multimedia database

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ABSTRACT

We introduce the most important characteristics of the human-machine interface of Santal, a system designed for medical users. Santal will be used by radiologists to create themselves multimedia databases introducing knowledge about medical imagery interpretation and diagnosis. Such databases are intended for two kinds of end-users, the interns and the experienced radiologists wishing to perfect themselves on a specific medical imagery speciality.

Santal has been created for users who are not developers and it presents specific tools for prototyping and developing multimedia databases. Its interface has been constructed to be adapted to expert knowledge representations shared by the radiologist community, such as for example, the notion of a referential case for a medical diagnosis. This system presents the users with different modules to be filled with specific knowledge which will be present in the final product (an atlas of medical images, an encyclopedia, a view board, a bibliography, a self-training module).

Our choices for the interaction between the users and Santal have been to facilitate the cooperation between them by representing a common context of interaction concerning the imagery patient record, the different modules, and their specific content. This context being common, it can facilitate the mutual communication of information and the execution of the two agents' respective tasks, by proposing a vocabulary and a description of these tasks adapted to the user's expertise.

Keywords

Expert knowledge representation, medical imagery, medical diagnosis, user-task model, multimedia system, interface design.

INTRODUCTION

This paper presents the design options for the interface and architecture of an ongoing project, named Santal. The main goal of this software is to provide a accurate help for developing multimedia databases in medical imagery. Computer-aided instructional applications with a multimedia interface are attractive for the radiologists due to the fact that different information sources as texts, static and animated images or sound concerning radiologic examinations and diagnosis are introduced and commented together (Henessey, Fishman, Kuhlman, Ney, Magid, 1990 or Baxter, Klein, Oesterle, 1997). The interface of this software has been created in response to a request from the radiologists, experts in medical imagery interpretations. These physicians want to create by themselves multimedia databases introducing specific knowledge in imagery domains used for self-learning (Durieux, 1994). The final databases created by Santal will be used for medical education of two populations of learners : residents and confirmed radiologists, both desirous to perfect himselves on a specific medical imagery speciality. It is developed with MetaCard environment and actually run on MacIntosh, Windows and Unix systems.

This system has an interactive interface for non-developpers people which has tools supposed to facilitate prototyping and development of databases (Kolski, 1997). Its specificity is to propose to physicians a model of man-machine interface adapted to expert knowledge representations shared by the radiologist community. Only elements of this interface centered on the expertise are accessible to the users, technical aspects linked to the application itself being hidden as much as possible. Thus we respect the interface man-machine and system partition (Coutaz 1990, Degoulet and Fieschi, 1991).

SYSTEM MAIN GOALS

The objectives of the project are the following :

- to be a good assistance for creating the final multimedia database efficiently guiding the user in the different proposed modules ;
- to require no specific programming expertise for the users;
- to respect cognitive representations of the users, especially their expertise in medical imagery. The system must use expert knowledge representations in, for example, the notion of "referential case" in medical diagnosis as a conceptual object or building an imagery patient record as a specific activity;
- to represent two models of users : the "user-designer" (the physician who creates the database) and the final "user-learner" (the physician who will consult it).

Why do we create such software ? As we have introduced it before, radiologists of an hospital departement were desirous to have adequate tools for creating multimedia softwares for instructional goals. The radiologic activities imply an increased amount of informations and knowledges concerning all specialised areas of medical imagery thanks to new imaging techniques. They have allowed to the radiologists more precise observations, therefore more accurate interpretations of their medical images. Moreover, the transfer of knowledge for intructional purposes needs images and verbal descriptions that only these specialists have the hability to collect and to comment. There are two kind of competences which must be transmitted to the students: the medical description and interpretation of images and the choice and the usability of the adequate technical materials in the appropriate situation. All theses knowledges concerned by a given speciality are teached by the adequate physicians. Their request was to be able to create themselves multimedia databases adapted to the evolution of their professional knowledge and practice.

We describe more particularly the preliminary designing options concerning the man-machine interface. We have to determine first, the specifications of the users models and their tasks, and then the specifications of the engineering model of the system (Gentner and Grundin, 1996) and finally the modalities of the cooperation between the system Santal and its users (Hoc, 1996).

DESIGNING THE HUMAN-COMPUTER INTERFACE

Building the user-task model

The users of Santal's authoring tools are experienced radiologists who want to communicate to others radiologists their own knowledge about a specialized area of this domain. This radiologic expertise concerns both theoretical and practical knowledge representations (Pellegrin, Bastien, Roux, 1993) which are used during the medical diagnosis activity (Hoc and Almaberti, 1995; Grenier, 1990).

As it has been described by the radiologists who have collaborated to this project, an accurate diagnosis needs two main information supports : a set of radiologic images belonging to a patient ("the imagery record"), and the clinical and biological informations belonging to this same patient ("the medical, or clinical, patient record").

The main task of a radiologist is to search and to identify accurate informations in these data to make a diagnosis. To reach this goal, a radiologist has to understand imaging anatomy, pathologic conditions and examination protocols (Baxter, Klein, Oesterle, 1997). Their activity is founded on the notion of "referential case". A referential case is presentation of the most typical features of a pathology identified on a patient and whose elements of description and diagnosis must be acquired by the students. Our radiologists have also described different knowledge transmission medias identified as the most important and the most usual ones in their professionnal activities : an atlas of images and commentaries about referential cases and associated diagnosis, a "show board" that presents a set of images allowing a comparative consultation, an encyclopedia including more general knowledge on the choosen topic, the related bibliographical references and an exercices set for training and self-evaluation like those used during the specialisation studies (cases studies, quizzes, anatomic drawings to fill...). All these different elements of knowledge have to be introduced in the databases created by the physicians thanks to Santal.

From a technical point of view, radiologists commonly use sophisticated medical imagery systems (tomography, magnetic reasonance imaging echographics, scanners and the classic radiographics). They are also familiarised with the computer-aided features of their equipment (i.e for digital image acquisition). We can consider them as experts in electronic imagery. So, the system may ask technical tasks as the first preparation of the images to fit with its own formats using software like Adobe PhotoShop.

In conclusion, the operators will have two principal tasks occuring at successive times of the authoring activity in interaction with Santal software to create its database :

- the first one is a prerequisite to the use of the software. This task concerns the collect of informations : the choice of referential cases, the selection of the images, the redaction of explicative and associate texts, the bibliographical basis and the creation of training exercises;
- the second one is synchronous with the use of the software. This second task consists in the realisation of the application, filling and customising a pre-existent specific skeleton proposed by Santal.

Building the engineering model of the interface

The main task of the system is to create the multimedia databases, according to a modular architecture inspired by experts' descriptions introduced earlier. Santal has three basic components which can be accessed by the main palette :

- Santal itself (in the menu "Santal") with its presentation, the preferences and the function Quit;
- the Project (in the menu "Project"), target of the system which can be initialised or reopened at this level;
- the Inspector (in the menu "Inspector") managing the access to the two other components :
- the Imagery Record Editor helping to create the radiologic images records and associated clinical descriptions;
- the Project Editor proposing a choice of the different modules to be included in the final product and assisting the user to create the choosen modules. These modules are the following : the Atlas, the Show Board, the Encyclopedia, the Bibliography, the Tutorials plus a Splash Screen module.

Three other functions are also available to the user in the main palette :

- the Editor managing the classical editions functions (Cut, Copy and Paste) and the text style functions (Fonts, Style, Size, Color);
- the Windows access, allowing to flip from a window to another one because of the different size of the windows (little ones should be hidden by the most largest ones);
- the Help access.

More deeply, the architecture of the system and representation of data are an oriented object model that constitutes the basis of MetaCard environment. So, the man and machine communications are constrained by the modalities of dialogue interfaces specific to MetaCard (i.e. metaphor of the" project ", menus, fields, buttons, dialogues windows) and those of the Macintosh or Windows system (i.e metaphor of the "office", direct manipulation, See and Point, WYSIWIG).

The "Santal vs Radiologist" cooperation principles

Our choice has been that the cooperation between Santal (the computer) and the Radiologist (the user) occurs during all the different tasks executed by the Radiologist. Santal and the Radiologist are going to cooperate in the achievement of the global task, that is the building of the final database. This cooperation concerns both a respect of some constraints asked by the operator or by the machine, and an adequate communication of necessary informations between them. From the radiologist' s point of view, there is a set of constraints that he has to follow which are induced by the oriented-object architecture of Santal. So, he will have to adaquately understand the global architecture of the system, expressed by the sequential organisation and the associated expression of the objects in the main menu bar. These named objects are "Santal", "Project" and especially an object called "Inspector" which is typically an oriented-object concept. Even when the task of the operator is the preliminary collection of informations, he has also to respect some technical constraints asked by Santal as :

- the images collected by the users must be saved in standart formats files (i.e. GIF format) and may

have two different sizes (a Normal size of 201 x 161 pixels and a Zoom one of 367 x 285 pixels);
- the text, if it is written on electronical support has to be saved on Text format,
- the bibliographical references are presented on the Medline references format.

In the same way, Santal will directly show to the user the result of its creative actions and choices, as it will be presented in the final product. So, the radiologist can evaluate the adequacy of the information presentation, its contents and, consequently, can decide to modify its database.

The representation of the man and machine situation, or "context of interaction" of the interface, must be common to Santal and to the user (Totterdell, Rautenbach, Wilkinson and Anderson, 1990). In our case, it concerns a shared knowledge of the different supports of information used by the radiologists : the imagery records, the different modules, and their specific content. This context being common, it would have to facilitate the mutual communication of information and the execution of the two agents respective tasks, by proposing a vocabulary and a description of these tasks adapted to the users expertise.

For example, in the Imagery Editor, the user has the tasks of naming a record, composing the content with images prealably selected and optionally associating an interpretation to them.

The system has the tasks of creating files filling with images of two sizes and text files linked to these images. These files must be included into the database project and will be used in the other modules.

With these two sets of tasks, we have defined the context of interaction as the building of radiologic images records (Totterdell, Rautenbach, Wilkinson and Anderson, 1990). A record is built in three steps accessed by the "Imagery" submenu. The first unit of interaction ("record") is used to create a set of imagery records, to delete or to name each of them. The second one ("composition") is used to include images in a given record. In this panel, the user can collect images in a normal and a zoom formats, give them a full text name, and eventually modify or delete each of them in the record currently under edition. An image being selected, the last panel ("interpretation") allows to write directly (or to copy from a prepared text) the associated medical commentaries.

CONCLUSION

If the cooperative man-machine interaction is illustrated by giving specific roles to the two participants, Santal is seen as an assistant to the database creation which is the responsibility of the radiologist. As an assistant, it has personal capacities because it is an "Expert in database and hypermedias". It proposes its help for :
- the planning thanks to the administrators (the Project, the Imagery Record Editor and the Inspector),
- the presentation of information by the homogeneisation of technical tasks accomplished by the user and by a direct visualization of the result of each action of the user in the interface.

The radiologist is seen as an author who provides the expert knowledge to the system, and manages the realisation of the database. He plans its own tasks execution by using proposals of Santal. He is alone to choose the knowledge contents and to modify at any time this database. So, he has the real mastery of the realisation of the task with the cooperation of Santal (Hoc, ibd).

We have briefly introduced in this presentation our choices for the building of an interface that we hoped be adapted to its users. Actually, this prototype has not yet been submitted to an ergonomic evaluation which should concern the three following points : the validation of our interface ergonomy, the globlal organisation of the system and the pertinence of our modules face to the specificities of cognitive representations of the experts. Such evaluations have to be undertaken on the two described populations, the first users, the authors, and the final user, the consultants.

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A Comparative Study of Digital and Cinematic Space with Special Focus on Navigation

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ABSTRACT
In order to better understand the characteristics of digital space, this paper investigates another artificial environment, cinema. Five common representational techniques of mainstream cinema are presented and explained: object continuity, point-of-view editing, spatial overlap, the 180° convention and sound. I present some speculations on how these devices have been, and might be, implemented in interface design to support user navigation. Such a comparison, though, has to be carried out with great caution since many interfaces are significantly more abstract than the realistic representation of mainstream cinema.

Keywords
Navigation, cinema, realistic/abstract spaces, visualisation techniques.

INTRODUCTION
Navigation seems to be a fundamental cornerstone in a growing number of human-computer interfaces. We navigate through our hierarchical file system, through hypermedia systems such as CD-ROMs or the Internet, through MUDs, graphical chats and VR environments; even in a word processing program we have to find menus and functions. The PERSONA project investigates the validity and the extension of this metaphor from 'real space' navigation, to 'computer space' navigation. Among other things, we seek to develop a conceptual framework in order to describe similar and diverging properties and affordances of spaces, ranging from 'real' geographic space and architectural space, to information space, semiotic space, social space, auditive space and different types of computer spaces. To this end I (as a film scholar) was brought into the project to see how *cinematic* space is constructed and apprehended. How can film be instructive when supporting navigation in digital environments? Can interface designers learn anything from 'designers of cinema'?

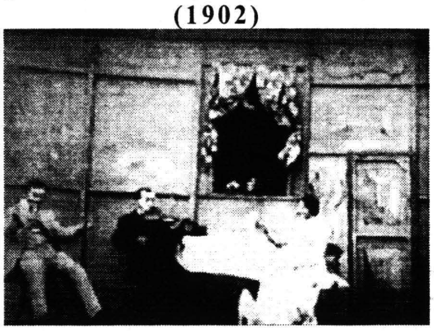
Navigation and Cinema?
Tentatively, navigation is a mental and physical activity involving an environment (geographical, informational or social) and a navigator, where the navigator is attending to or monitoring the environment along some form of goal (more or less specified and concrete; cf. the distinction between *wayfinding* and *exploration*; Benyon & Höök, 1997). With this goal in mind, whether it be a geographical place or a task, the navigator chooses a path or otherwise interact with the environment in order to reach this goal. All these activities might be assisted by some earlier conceptualisation of the environment (cognitive maps etc.) or with some form of tool (maps, signs, other people). Wayfinding consists of orienting oneself in the environment, choosing the correct route, monitoring this route, and recognising that the destination has been reached (Downs & Steas, 1973). According to this sketchy definition the spectator of a mainstream film does very little navigating. Although she does travel through space in a transferred sense, the goals are set by somebody else; she does not make route decisions; she does not physically interact with the environment and there is no voluntary movement. This is all done by the narrator. So why bother navigation with cinema?

Orientation and Cinema!
Cinema seems to be extremely good at one dimension of the navigating experience, namely *orienting* the spectator, making it possible to determine the spatial relations between objects and their relation to the navigator. In 'real life' navigational situations maps and overviews are important tools to accomplish this (and to determine the direction to the goal).

In most electronic worlds and spatial layouts, however, the size (and changing nature) of the information/activity space, the restricted screen space, as well as the cognitive limitations of the user, make overviews useless or impossible. The system has to choose specific 'slices' of information or activity space, and hide others that are considered to be less interesting/usable for the moment.

The visualisation of cinematic space appears to encounter analogous problems. In early cinema up till 1903-5 the events in the very short films (1-4 minutes), were represented in a *long shot* style, heavy influenced by the vaudeville tradition in which the major part of these very short films were distributed and exhibited (fig. 1). The whole of the proscenium was displayed and all action took place within the frame. This 'overview-style' rarely used cuts, respected the 'whole-ness' of the fictive space and events, and explicitly established the spatial relations between actors, props and objects (Elsaesser, 1990). In the long shot style spatial relations were unambiguous to the spectator.

Figure 1: *The Life of Charles Peace* (1902)



However, soon cinema's transformation into a primarily narrative and storytelling medium, demanded the introduction of editing (e.g. in ellipses and changing fictive locations) and closer-ups (e.g. in order to focus on narratively interesting details like faces and actions) (Gunning, 1994; Bordwell, Staiger & Thompson, 1985; Burch, 1990; Elsaesser, 1990). This *analytical cutting* technique naturally enhanced the expressive potential of the medium, but also disrupted and fragmented the continuous space of the long shot style. Every cut meant a new spatial position and angle. Every close-up meant forsaking spatial context, and objects/landmarks within the scene thus ended up *off-frame* and out of sight. The overview of the space was lost.

As all of these techniques made it more demanding for the spectator to build a coherent, unambiguous and continuous space, there developed within 'classical' Hollywood cinema (Bordwell, Staiger & Thompson, 1985), a number of conventions and devices in both composition and editing that attempted to limit this disruption of the cut. These techniques sought to 'support' the spectator's orientation and comprehension of space. Many of these serve as *offscreen indicators*, implying the presence and direction of objects in *off-screen space.* These conventions often exploit basic psychological dispositions in the spectator which make them appear 'natural' and to many viewers they go unnoticed (Persson, forthcoming).

The rest of the paper will present five of these and discuss their present or potential applicability in computer interface design, and whether these might support orientation.

OBJECT CONTINUITY

In the real world we have quite specific expectations: we expect objects to be whole and continuous even when parts of them are occluded.

If we represent space 'realistically' (by painting, photograph or moving images etc.), the spectator will project the same expectations on it. Although the frame ends at the neck of the man in fig. 2, the viewer does not interpret this as a picture of a decapitated head. She expects he has a body and that this body continues outside the frame into offscreen space. Or consider a hand coming into the image, a shadow, or perhaps some cigarette smoke. They all signal the presence of someone/something in offscreen space that is not explicitly displayed within the borders of the image. In co-operation with the spectator's knowledge of object appearances, these compositions trigger expectations, questions and anticipations on the implied offscreen space. The basicness of the perceptual knowledge makes a close-up very easy to understand.

The same device is used in computer interfaces, for instance in graphical MUDs or in VRML collaborative environments where it is possible to zoom in and out and get closer looks of people and objects. Close-ups in these worlds work like cinema close-ups since the representation triggers real world expectations: the space stretches out beyond the frame; concepts of left-right/up-down off-screen space are meaningful; objects look and behave more or less like everyday objects (fig. 3).

However, many (if not most) interfaces are not realistic in this sense. In *abstract* environments like the operative system of Windows or Mac OS (fig. 4), the background is undefined (neither interior nor exterior, no horizon or walls), the objects (buttons, menus, document icons, windows) do not look like or behave like everyday objects (they are flat, float around, make windows pop up), and things might happen here that have no equivalents in everyday life (scrolling etc.). The space offscreen (right-left or below-above) does not contain anything particular and does not trigger any particular offscreen space expectations. Everything of interest is contained within the frame. The landscape does not 'stretch out' into the distance in any direction.

Since this kind of representation fails to trigger user's expectations on objects and space it is difficult to exploit object continuity composition techniques. For instance, I have on several occasions observed fairly computer experienced users browsing my and other's web sites and was struck by their inability to understand that the information continued further down or up the 'page' (accessible by scrolling). Like early cinema spectators, they considered the screen to

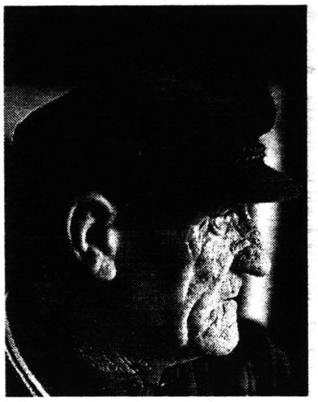


Figure 2

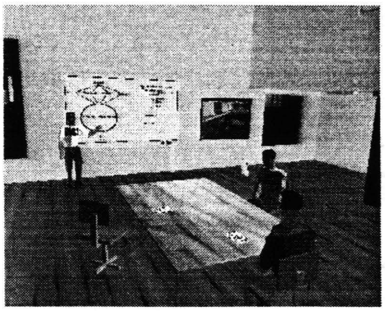


Figure 3: The realistic VRML space of *DIVE*

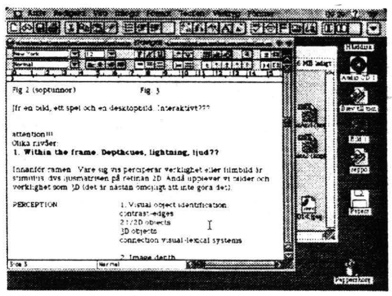


Figure 4: Abstract Mac space

display the whole situation. Unlike human bodies, bicycles and cars, web 'pages' and 'documents' are not everyday objects, and users have no expectations about what a 'whole' document/page looks like (but see the hypertext documents in Páez, Bezerra da Silva-Fh & Marchionini, 1996). Would the problems be precluded if the design triggered such a conception in the user, for instance by designing web pages as human bodies?

GAZE DIRECTION POINT-OF-VIEW EDITING

In everyday life, following another person's gaze is a very basic and useful behaviour (Butterworth, 1991). By looking at the same objects as the gazer is looking, you can guess where her attention is directed and perhaps from this speculate about her mental dispositions (beliefs, desires, feelings, intentions etc.). This ability is not restricted to humans but shows up in quite complex forms in animals as well, which indicates its fundamental function (Gómez, 1991; Ristau, 1991).

Gazing behaviour in cinema and cartoons is extremely important in order to relate different shots and spaces, and activate offscreen space. Consider fig. 2 above again (assuming this is a moving image of the man). Following the gaze of the man, the spectator typically infers that he is attending to something offscreen, although this is not explicitly displayed at the moment. If we cut from this image or transfer to another shot of, say, the burning house in fig. 5, then the viewer most likely infers that the man is looking at the house: when the shot of the old man is shown, the spectator assumes that there is something occupying offscreen space (right), and when the shot of house is shown, the spectator infers that the old man is somewhere offscreen (left?). This temporal juxtaposition of spaces thus generates spectator assumptions about the man's *point-of-view* and to what he is attending, but also that the two spaces are within sight of each other in the fictive space (that is, pretty close). This trope is extremely common in all genres of moving images.

Interestingly, 'the man looking at the house' is never explicitly present within the frame. The spectator never *sees* the two together. The spatial relations between the shots only belong to the imaginary, mental space that the spectator is *constructing* in her mind during viewing. In reality, these two spaces possibly never met at all: the man may be shot in Stockholm, and the house in Limerick.

Although more and more digital environments are inhabited with agents, avatars, personal guides and assistants, gaze behaviour is not employed that often. *Microsoft's Office Assistant*, for instance, communicates textually/verbally and by bodily postures, but pointing and gazing at objects within as well as outside the frame, would perhaps enhance the orientation support. In graphical chat environments like *Palace*, the avatars are represented as smile-faces, but they cannot look at or display gaze behaviour like in social situations. In other collaborative environments like *DIVE* or *Active Worlds* the avatars are detailed enough to exhibit gazing behaviour. The user can turn around and change point-of-view (through keyboard and mouse commands), and other users can see in which direction the avatar is looking. Here offscreen space and gazing direction cues work in similar manners as in cinema (and the real world).

But how might gazing support orientation, for instance in a hypertext structure? The main function of point-of-view editing is to connect and spatially relate two disparate (but juxtaposed) spatial segments. One of the parameters of the 'lost in hyperspace problem' is that the pages/nodes visited are difficult to spatially relate. In abstract space there is no point in asking whether this site is left/right up/down of the former one. By introducing humanoids into the browsing activities, which display various kinds of gazing behaviour between on-screen and off-screen nodes, the hypermedia structure might gain in realism and orientation might be supported. Exactly how this might be implemented is still an open question.

Figure 5

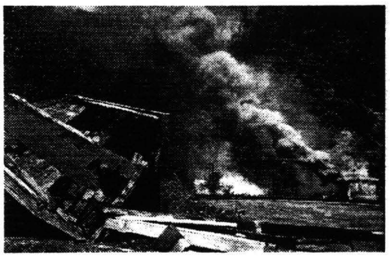


Figure 6: *Notorious* (1946)

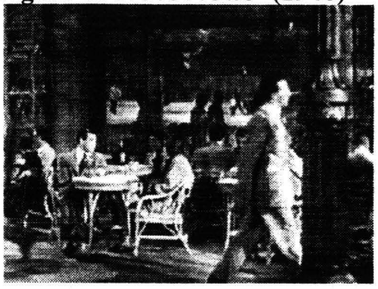
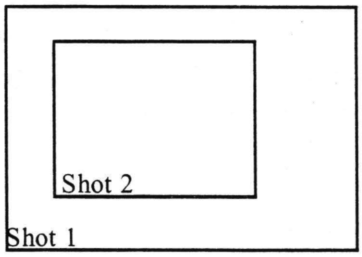


Figure 7

Figure 8

Figure 9

Figure 10



SPATIAL OVERLAPS

In mainstream cinema, a new scene is often initiated with a wide *establishing shot* (fig. 6): the camera typically cuts to a closer view as the action or dialogue gets more intimate (figs. 7-9). Although shifting angle and position, closer-ups stay within the same spatial segment as the establishing shot. This technique is called *spatial overlap* (fig. 10).

One important function (among others) of establishing shots is to give the spatial setting for the following closer-ups. If the filmmaker has cut from a preceding scene to the close-up of fig. 9 the spectator would have had some 'orientational' problems: Where are we? What kind of situation is this? With whom is he talking? What is the spatial relation between this shot and the former scene?

As the scene is edited now, we first get an overview of the street, then the table with *both* characters. After that we cut closer to medium-shot, still with the other character's shoulder within the frame, until we reach the close-up of a face with no *explicit* clues to what goes on in the surrounding off-screen space. However since there have been spatial overlaps the spectator knows pretty well where the close-up is set and how its offscreen spaces is structured. Overview shots and spatial overlaps provide information and expectations on offscreen space in closer-ups. If the filmmaker wants to create an unambiguous space, spatial overlaps is a useful technique.

Computer interfaces often use overlapping strategies. Different sorts of *index pages* (on web sites, CD-ROMs etc.) have the basical same function as the cinematic establishing shot. An initial overview provides the user with some conception of what is to be found outside the frame of the subfile she will be visiting. The index page sets expectations on the *offscreen information* of the upcoming subpage.

This comparison does however falter slightly. Once again the computer space is often much more abstract than cinematic space. In contrast to the scene from *Notorious* above, in which the establishing shot provides the spatial surroundings and specifies the offscreen space of the upcoming close-ups (in fig. 9 we infer the woman is somewhere offscreen right), the index page does not establish *spatial* relations, but rather *semantic/structural.* When visiting a subpage, the user cannot tell whether other subfiles is to the left or right, and this is characteristic of abstract space.

Could we support navigation if we spatialised the index- and sub-nodes, and if the movement from the former to the latter were experienced as a zooming-in or a cut-in? Many 3D browsers seem to employ these techniques. However, I think spatialisation *per se* is unlikely to help navigation unless it is accompanied with a coupling structure-content. There has to be some relation between the spatial relation and the content (the same kinds of things in the same surroundings). How this could be applied in large and constantly changing information environments like the web, will be a critical challenge.

THE 180° CONVENTION

In all of the above cases there is another underlying crucial convention, stating that directions within the scene form 'invisible' lines over which the camera must not cross. Gazes and movement are such directions. Consider again the scene from *Notorious* (fig. 11). In this scene the gaze line between the two characters forms the 180° line. An establishing shot (camera position 1) informs the spectator of the overall spatial arrangements: A is to left hand side of the image looking rightwards, and B is on the right-hand side of the image looking leftwards. These directions of gazes are maintained in the closer-ups (camera positions 2 and 3), in spite of the fact that the angels of the camera have changed. However, if the camera were to cross the 180° line to camera position 4, then suddenly A would be looking *leftwards* (this shot is not included in the actual film - I have just inverted the shot from camera position 3). This might create some form of disorientation: the shot seems to suggest that A is looking away from B and not *towards* her. Crossing the 180° line endangers the spatial coherence between shots and makes the spatial relations ambiguous.

Not many systems let 'the camera' move around and change positions in virtual space. In some games and most VR systems the user's perspective is the camera and it follows where the user goes (either the 'camera' is placed in the very eyes of the avatar with only hands visible (*Riven*), over the shoulder (*Tomb Rider*) or with the face of the avatar in full view). The user moves around but the perspective stays with the user/player, which means that 180° convention is not applicable or necessary.

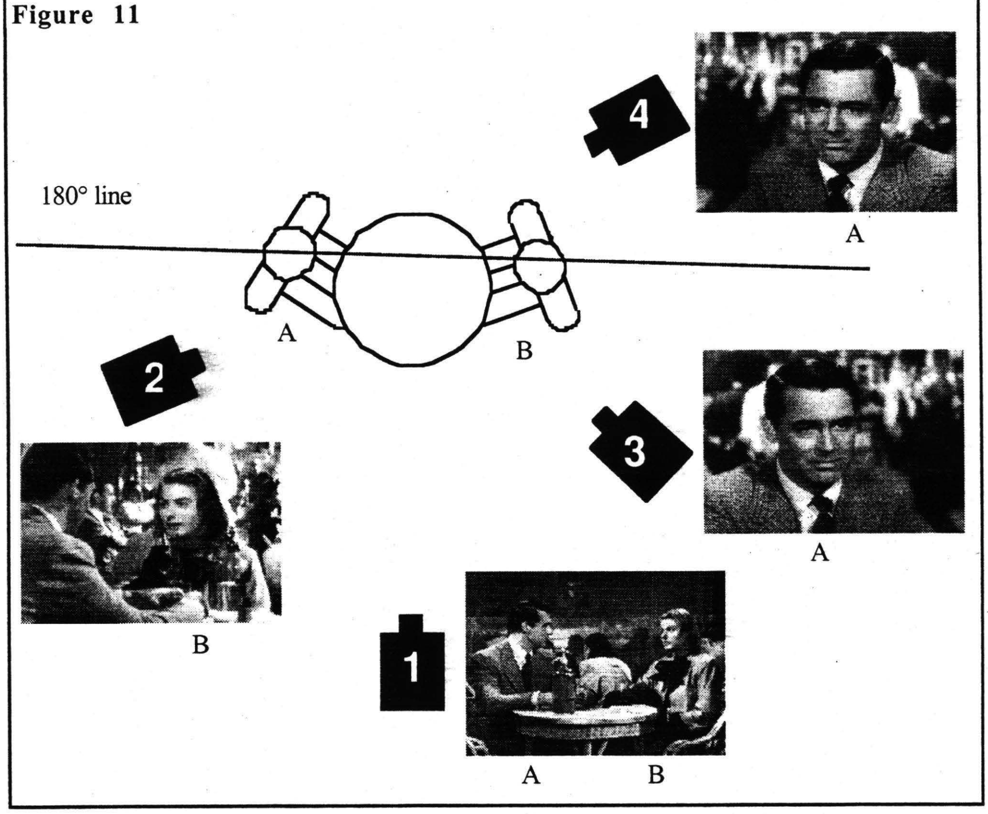
In other systems camera perspective is more 'objective' and we get to see characters from an outsider's point of view. In games like *Full Throttle* (1994), the editing is carried out with cinema style consciously in mind, taking great care to follow the 180° convention.

In some dynamic 3D environments used for scientific and educational application within molecular biology, computer engineering, medicine etc., the user is freed from camera control since the tasks performed are complex and demand total attention (Bares & Lester, 1997). In these systems the real-time camera planning is carried out by the system and entails selecting camera position and viewing directions in response to the user's activities and object manipulations. Since the system has to make on the fly decisions about camera angles and distances, it is perhaps in this context the editing techniques of cinema have their most useful application. In order to provide a continuous space and reduce the disorientation in the user and for her to execute the task as efficiently as possible, the 180° convention as well as other editing techniques would be worth considering (Bares & Lester, 1997).

SOUND

Sound is important in implying presence and direction of off-screen space objects and creating spatial connections between different shots. Auditory information creates expectations about surrounding space, and in a style where the camera cuts closer every now and then sound is extremely valuable to film-makers, both for narrative effects and for orientation (Bordwell & Thompson, 1993).

Figure 11



Considering the huge navigational and space creating potential of sound, it is rather odd that it has not been exploited more in interface design. At best, the auditive channel is used for *foreground* sounds and synthetic warnings, but cinema exemplifies the possibilities of *contextual* and *background-ambient* sounds (Ferrington, 1996), particularly in relation to offscreen space. By designing a *soundscape* (Macaulay et al. 1998) that makes the user aware of offscreen phenomena such as the contents of adjacent nodes in a hypertext, or other users visiting the same page as you are for the moment, the orientation possibilities would increase dramatically. Studying the techniques of cinema would in this context be a good start and is definitely worth a closer study (Macaulay et al. 1998).

CONCLUDING COMMENTS

We can better understand affordances and properties of digital environments if we compare them with other artificial environments like cinema and fiction. On several occasions I have hinted at and promoted a more 'realistic' design of computer space. Triggering expectations on space and objects is good because this will greatly enhance the interaction between human and computer, as well as orientation and navigation. If users can apply everyday knowledge, we will get closer to *natural design* (Norman, 1988).

But we must ask, is realism really the objective here? It seems that the very point of making and constructing virtual worlds is to provide users with activities that are *not* possible to accomplish in the real world. If I write a text on my virtual typewriter I will be able to erase, copy, edit etc. text in a much more efficient (albeit more artificial) way than on my real typewriter. And if I am interested in a university abroad I do not need to wait for mailed information, but can 'teleport' myself to this information with the help of a web browser.

Thus, dealing with interface design in general - and with navigation design in particular - there seems to be a trade-off between realism and abstraction. It is precisely that point of intersection we have to strike in order to attract users with low abstraction and computer ability, and still build tools that will accomplish things and be forceful.

ACKNOWLEDGEMENTS

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Issues of Navigation in the use of Computerised Procedure Presentation

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ABSTRACT

The introduction of information technology in control rooms has created a need to navigate in information spaces. This is illustrated by a description of the navigation needs for typical process control tasks. Following that, six basic navigation principles are applied to the case of computerised procedure presentation with a distinction among three major types of emergency operating procedures. Based on the considerations about navigation principles and formats, it is concluded that navigation by means of embedded links in conjunction with a graphical, flow-chart based format navigation will minimise the operators' problems. This recommendation is based on the assumption that procedures are generated well in advance of the time when they are used, i.e., that they exist as pre-defined procedures.

Keywords

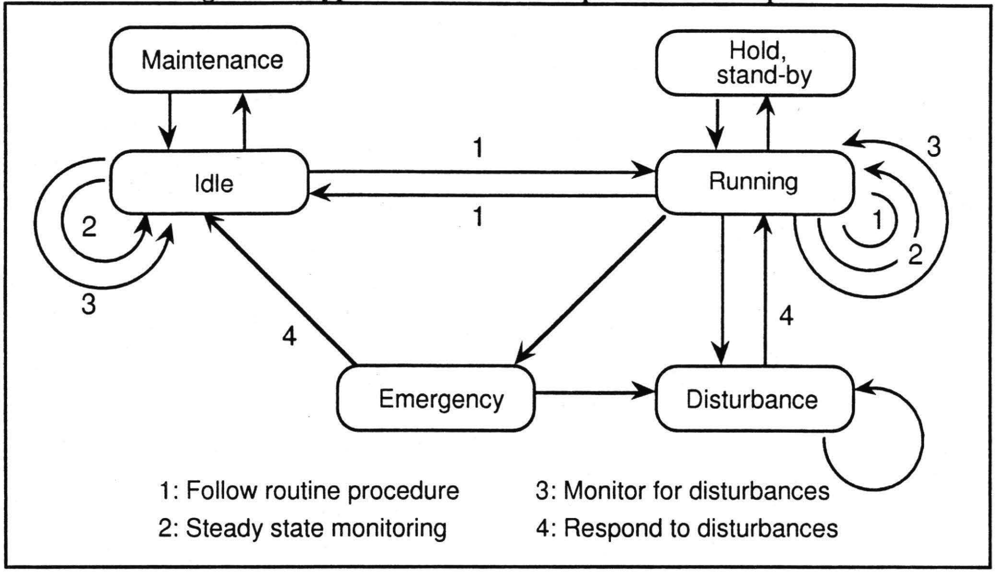
Navigation, human-machine interaction, nuclear power plants, emergency operating procedures.

INTRODUCTION

Navigation can be defined as the process of moving from one place to another in a conceptual space. First generation control rooms were designed so that the information needed to control the process was provided by means of hardwired instruments and recorders on wall panels. Since all the information was permanently available, the issue facing the operators was one of selecting or locating what they needed among the **actual** information rather than finding it in or retrieving it from the **potential** information. Navigation in the information space was therefore not a major issue in first generation control rooms. The underlying design philosophy was, in principle, to present everything that was measured and then leave it to the operators to find and interpret. In reality the situation was not quite that bad because the operators, of course, were appropriately trained to work in the control room and because the presentation was facilitated by following established ergonomic guidelines, e.g. the "paint, tape, and label" principle.

In the second-generation control room central process computers were used to provide information presented via VDUs. The main control panel contained a console with a number of VDUs - typically six or seven - supplemented by a small number of auxiliary control panels. Routine operations were often automated, but the control equipment remained based on hardwired switches and manipulators rather than screen-based icons. The increasing use of computers had two significant effects. Firstly, that the limitations of the "one-sensor, one-instrument" relation were removed, so that it became possible to collect much more information than could be physically presented at the same time. Secondly, that the use of computerised presentation, such as VDUs, reduced the surface or real-estate available for information presentation. The information that first migrated to computer-based displays was alarm lists and detailed process mimic diagrams.

Figure 1 Typical tasks in the process state-space



Even though much of the basic information still was presented via instruments on wall panels, supported by various types of process mimics, a significant part was provided via the VDUs. This created a need for the operators to retrieve the information from the computer systems, or generally finding it among the potential information (Woods et al., 1990).

Finally, in the third generation control rooms, such as the ABWR or APWR designs (Yugami et al., 1996), information presentation is predominantly accomplished by workstations supplemented by a centrally positioned large display panel as well as some smaller consoles. Control is almost exclusively carried out via computer-based devices, such as touch screens, keyboards or WIMP interfaces. The level of automation can be very high, and the operators' tasks are consequently often limited to process monitoring and disturbance handling. In these control rooms the navigation problem has been amplified due to the inherent weaknesses of information technology - or perhaps due to the limitations of the designers' ingenuity. The most important measurements and indicators are still permanently displayed with the explicit purpose of providing a process status overview and a common frame of reference. But the majority of the information is presented in other ways using powerful computational methods and sophisticated interface techniques.

Navigation and process control

Information is needed in process control for a number of different purposes. This can be illustrated looking at a generic state-space diagram with some details about the typical uses of information in each state, cf. Figure 1.

For the sake of the example Figure 1 only shows the tasks for the main process states. In the state of normal operation ("running") the typical tasks are to maintain the state by following routine procedures (loop 1), to monitor the state to meet efficiency goals (loop 2), and to monitor the state to meet safety goals (loop 3). In the state of disturbed operation, including emergency operation, the typical tasks are to monitor for (further) disturbances (loop 3) and to respond to the disturbance by trying to bring the process to a safe stand-by state (loop 4). The transition from normal to disturbed operation is obviously not something that the operators bring about intentionally. Finally, in the state of stand-by, the typical tasks are to change into the normal operation state by following routine procedures (loop 1), to maintain a steady state monitoring (loop 2), and to monitor to meet safety goals (loop 3).

The information needs of the four typical tasks are summarised in Table 1. This shows that there is a high need of information navigation when the process is out of the normal operation state. Even in the following of normal procedures, some level of navigation may be required, although this usually can be offset by the accumulated operating experience. In the cases of monitoring disturbances and responding to disturbances the needs for information - general as well as specialised - are high, and the need of navigation is consequently also high.

Navigation principles

There are several principles by which the navigation can be accomplished, as summarised by Table 2. In describing these principles it may be useful to think of a concrete example, for instance that of finding a specific display page that contains some sought for information.

Table 1: Information needs in typical process tasks.

Typical process task	*Need of general process information*	*Need of specialised process information*	*Use of procedures*	*Dependency on or need of navigation*
(1) Following routine procedures	High	Low	High	Medium
(2) Steady state monitoring (efficiency)	High	Low	Low	Low
(3) Monitoring for disturbances (safety)	High	High	Low	High
(4) Responding to disturbances	High	High	High	High

In practice, several of the navigation principles are often combined in the same system. If this is properly done, it can considerably improve the navigation. On the other hand, the risks of creating confusion and introducing additional tasks are not negligible.

EMERGENCY PROCEDURE TYPES

The role of operators in a complex task such as Nuclear Power Plant (NPP) control is largely governed by a combination of their experience and training, together with specific forms of performance support - particularly the operating procedures. A procedure in this sense is a carefully designed description of the course - or courses - of action that must be taken in a given situation. The nuclear industry and its regulators are particularly interested in those procedures that deal with deviations from the normal functioning, that is, the emergency operating procedures (EOP). These procedures effectively serve as a guarantee of plant safety.

Following the Three Mile Island Unit 2 accident in 1979, investigations identified deficiencies in the EOP as a contributing factor to the incident. There was subsequently a great deal of effort world-wide focused on how best to provide procedures for emergency situations, relating both to their contents and structure. This has resulted in the common distinction among three types of EOPs: event-based, symptom-based and function-based.

Event-Based Procedures

Procedures for NPP incident conditions have traditionally been event oriented. Such event-based procedures are written to address a specific situation, either a normal evolution or a pre-analysed accident. Pure event-based procedures require the operating crew to identify the specific event before selecting the correct procedure as the procedure itself does not provide assistance in determining the event that caused the problem. When the situation develops in a manner different from that assumed by the procedure, or if multiple failures occur simultaneously which complicate the observed indications, diagnosis of the initial events can be very difficult. Selection of incidents that require EOP support is based on PRA studies (DOE, 1992) and the structure has essentially been linear, representing one prescribed solution for every pre-analysed event.

Event-based procedures are characteristically sequential specifications of the actions or steps that must be taken to accomplish a given goal, cf. Cain (1985). Once the correct procedure has been identified by the diagnosis, there is little or no reason to consider alternatives, to confirm the correctness of the diagnosis, to combine two or more procedures, etc. The structure of event-based procedures is therefore essentially linear, with each sequence representing a prescribed solution for a pre-analysed event. As event-based procedures are basically monomorphic, the recommended mode of navigation is constrained movement. This may be supplemented by a cautious use of a simple form of direct access, possibly using a procedure map to indicate both current position and possible access points. Event-based procedures may further be supported by process linking and automatic progress monitoring; this kind of support should provide few risks, since the movement is confined to a single dimension.

Symptom-Based Procedures

Symptom-based procedures were developed after the TMI accident to redress the recognised shortcomings of event-based procedures (Colquhoun, 1984). Symptom-based procedures address the operator's role and special needs by providing a network of predefined symptom-based strategies for systematically responding to any developing emergency transient. Patterns or groupings of symptoms that signify danger to equipment or personnel, lead the user to an EOP that directs mitigating actions even if the cause of the incident is unrecognised. Manifest symptoms are used to guide the user to the correct procedure and the direction provided by the EOP is based on observations of actual component or system performance rather than a preconceived idea of the situation. Such procedures can prevent damage to equipment or personnel even when the initiating event is unknown and they are therefore especially useful for events that are difficult to predetermine or diagnose by the user.

Table 2: Definition of main navigational principles

Navigation principle	*Definition*
Direct Access	Allows the user to go directly to the target item. Direct access requires that each item of information has a unique code, and the item is retrieved by entering the code as input to the system.
Constrained Movements	Movement on the display surface in a limited number of directions. Can also be in terms of dimensions such as aggregation-decomposition or (functional) system topography. Constrained movement may refer to a polymorphic organisation of the information or be defined relative to the current position.
Menu-Based Navigation	The menu structure represents a hierarchical path that leads from a small number of top level items (roots) to the lowest level (leafs), which typically are the functions or items of information that are desired. Menus are normally fixed, but can easily be made adaptive in order to reduce the length of the path.
Embedded Links	Access to other information items is accomplished through links that are defined as part of the current display. Embedded links uses the principle of constrained movements via elements of the display itself rather than by an external device such as a keypad
Semi-automated Navigation	User specifies the target item rather than the path. Corresponds to advanced direct access in terms of the semantics of the information space
Adaptive Navigation	Added feature that can be applied in addition to most of the other principles, except direct addressing. Has several different forms, e.g. State Dependent Navigation, User Dependent Navigation, Anticipatory Navigation

Since the symptom-based procedure includes diagnosis it generates non-trivial branches. This means that the overall structure of a symptom-based procedure as it is being executed may become more like a network than a sequence or path. Symptom-based procedures also contains explicit checks or verifications of previous diagnoses, and may include links or transitions to other symptom-based procedures, as well as to event-based procedures. As symptom-based procedures are potentially polymorphic and may have a relatively complicated logic, the navigation should combine the use of a simplified graphical representation with embedded links. The use of process linking and automatic progress monitoring is not recommended, since it may unnecessarily complicate the use of the procedure and cause the operator to become lost.

Function-Based Procedures

The key feature of function-based procedures is the emphasis on maintaining certain predefined critical functions at all times. According to the arguments put forward by Corcoran et al. (1980) critical functions present a systematic approach to mitigate the consequences of an event. Function-based procedures provide an approach that is flexible and adaptable to many different conditions. If an incident occurs the response actions are prioritised to identify the critical functions being challenged and serve either to restore the success path that is not functioning properly, or to provide an alternative success path. Since this approach does not require the operators to diagnose the cause of the event, "difficult to diagnose" events do not lead to a loss of time. Instead, attention is immediately focused on the challenged critical functions and on implementing success paths to maintain or restore these functions.

Function-based procedures provide the operator with a way of identifying the currently most important goals rather than with an ordered, pre-defined description of what needs to be done. The actions needed to achieve the goals - e.g. to maintain a critical safety function - are based on the identification or generation of appropriate success paths. This can be done either manually or automatically, or as a combination of the two. The navigation required for function-based procedures refers to the associated information space rather than to a procedure *per se*. The concept of a success path strongly suggests that a graphical representation is appropriate, typically based on conventional process diagrams. Since the success paths in principle are constructed for the current situation the implementation of the required actions cannot be expected to exist in a ready form. It therefore seems reasonable to suggest the use of embedded links, coupled to the success paths, to retrieve the supplementary information needed to activate the success path.

NAVIGATING EOP TRANSITIONS

Each of the three types of EOPs has been developed to cover a certain range of situations, and none of them are sufficient to cover all the possible plant states or safety levels. It is common to distinguish among four different levels, called normal operation (level 1), within design base accidents (level 2), beyond design base accidents (level 3), and severe accidents (level 4).

Within level 2, event-based procedures are used for situations in which event diagnosis is clear, and symptom-based procedures for when the event cannot be diagnosed. If it is impossible to bring the process back to a safe state using the chosen procedure, then level 3 is entered. At this level the critical function procedures are implemented in an attempt to prevent accidental consequences from occurring. If even these fail and one or more critical functions are lost, level 4 is entered where accident management procedures are needed. (Accident management procedures provide an organisational framework for emergencies by defining the responsibilities of the people involved with respect to their detailed roles within the emergency arrangements, the resources available on-site, and details on how these interface with the emergency services.)

The transition from normal operation (task based) procedures (level 1) to EOPs (level 2) is not considered to be a problem, since the occurrence of the disturbance basically means that normal operation ceases and the EOPs are the only concern for the operators. Even when the disturbance has been brought under control, the plant may not return to a normal operation state but rather move to an idle state, cf. Figure 1. The transition from function-based EOPs (level 3) to accident management EOPs (level 4) only occurs if a critical function has been lost. In this situation the transition is clearly defined and there is no possibility of returning to the previous level. The transition between function-based EOPs and accident management procedures is consequently not considered here.

There are thus two important transitions that may happen between EOPs: the possible transition on level 2 from a symptom-based to an event-based procedure, and the transition from level 2 to level 3, i.e., from an event or symptom-based procedure to a function-based one. On level 2, within design base accidents, either event-based and symptom-based procedures may be applicable although they are not normally used both at the same time. The selection is based on whether it is possible to diagnose the event, in which case the event-based procedures are used to provide the most efficient mitigating actions.

The transition from a symptom-based to an event-based procedure takes place when a final diagnosis or identification of the situation has been made, or when a stage in the procedure has been reached where the remaining activities are part of a standard routine response. In this case there is no need to make use of the more complex, but also more flexible, format of a symptom-based procedure. This transition is predominantly one-way, since the event-based procedure does not include the option of revising the diagnosis that provided the entry condition.

The other possible transition, from event-based or symptom-based procedures to function-based procedures, is always in one direction only. If safety is not upheld, the process will enter into the emergency management region from which there is no return to the level of event- or symptom-based procedures. If safety is upheld, the process will go into a safe shutdown state, which also is beyond the scope of event- and symptom-based EOPs. The one-way nature of the transition helps to simplify the navigation issues. As described above, the symptom-based and the function-based procedures are rather similar with regard to navigation, and the transition between these two types of procedures should therefore not present any serious problems.
There is a greater difference between the navigation principles for event-based procedures and function-based procedures. The former were recommended to use constrained movement based on the use of the keyboard (or special function buttons) rather than a pointing device. The actual representation in the display could be either graphical or text, with no clear preference from the point of view of navigation itself. The choice should rather depend on the predominant representation used for the rest of the control room. Seen in relation to the transition problem it does seem reasonable to achieve a high degree of consistency between the different procedure types. Since both the symptom-based and the function-based procedures made use of graphical presentations and navigation by means of embedded links, it would be consistent to recommend that the same approach is taken for the event-based procedures. If this recommendation is followed, the problems of transitions between different procedure types should definitely be minimised. The implication of this recommendation is that the event-based procedure is seen as a special case of the symptom-based procedure, where the diagnosis is made in the very beginning, and where the rest of the procedure consists of a simple sequence of actions.

SUMMARY AND CONCLUSIONS

This paper has presented a number of fundamental navigation principles, followed by a discussion of the three main types of EOPs, event-based EOPs, symptom-based EOPs, and (safety / critical) function-based EOPs. The navigation demands for each EOP type were analysed with a recommendation of the appropriate navigation principle. For event-based procedures the principle of constrained movement was seen as the most appropriate, used in conjunction with either a text or a flow-chart based format. For symptom-based and function-based procedures the principle of embedded links was seen as the most appropriate, used in conjunction with a graphical, flow-chart based format. It was also pointed out that there were relatively few navigation problems in function-based procedures *per se*, but that there might be some important issues in connection with the use of the success paths that are closely associated to the safety function concept.

Concerning the issues of transition between different procedure types it was found that the only significant transition was from event- or symptom-based procedures to function-based procedures. Given the considerations and recommendations about navigation principles and formats, it was concluded that it would minimise navigation problems, and presumably enhance performance reliability, if the same approach was used for all three types of procedures, i.e., navigation by means of embedded links in conjunction with a graphical, flow-chart based format. Incidentally, this might also help to ameliorate some of the general problems of cross-referencing. This recommendation is based on the assumption that procedures are generated well in advance of the time when they are used, i.e., that they exist as pre-defined procedures. A more radical approach would be to move towards procedures generated on-line, but this remains a possible item for future research.

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Towards a Conception of HCI Engineering Design Principles

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ABSTRACT

Current HCI design knowledge is generally not well specified and thus not validatable. There is a need for more formal design knowledge, which can be validated, such that guarantees may be developed. This need would be met by Engineering Design Principles (EDPs). EDPs support the specification then implementation of a class of design solution for a class of design problem within the scope of the EDP. A conception of the general EDP (GEDP) is proposed here, illustrated with reference to internet-based transaction systems. The GEDP is derived from the conception of the general design problem of an engineering discipline of HCI, and the general design solution, as conceptualised here. This conception of the GEDP, it is argued, is sufficiently formal to support the initial operationalisation of class-level design problems to support the development of class-level EDPs. A strategy for developing class-level design problems is proposed and illustrated with reference to transaction systems. This strategy appears promising for the development of class-level EDPs, supported by empirical guarantees.

Keywords

Engineering, design principles, conception, human-computer interaction, performance guarantees, internet transaction systems.

NEED FOR HCI ENGINEERING DESIGN PRINCIPLES

Current best practice in HCI design has produced many technologies that interact with the user to perform effective work. However, the knowledge applied in the design of these technologies is all-too-often not explicitly stated and so not formally conceptualised, although it may be successfully operationalised by designers. Reliance on such 'craft' skills militates against the identification, and so the validation, of successful design knowledge and, as a result, its take-up and re-use. The lack of validation and the consequent ineffective development of design knowledge thus leads to slow and inefficient HCI discipline progress (Long 1996). There is a need for more formal HCI design knowledge, that is, whose conception is coherent, complete and fit-for-purpose, such that guarantees may be developed and ascribed. HCI Engineering Design Principles (EDPs) would meet this need by establishing these guarantees on the basis of analytic and empirical testing, leading to their validation. EDPs are explicit, and so validatable, prescriptions of substantive and methodological design knowledge which, when applied to a design problem within the scope of the principle, would support the specification then implementation of a design solution with guarantee (Dowell & Long, 1989). The development of such knowledge would thus increment the knowledge of an engineering discipline of HCI and would be fit-for-purpose, by providing support with a better guarantee for the practices of solving HCI design problems.

The benefits of such EDPs would be numerous. By employing design knowledge, which has already been shown to support the development of successful design solutions to design problems of a similar type, the need for iterative system development would be reduced. The first iteration would benefit from previous solutions. The re-use of such design knowledge would thus reduce the development time for a technology for which a principle had been formulated. Consequently, the cost of iterative usability testing would be reduced. Furthermore, the structuring of EDPs, at varying levels of generality, would support the re-use of successful design knowledge in new design problems, providing these problems could be characterised similarly at a general level. EDPs would also facilitate design knowledge organisation, by offering a structure with which to taxonomise acquired design knowledge, relating to classes of design problem.

This paper seeks to inform EDP development by conceptualising design knowledge sufficient to prescribe a general design solution (GDS) for a general design problem (GDP). Conceptualisation of such design knowledge, once the general EDP (GEDP) has been established as applicable, is required by EDP development to make explicit the concepts, which need to be instantiated as class-level EDPs (CEDPs). The process of EDP validation comprises four stages: conceptualisation; operationalisation; test; and generalisation (Long, 1996). These four stages support the development of formal, and so validatable, HCI engineering design knowledge. Conceptualisation supports the identification of promising knowledge, which guides instantiation of the GEDP, to produce a CEDP. Instantiated CEDPs may then be operationalised, tested and generalised. These four stages of validation support the ascription of performance guarantees.

This paper begins with an expression of the GDP of an engineering discipline of HCI, as proposed by Dowell and Long (1989; 1998), which is then used to inform the conceptualisation of the GDS, the components of the GEDP and the relationships between the GDP, the GEDP and the GDS. GEDP concepts are illustrated with respect to internet-based transaction processing systems (transaction systems). These transaction systems are in widespread use in electronic commerce, e.g. the order collation and payment system in an internet bookshop. The second section addresses CEDP development issues. Two contrastive strategies are presented, the 'initial instance' strategy (Stork & Long, 1994) and the 'initial class' strategy, as proposed here. These strategies are assessed and the 'initial class' strategy is developed by consideration of class-level design problems (CDPs) and an approach to developing CDPs to support the development of CEDPs. CDPs are illustrated with respect to transaction systems.

PRACTICES SUPPORTED BY EDPS

Long and Dowell (1989) characterise disciplines as comprising: a general problem with a particular scope; practices which provide solutions to the general problem; and knowledge, which supports those practices. EDPs would be the knowledge of an engineering discipline of HCI. They argue that disciplines, and so knowledge, may be characterised by the completeness with which solutions are specified, supporting the practices of implement and test, if incomplete; or specify then implement, if complete. EDPs seek to support the practices of specify then implement by employing formal, and so validatable, design knowledge, which offers complete, coherent, prescriptive design support. The efficacy of prescriptive design knowledge may be seen in more mature engineering disciplines (such as electrical engineering), in which discipline knowledge supports the complete and coherent specification of design solutions prior to implementation.

CONCEPTION OF THE RELATIONS BETWEEN GDP, GEDP AND GDS

To support the development of such EDPs, Dowell & Long (1989) proposed a conception of the GDP of an engineering discipline of HCI in terms of: work; the interactive worksystem; and performance, as task quality and worksystem costs. This conception of the GDP is summarised below to inform the conception of the GDS and GEDP as proposed here. By conceptualising the relations between the GDP, the GEDP and the GDS, coherence and completeness may be assessed. The conception of the GDS is proposed here in terms of: work; the interactive worksystem; and performance, as task quality and worksystem costs. The concepts of the GDP are thus recruited into the conception of the GDS. The concepts of the GDP form criteria for the success of the GDS; use of the same concepts supports assessment of the success of the GDS in satisfying the criteria in the GDP. The conception of the GEDP of an engineering discipline of HCI is proposed here in terms of: scope, comprising a class of users, a class of computers and a class of achievable performances; substantive component; methodological component; and guarantees. These relationships between the concepts of the GEDP and their relationship to concepts contained in the GDP and GDS are discussed later. The discussion of these relationships supports the conceptualisation of complete and coherent relations between the conceptions of the GDP, GEDP and GDS of an engineering discipline of HCI.

GENERAL DESIGN PROBLEM

A *design problem*[1] expresses an inequality between *actual performance* (Pa) and *desired performance* (Pd) of some *interactive worksystem* (i.e. Pa ≠ Pd) with respect to some *domain*; a successful *design solution* specifies some interactive worksystem (hereafter worksystem) which achieves the desired performance (Pa = Pd) with respect to some domain. Worksystems comprise *users* and *computers*, both of which have *structures* supporting *behaviours*. The desired performance is expressed as *work*, achieved to a desired level of *task quality*, whilst incurring an acceptable level of *costs* to the worksystem.

Work is expressed as *transformations* of the *attribute values* of *objects* in the domain of the worksystem. These domain transformations are achieved at some desired level of task quality (Tq), whilst incurring some acceptable level of costs to the user (Uc) and the computer (Cc). Attributes are features of domain objects, which afford transformation by the worksystem. The goals of the worksystem are defined as a *product goal,* which is a transformation

[1] Concepts from Dowell & Long which inform the conception of the GDS and GEDP are in italics on first exposition.

of object attribute values. Realisation of a product goal may involve the transformation of many attributes and their values, these transformations being termed *task goals*. Thus, a product goal may be re-expressed as a *task goal structure*, which specifies the order and relations between a number of task goals, sufficient to achieve the product goal. As more than one task goal structure may be sufficient to achieve a product goal, it is necessary to distinguish between alternative task goal structures in terms of task quality. Task quality describes the difference between the product goal and the actual transformation specified by a task goal structure. This concept supports evaluation of alternative structures of this type (Dowell & Long, 1989).

The worksystem comprises one or more users interacting with one or more computers, each of which is characterised by structures which support behaviours. Desired performance is thus effected by a particular class of user and computer structures, supporting behaviours, which achieve domain transformations, whilst incurring some acceptable level of costs. Worksystem structures are necessary to support behaviour, e.g. knowledge of financial transactions is necessary to support transacting behaviours. Worksystem behaviours involve the transformation of object attributes and their values, e.g. transferring ownership of goods from the vendor to the customer in transaction processing may be expressed as transforming the attribute 'owner' from value 'vendor' to value 'customer' for domain object 'book *x*'.

SUBSTANTIVE AND METHODOLOGICAL EDPS

Dowell and Long assert that EDPs may be either substantive or methodological. They state that substantive EDPs "prescribe the features and properties of artefacts, or systems that will, constitute an optimal design solution to a general design problem." Methodological EDPs "prescribe the methods for solving a general design problem optimally." (Dowell & Long, 1989). In the conception of EDPs proposed here, substantive and methodological knowledge is assumed to be unitary. The issue of whether optimal solutions are commensurate with EDPs is not addressed, as the guarantees ascribed here would be derived from empirical testing. Thus, these guarantees cannot be claimed optimal, but empirically established.

NEED FOR CONCEPTION OF GDS AND GEDP

The Dowell and Long conception supports the development of EDPs by offering a coherent and complete expression of the GDP to be addressed by the GEDP. However, the relationship between the concepts of the GDP and the concepts of the GEDP are not formally conceptualised. Furthermore, the conception of the GDS is implicit. Thus, the relationship between the GEDP and the GDS is not formally conceptualised. The GDS is conceptualised below, as required to inform the development of EDPs.

CONCEPTION OF GDS

A ***design solution***[2] contains the specification of a ***worksystem*** for which the ***actual performance*** equals the ***desired performance*** (i.e. Pa = Pd), as stated in the ***design problem***. Worksystems comprising ***users*** and ***computers*** are conceptualised as ***structures***, which support ***behaviours***, which interact to perform ***work*** in a ***domain***. Work is expressed as ***transformations*** of ***object attribute values*** to achieve ***task goals***, which comprise a ***task goal structure***. The ***quality*** with which the task goal structure achieves the ***product goal*** specified in the GDP is expressed as Tq and the ***costs*** incurred by the users and computers are expressed as Uc and Cc.

CONCEPTION OF GEDP

A conception of the GEDP may be considered complete, if its expression is sufficient to identify the applicability of the GEDP, in terms of the GDP. It may be considered coherent, if its expression is sufficient to prescribe design knowledge for specifying the GDS. The ascription of performance guarantees must also be explicitly conceptualised for coherence.

The conception of EDPs proposed here includes the concepts of: scope; comprising a class of users, a class of computers and a class of achievable performances; substantive component; methodological component; and performance guarantees. This conception of the **GEDP**[3], it is argued, is sufficiently coherent and complete to support the initial operationalisation, test and generalisation of EDPs, and so is potentially fit-for-purpose. The concepts of the GEDP are formally conceptualised at a level commensurate with the conception of the GDP. This conception of the GEDP supports carry-forward of coherent and complete design knowledge by supporting the expression of design knowledge, at the appropriate level of generality. This knowledge supports the operationalisation of **CEDPs**, and its success determines whether it is fit-for-purpose. CEDPs formally specify the relationship between a CDP and a corresponding CDS. The concept of classes supports the representation of design knowledge at different levels of generality. These classes are identified by reference to the scope of CEDPs - class hierarchies are not intended to constitute a taxonomy of all possible CDPs, but rather only of those CDPs for which a CDS exists. The ultimate success of a CEDP is measured by the performance achieved by the specific technologies supported by its

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[2] Concepts from Dowell & Long which have been recruited into the conception of the GDS and the GEDP are in bold italics on first exposition.

[3]Concepts which are novel to this paper are in bold on first exposition.

application. The associated guarantees are based on the empirical testing of a series of instances of CEDP application. The coherent and complete conceptualisation which guides this operationalisation may thus be assessed for fitness-for-purpose.

The concepts of the GEDP are informed by the concepts of the GDP and GDS, as the purpose of the GEDP is to identify its applicability to the GDP and prescription of the GDS, if applicable. The GEDP supports the prescription of a GDS, which achieves the desired performance stated in the GDP, if identified as applicable.

Scope of the GEDP

Specifying criteria for identifying ***design problems***, to which an EDP may be applied, ensures that the knowledge is applied only to those design problems for which it supports the specification of a ***design solution***. Design problems contain not less than one or more ***users***, interacting with not less than one or more ***computers***, and some ***desired performance***. The **scope** of the GEDP thus comprises a **class of users (U-class)**, a **class of computers (C-class)** and a **class of achievable performances (P-class)**. If the user and computer in the design problem are members of U-class and C-class respectively, and the desired performance stated in the design problem is a member of P-class, then a design solution would be produced and the ***actual performance*** of the solution would equal the desired performance stated in the design problem. The relationship between U-class, C-class and P-class is developed by empirical testing of the implemented design solutions, produced by CEDP operationalisation. If the user, computer or the desired performance are outside the scope of the principle, then there is no guarantee that the design solution may be specified then implemented.

For transaction systems, the criteria for establishing U-class membership would establish the minimum structures and behaviours required for some user, in conjunction with some member of C-class, to achieve a performance which is a member of P-class. Such structures might include knowledge of financial transactions with card-based payment technologies. Supported behaviours might include matching goods descriptions to their shopping goals. The criteria for C-class membership might include structures such as a Virtual Shopping Cart, and supported behaviours, such as real-time processing of payments via the internet. P-class would specify the product goal, e.g. support the exchange of resources for currency, which could be achieved by members of U-class and C-class, to a desired level of task quality, whilst incurring an acceptable level of costs.

Substantive and Methodological Components of GEDP

EDPs contain substantive and methodological design knowledge which may be applied to any design problem within the scope of the EDP. The **substantive component** is characterised by the conceptualisation of user and computer ***structures*** and ***behaviours***, comprising the ***worksystem***, which are present in some instance of the class of users (U-class) or class of computers (C-class) respectively. The **methodological component** supports the conceptualisation of a ***task goal structure***, comprising ***task goals***, to be effected by the worksystem, which achieves the ***product goal*** stated in P-class. The product goal specifies the ***work*** to be effected in the ***domain*** by the worksystem, in terms of ***object attribute value transformations.*** The structures and behaviours specified in the substantive component are sufficient to achieve the task goal structure specified in the methodological component to an acceptable level of ***task quality***, whilst incurring some acceptable level of ***costs***; where task quality and worksystem costs are members of P-class. This sufficiency is supported by empirical testing of a CEDP, which indicates whether the GEDP is fit-for-purpose.

Support for the conceptualisation of user and computer structures and behaviours may take the form of models of interaction between user and computer, expressed as structures supporting behaviours. In the case of transaction systems, a mercantile model of the stages of a transaction to support the specification of behaviours, sufficient to achieve the required domain transformations, would constitute candidate substantive knowledge. One such model (Kalakota & Whinston, 1996) characterises a transaction as: prepurchase determination (information seeking); purchase (agreement of a contract for exchange); and postpurchase interaction (exchange, and evaluation of the product). This model might indicate that information seeking behaviours are necessary to complete a transaction, these behaviours being supported by structures, e.g., purchasing goals, hands.

Summary of GEDP Conception

This paper proposes a conception of EDPs within which guarantees may be developed for formal HCI engineering design knowledge. The conception proposed thus far comprises the following concepts and relationships:

For any design problem {user, computer, Pd}
and any EDP {U-class, C-class, P-class, substantive component, methodological component}

If user is a member of U-class
and computer is a member of C-class
then user structures and behaviours, and computer structures and behaviours, stated in the substantive component are present.

If user structures and behaviours and computer structures and behaviours specified by the substantive component are present then the task goal structure specified by the methodological component is achievable.

If the task goal structure specified in the methodological component is effected by a worksystem comprising the structures and behaviours specified in the substantive component
then the product goal will be achieved, task quality will be x, user costs will be y and computer costs will be z.

If task quality x, user costs y and computer costs z are achieved,
Then Pa = Pd.

Therefore, Pd is a member of P-class for a worksystem comprising instances of U-class and C-class.

This conception may be said to be coherent, as it is based on two relationships: the relationship between the task goal structure and Tq for some product goal, and the relationship between the worksystem structures and behaviours, sufficient to achieve this task goal structure, and Uc and Cc. These relationships may be said to be coherent, as performance is a function of the efficacy with which some task goal structures are achieved by some worksystem structures and behaviours. The GEDP conception may be considered complete, as the concepts of the conception of the engineering discipline of HCI, which inform its development, appear within it. The issue of fitness-for-purpose will be addressed via operationalisation of the conception of the GEDP to inform the development of CEDPs, which may then be tested and generalised.

Validation and Ascription of Guarantees to EDPs

Operationalisation of the GEDP as CEDPs supports empirical testing of the class-level design solutions prescribed. This testing establishes whether the GEDP is fit-for-purpose, that is, it supports the specification then implementation of a design solution which achieves the desired level of performance stated in the design problem. The fourth stage of validation, generalisation, involves establishing the generality of the CEDP. These four stages of validation support the ascription of a guarantee that a worksystem, which performs the task goal structure specified in the methodological component of the EDP, achieves a level of Tq within the P-class stated in the EDP. A second guarantee, that the substantive component supports the specification of a worksystem, which exhibits the structures and behaviours sufficient to achieve the task goal structure, specified in the methodological component, whilst incurring a level of costs within the P-class stated in the EDP, may then be ascribed. A third guarantee, that correct application of the EDP to a design problem, within its scope supports the specification then implementation of a design solution which achieves Pd, is then ascribed on the basis of the former guarantees and further empirical testing. EDPs thus support the specification then implementation of a design solution which achieves the desired performance, if the design problem is within the scope of the EDP.

STRATEGY FOR CEDP DEVELOPMENT

Stork & Long (1994) have applied the conception of HCI to establish a basis for developing EDPs. They have operationalised the general HCI design problem by metricating the concepts, of which it is comprised, to express a specific design problem (SDP) in the domain of domestic energy management. Metrication provides observable and measurable criteria against which to assess performance. The design solutions (SDSs) of such specific design problems and the abstraction of prescriptive knowledge would constitute an EDP - the goal of Stork and Long. However, the operationalisation of an SDP *per se* does not ensure that a CDP, of which the SDP is an instance, will be found, other than by the assumption of a single domain. This strategy may be termed the 'initial instance' strategy, as it seeks to develop CEDPs by specifying design knowledge for SDPs, by means of SDSs, and then generalising across instances. This approach may be contrasted with an alternative 'initial class' strategy for CEDP development, as proposed here. The 'initial class' strategy supports CEDP development by constructing solutions to CDPs and then construing relevant design knowledge. Because this knowledge is construed at the class level, it is promising for CEDP development. The development of CDPs prior to operationalisation is therefore desirable, as this development constrains the DPs operationalised to those which offer promise in supporting the identification of class-level knowledge.

A class may be considered promising for development, if an SDS exists and there are SDPs which share features of the solved SDP. Once such an initial class hypothesis has been formulated, the viability of the class may be assessed by examination of the work performed and the worksystem structures and behaviours sufficient to achieve Pd. If the performance achieved by the worksystem (Pa), specified in the SDS, is similar to the Pd of other SDPs (i.e. Pa = Pd), then the SDPs show promise for CDP development.

Method for CDP development

The first phase of the 'initial class' strategy for CDP development involves identification of an SDP and a corresponding SDS. The second stage involves identifying further SDPs which require a similar Pd, which supports specification of P-class. The user(s) and computer(s) which are to achieve P-class are then assessed for similarities. They may be considered similar, if the user(s) and computer(s), specified in each SDP, comprise sufficient structures supporting sufficient behaviours to achieve P-class. If this sufficiency holds, these user(s) and computer(s) form U-class and C-class of the CDP respectively.

In practice, once P-class has been specified, developing CDPs involves identifying U-class and testing instances (members) of this class interacting with instances of C-class. These instances of U-class and C-class are then used to inform the development of a CDS, which achieves P-class. The level of generality should be considered prior to development. Classes which contain very few instances low in the hierarchy contain design knowledge which is very specific. The costs of developing a class at a given level of generality should be balanced against the number of instances to which it may be applied successfully.

Candidate CDPs: Internet-Based Transaction Systems

A class of transaction system design problems has been identified and is presented to illustrate the concept of CDPs. This parent class has three instances (subclasses), each of which is also a class. Each subclass is characterised by P-class, to be achieved by U-class interacting with C-class with respect to some domain. The general characteristics of each of these CDPs are inherited from the parent class. The subclasses of transaction system CDP are: (homogeneous) physical goods (e.g. books); information (e.g. online newspapers); and banking and finance (e.g. loans). These subclasses are abstractions over SDPs, e.g. a design problem concerning a transaction system to support the effective exchange of books for currency in an internet bookshop is an instance of the class of (homogeneous) physical goods.

Subclasses may be distinguished by P-class. Differences in the product goal required for each of these subclasses have been identified for physical goods and information sub-classes (Hallam-Baker, 1997). In addition to these two classes, a banking CDP has been developed. The classes differ in the nature of the resources exchanged, the immediacy of the exchange, the possibility for reversing the transaction and the potential loss to the vendor. These differences in product goal indicate that the CDSs for these subclasses will specify classes of worksystem with different task goal structures, as the respective worksystems perform different work.

It should be noted that candidate CDPs are identified on the basis of differences in the domain objects transformed by the respective worksystems. Operationalisation of CDPs will support the assessment of whether such differences will result in different worksystem specifications. Each CDS specified is then assessed to establish the task goal structure, sufficient to achieve a level of Tq within P-class. This sufficiency informs the development of the methodological component of the corresponding CEDP. The worksystem structures and behaviours sufficient to achieve the task goal structure, whilst incurring a level of Uc and Cc within P-class, are then construed. These structures and behaviours inform the development of the substantive component of the CEDP. Validation and the ascription of guarantees are based on subsequent operationalisations of the conceptualised CEDPs.

FUTURE RESEARCH

The 'initial class' strategy will be operationalised, resulting in CDPs and CDSs for the three transaction system subclasses identified. These CDPs and CDSs will be used to inform CEDP development. The resulting CEDPs will be operationalised and tested to inform the development of guarantees. If these stages of validation are successful, the CEDPs will be generalised and the CEDPs may be considered valid. Abstraction of these subclass CEDPs will be used to produce the parent CEDP, which will then be operationalised, tested and generalised.

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Air Traffic Control as a Distributed Cognitive System: a study of external representations

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ABSTRACT
This paper describes an early approach to understanding current air traffic control (ATC) systems. The analysis is based on a distributed cognition analysis of the representations present in air traffic control, and their distribution, manipulation, and propagation through the ATC system. The work is being carried out as part of the Esprit Mefisto project, and has as an eventual aim the exploration of user interface requirements concerned with safety and usability.

Keywords
Air traffic control, distributed cognition, external representation

INTRODUCTION
The control and direction of air traffic is a highly knowledge and information intensive activity. Therefore, the focus for studying air traffic control and how it functions as a robust, safe system, will be the representations present in the ATC cognitive system, how they are used, and how they are distributed across multiple artifacts and agents. Thus there is a need to broaden our perspective and look at the systems that allow action and decision making — whether correct or erroneous — to take place.

In this paper we describe an analysis of ATC which is related to some of the well known ethnographic studies of ATC (e.g., Randall et al., 1994) and draws more centrally on Distributed Cognition (Hutchins, 1995a; Hutchins, 1995b) as a framework to explore issues in the design of new technology. In contrast to some of the earlier ethnographic studies, we focus not on the "accidental" emergent properties of artefacts, but on the central "official" roles they play in the work system. This work is being carried out as part of a larger project in which observational and interview data has been collected at ATC centres, principally in the unit controlling the approach to Rome's Fiumicino airport (Marti and Palmonari, 1998).

ATC is a collection of systems and work practices that is currently undergoing great change as a result of commercial, operational and technological pressures. The aim in this paper is to analyse representations, their interrelation and role in work activity as part of a contribution to the ongoing debate about the impact of automation and technology change in ATC.

ATC AS A COGNITIVE SYSTEM
This paper moves forward an agenda for studying complex work systems as distributed cognitive systems (Hutchins, 1995a; Hutchins, 1995b). One motivation for taking this approach is reflected in the observation that "a critical focus of design must be the provision of the information or resources that support and inform the decision-making process, rather than the formalisation and encoding of the process itself." (p 147, Dourish, 1997).

The approach focusses on analysing representations — primarily those that are visible and external to the human actors, and only secondarily making inferences about representations "internal" to the actors. Taking external representations as central leads to a view that they constitute a rich cognitive environment within which the work of individuals takes place. In addition, external representations can be seen as mediating the relationships between co-workers in a collaborative environment (e.g., see (Norman, 1993) for many examples).

A central tenet of distributed cognition is that cognition should be regarded as a property of a *system* of individuals and external representational artefacts, carrying out some activity. A consequence of this is that it is appropriate to take our "unit of analysis" as a wider system rather than a single individual (indeed, the appropriate unit of analysis may often be flexible and dependent on circumstances — see (Marti, 1998)). For the current purposes, "the system" will construed as the controllers working on an approach sector, the pilots under their control, and the wide range of artefacts, of varying degrees of technical sophistication, that form a part of the controllers' work.

In the remainder of the paper we look first at ATC in terms of the computational properties it possesses and the goals it achieves. We then treat ATC as a system of representational artefacts and look at how they are used to effect the computational processes. Finally, discuss some of the implications of the approach in looking critically at new design suggestions.

THE COMPUTATIONS OF AN ATC SYSTEM

In the most generic terms, an ATC system can be seen as undertaking a computation to maintain separation between aircraft in a region of airspace, and at the same time attempting to improve the routing of aircraft through the airspace.

We can think of the behaviour of an aircraft over time as a trajectory through four-dimensional space, including the aircraft's current location, the history of its route and predictions about where it will be in future. Focussing on the maintenance of separation between aircraft, the "computation" accomplished by the system has three main parts:

- Looking for near intersections of four-dimensional trajectories, or rather looking for times where two 4D trajectories are not separated in 3D space (see CAA, 1995 for the rules concerning separation).
- When a future conflict is detected (or as a result of the need for expedition) some action is taken by the controller. A number of possibilities are available (to alter the height, speed, or route of either or both aircraft); whichever strategy is chosen will change the future 4D traffic picture.
- The projection into the future must be updated constantly, to reflect changes occurring at the current time (e.g., as a result of controllers' decisions and actions, or of external factors, such as an aircraft being delayed).

Simplification of the 4D problem

It is crucial to note that solving the conflict detection problem in three spatial and one temporal dimensions is often complex, but a number of constrained special cases can be discerned. Even more interesting is the observation that these special cases allow controllers to exploit some of the constraints that arise in particular air traffic situations or phases.

In some situations it is not feasible for the controller to attempt to separate aircraft vertically (for example, aircraft in the approach phase). Thus, it is only necessary to look for conflicts in horizontal space (since vertical separation cannot be relied upon). Further, if several aircraft are following the same route then a further degree of freedom — to separate them on different tracks — is removed. Therefore, the only mechanism available to controllers is to separate aircraft longitudinally, controlling the spacing between them, in terms of time or distance.

In other situations, a choice can be made not to rely on horizontal separation (for instance, where airways intersect in the en-route phase). Once again, the computation involved in detecting conflicts (and indeed the means available for resolving them) is considerably simpler that the 4D case, involving only the vertical dimension.

As we shall see later, the representational system present in ATC, and indeed the whole ATC environment, is arranged so as to permit "simplifications" of the general four-dimensional problem that are easier for participants to solve.

SYSTEMS OF EXTERNAL REPRESENTATIONS

We turn now to the external representations present in ATC, their interrelationship, and the way they support solution of the computational problems. It is important to look not only at what information is strictly represented in a medium, but also at properties of the particular representational form that support inference and judgement.

Charts and standard routes

A number of standard routes through the airspace exist, particularly on the approach to airports, and are noted on charts along with other important features (radio navigation aids, geographical features, etc.). The standard routes can be seen as a prescription of how certain manoeuvres should be made (though evidence suggests that, in fact, they're not used in that way). Another view is to see the standards routes and procedures as artefacts, embodied in charts, the memories of controllers and pilots and the flight management systems of aircraft, and thus shared between controllers and pilots. Such distributed representations of standard routes serve both as "resources for action" and as common ground that allow participants to make sense of the other's actions.

Flight strip — projected states of aircraft

One of the most studied ATC media is the *flight progress strip* (Figure 1), which provides on a paper strip a representation of the behaviour of a single aircraft. Printed text on the paper strip includes the aircraft's callsign, flight level, speed, estimated time of arrival at the next waypoint, and the filed flight plan.

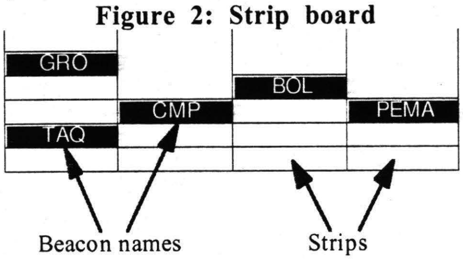
Figure 1: A flight progress strip

In addition, strips possess a number of other properties: they capture, through handwritten annotations some of the history of communications with the aircraft, and can even indicate (through pen colour) which controller was responsible for which annotation. As a publicly visible, shared artefact, strips are one of the media through which the controllers on a sector (planner and tactical controller) communicate. The contents of a strip can be read by an individual, spoken aloud, and can be both the referent and the medium of controllers' communication.

Strip board — projected state of airspace

The strips corresponding to aircraft currently in a sector are collected together in a *strip board*, in order of estimated arrival time, grouped under the names of beacons along the route (Figure 2). If the route of an aircraft passes across several beacons, then a corresponding number of strips will be printed and inserted into the relevant places in the board. The strip board is interesting as it provides a "schematic" model of airspace, showing locations and routes between them, and, when populated with "live" strips, the projected (4D) progress of aircraft through this space.

Figure 2: Strip board



An essential characteristic of the "four dimensional map" provided by the flight strip board is that it gives the controller *simultaneous* access to the important aspects of the projected future status of all traffic. As a model of physical space, the strip board is interesting: what it represents is (some) important points in space, and a rough indicator of the spatial relation between them. Within this space, strips are representations of aircraft, and the order into which they are sorted is a representation of time. The strip board does not, however, preserve the physical relationships of the real world (distance, direction, area, etc.) that certain more conventional map projections do (for these features, other media, such as the radar screen, must be consulted). What this rather crude map does represent, though, is sufficient for carrying out the ATC tasks for which it is designed.

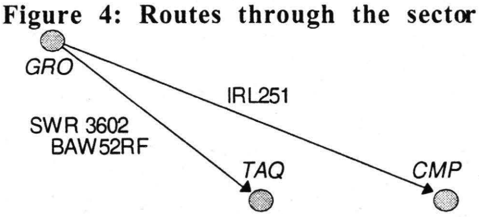
Observations in the approach control suite for Rome airports show that the part of the strip board configuration shown in Figure 3 is typical. The strips in Figure 3 are much simplified showing only the estimated time of arrival, flight level and callsign for each aircraft, and are arranged under each beacon in order of estimated time of arrival. Note the presence a strip per aircraft for each beacon along the route.

Figure 3: Strip board with strips

GRO					
10.14	290	SWR3602			
10.08	410	IRL251			
10.03	370	BAW52RF			
TAQ					
10.22	290	SWR3602			
10.09	370	BAW52RF	CMP		
10.03	6	COA44	10.17	410	IRL251

One can fairly immediately discern that this overlaying of flight plans of individual aircraft with a representation of the airspace highlights two of the standard approach routes: GRO-TAQ, and GRO-CMP, as in Figure 4.

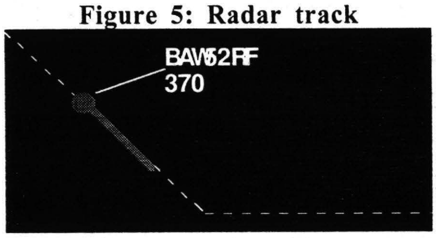
Figure 4: Routes through the sector



Radar — a window on the real world

Perhaps the most obvious and compelling representation of the air traffic situation is provided by the radar screen. At the simplest level, the radar screen provides controllers with a snapshot of the current horizontal (i.e., 2D) locations of aircraft, represented as a spatial analogue — the "blips" on the screen. Secondary surveillance radar data can be added to show the aircraft's identity (i.e., its callsign), and current height, represented numerically as part of the textual "data block" (Figure 5).

Figure 5: Radar track



In addition to the data block, speed and heading is shown as a vector indicating where the aircraft is expected to be at some time in the future (e.g., 30 seconds ahead). The data block and blip are easily co-ordinated by their physical proximity. However, the data block can be co-ordinated with the corresponding flight strips only by means of the alphanumeric callsign, a process requiring the controller to read, interpret and remember the callsign. All this adds up to a device that delivers to controllers a representation of space and aircraft moving in it, in a combination of 2D spatial analogues, augmented with textual and numeric labels.

The radar constitutes a rather incomplete model of the future; in particular, although the future behaviour of the flight may be shown in the two horizontal dimensions, the future altitude and estimated time of arrival is not shown. However, the radar (compared with the strip board) gives an up to date picture of the current state of the airspace rather than the planned or estimated state. As such it is critical to the process (which without it, could only be achieved with a combination of VHF radio together with the strips).

Callsigns — co-ordinating objects
The callsign of an aircraft (often based on the airline's flight number) is a representation of the aircraft's identity that can readily be converted between a number of media (flight strip, radar data block, verbal communication). It therefore serves as an important (indeed the only) means of co-ordinating the information represented in these various media. It is precisely the convertibility (e.g., by reading aloud) of the callsign that allows it to play this co-ordinating role.

Communications — mediation of control
Communication that takes place both between controllers and, via VHF radio, between controllers and pilots can also be seen as a system of representations. Like other representations, verbal communications can only be fully understood in terms of their relationship to other structures and cognitive artefacts. Much of the explicit verbal communication between the controllers in a sector refers directly to other artefacts in that environment (such as when one controller indicates to the other that some external representation has changed).
Verbal communications are also situated in the network of artefacts and information, and are made comprehensible by reference to a larger context of shared representations. For instance, sense can often be made of utterances only by reference to the relation they have with other structures such as standard procedures, strips or radar.

One of the essential properties of the verbal medium is that information such as speeds, altitudes, headings (as well as callsigns) can easily be transformed into speech from textual representations.

ACTIVITY AND IMPLEMENTATION

We now look two aspects of how representations are manipulated and used to achieve computational goals in ATC activity: how conflicts may be detected in future flight plans, and how artefacts help to mediate some of the communication that takes place.

Conflict detection

Not only does the configuration of strips shown in Figure 2 serve as a representation of the four dimensional real world, it much more importantly is a form that permits some of the computational goals to be achieved in a fairly direct way.

A number of factors about the dynamic situation can fairly readily be determined using simple, partially perceptually-based, operations. For example, the fact that three aircraft (SWR3602, BAW52RF, and COA44) are in the same region of airspace, and following the same route can be inferred from their positions in the board. A simple comparison of digital flight level values (290, 370, 6) yields the fact that the three aircraft are vertically separated.

A further arithmetic operation is required in order to decide whether, based on the digital ETA values, the aircraft are longitudinally separated (in time) as well. For instance, SWR3602 and BAW52RF are separated at TAQ by 13 minutes. In combination with other information about the two flights and the regulations governing separation standards (CAA, 1995), an assessment can be made about whether this separation is adequate.

The performance of this task exemplifies the economy of flight strips as representations in this context. Only the important information is present (or at least unimportant information is easily ignored), and items that are to be compared or combined are adjacent in the list of flight strips (i.e., in most cases it is only necessary to consider strips that are vertically adjacent or close together).
The same goal can be achieved in a rather different way using another medium: the radar screen. Rather than arithmetic and knowledge of the distances involved, longitudinal separation can be achieved using the relative positions of blips and vectors.

The strips and radar can therefore be seen as embodying very different representations of the presence or absence of conflicts, supporting controllers in carrying out different kinds of operations.

The ATC suite as a collaborative system

The flight progress strips, the strip board and radar screen form an important part of the medium through which the two controllers on a sector communicate. Such communications support co-ordination both directly as part of the work (e.g., writing on strips or pointing at the radar), and indirectly, to gain an awareness of the state of the work (e.g., being able to gauge a colleague's level of busyness by the number of strips that are present).

Even overt verbal communication is often understandable only in the context of information artefacts and knowledge shared between the conversational participants. It should be noted, however, that that the strips are not simply a "channel" through which communications take place. The strips are closely integrated with the work activities of individuals as well as the co-ordinating activities within the team.

THE STATUS OF ARTEFACTS IN THE WORK OF ATC

In the analysis of cognitive artefacts and external representations a number of themes have emerged. Three of these are the different properties that different media exhibit, the redundancy that exists in complex representation systems, and the ways that information can be integrated in artefacts.

Properties of the media

The description of media has touched on a number of properties that are crucial to understanding the functioning of cognitive artefacts.

Flexibility and timeliness of representations

- Some media (e.g., strips) are updated and modified in a flexibly, whereas others are not.
- Some media can change autonomously to reflect changes elsewhere in the system (e.g., the radar).

Accessibility of representations

- Media vary in *persistence* from permanent (e.g., strips) to relatively transient (verbal communications).
- Artefacts are shared to different degrees between agents. They may be: local to individuals (mental picture); shared in the control room (radar, strips); shared by controllers and a single pilot (flight plan, current flight level); globally available to all (standard routes; VHF communications).
- The sequentiality of media places constraints on the order and concurrency of accesses.

Operations and actions

- Representational forms can be symbolic (e.g., textual or digital) or analogue (e.g., radar). Different forms afford different cognitive or perceptual operations (e.g., calculation on digital data or anomaly checking on analogue ones).
- Representations in some media are more readily translatable to other media than others (e.g., a digital value can easily be converted to a verbal form by reading, whereas an analogue description of heading is less easily propagated).
- Similarly, certain combinations of media can be more easily be compared and combined than others (e.g., comparisons of SSR and strip heights versus radar and strip representations of current heading)

Redundancy in complex systems

The representations overlap and coincide, producing a redundant composite picture when they are brought into co-ordination (Hutchins, 1995b). Redundancy is often a crucial factor in a system's robustness, especially when, as in this case, the media do give different, complementary (rather than merely duplicated) views of the situation, both as it currently is (radar) and as it is expected to be in the future (strip board).

Redundancy isn't simple, and isn't simply the same as replication. It is often remarked that paper strips offer a "low tech" backup system for ATC. A more interesting aspect of the apparent redundancy between radar and strips is that the two media allow very different access to overlapping information, and allow the task of conflict avoidance to be carried out in different relatively independent ways by different people (planner and tactical controller).

Non-integrated representations

For a number of tasks, it is necessary for a controller to be able to bring two (or more) of these representational media into co-ordination. Two of the best examples occur when information represented in the flight strips is brought together with information in either the radar display (for example, to combine vertical and horizontal state as part of the conflict detection process) or the verbal channel (to relay instructions to aircraft, or to annotate the strip to reflect the state of the world). Where multiple media exist, it is tempting to think of integrating them in a single co-ordinated representation. However, (Mackay et al., 1998) describe a novel design suggestion for making the co-ordination of flight strip and radar information easier, without requiring physical integration.

IMPLICATIONS FOR DESIGN: PAPER AND ELECTRONIC STRIPS

A number of design proposals for future ATC technology involve replacing paper flight progress strips with computerised versions. The idea is attractive for a number of reasons, allowing more integrated data processing and data link communication, and removing the need to manipulate paper strips.

Given the approach developed above, we can look at how a how the introduction of electronic strips impact this network of representations, with particular emphasis in the "themes" identified above.

The particular technological future we have in mind is one where both planners and tactical controllers are presented with similar displays of the traffic situation, showing both radar-type data and electronic representations of flight strips. The strips are still organised under beacon headings, but only a single strip exists for each aircraft, under the beacon that it is currently flying towards.

Representations of the future

The provision of only a single strip for each aircraft would seem to remove one of the planner's principal tools for looking into the future (i.e., having strips for future legs of the flight as well as the current one), so as to detect conflicts and spot opportunities for improving routings. The future progress of an individual aircraft can be displayed on the radar format (after an explicit action by the controller) as could estimated arrival times and altitudes. However, the achievement of conflict avoidance now relies on computerised tools (such as the PHARE problem solving and conflict probe tools (Reichmuth, 1994)), rather than on controllers and representational systems with which they're provided.

Redundancy

The extent to which this new system contains redundant representations differs from the previous technology, both in the trivial sense (paper strips as a backup in case of computer failure) and in a more subtle sense. The all-electronic system appears to provide fewer ways for the team of controllers to go about achieving their goals, and fewer independent views on the situation.

Integration

Clearly, the burdens associated with integrating information in different media (particularly in the strips and radar) are reduced or eliminated. However, at the same time, any benefits that derive from the requirement on humans to integrate information (such as reinforcing controllers' mental picture) are also reduced.

Visibility

The physical arrangement of displays in the new system means that electronic strips will not be the shared artefacts that paper strips are. While electronic communication may enhance the communication of the *content* of the strips, the physical separation will undoubtedly make communication *about* the strips less effective. Further work will be needed to assess the significance of this change in the technical m mediation of communication between controllers.

DISCUSSION AND CONCLUSION

The distributed cognition framework employed here has allowed us to reach an understanding of ATC work in terms of representational artefacts and how they are used.

One criticism that might be levelled at the approach is the lack of a method that takes us from analysis to designs. However, what the analysis of representations has allowed us to do is reflect critically on the part that new technologies and new representational systems might play in future in this complex work domain. An unfortunate conclusion to draw from any analysis of representational media would be that the provision of external representations improves matters by reducing cognitive burdens. Clearly, as the discussion of redundancy and integration highlights, it's not just the presence and distribution of representations that is important, but also the interrelationship between media.

The aim here isn't to resist new technologies like datalink, electronic strips, and stripless control. Instead, we have tried to look at what factors in the current regime help to make it operate in a relatively robust manner, with the aim of using this to inform the development of new ATC systems.

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Human Error Management: towards an ecological safety model. A case study in an air traffic control microworld

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ABSTRACT

In process control, human errors are recognised to be the primary or secondary cause of most accidents/incidents. Until now, most of the solutions proposed to reach an optimal safety were closely related to a logic of error suppression. However, it appears that a better way to improve safety consists in controlling errors and their negative consequences. We refer to the concept of human error management. In this context, the ecological safety model will be introduced and studied through an experiment based on a micro world. Those results will be compared with the results of an older experiment to discuss human error management from a "collective" point of view.

Keywords

Human error, Error detection, Co-operation, Ecological safety model

INTRODUCTION

In most situation of process control, most of the cognitive activities are influenced by the presence of "risks". We can distinguish (Amalberti, 1996) the external risks which concern the objective risk of accident in a specific situation and the internal risks which concern each operator's own cognitive risks (a notion strongly linked to the notion of errors). Our study will be focused on the management of internal risks, management of errors.

MANAGEMENT OF ERROR

The management of errors is the whole process from the error detection to its recovery (Johannsen, 1988, Sellen, 1994, Zapft and Reason, 1994).

Detection stage

Empirical studies on the detection of errors are scarce compared to those on the mechanisms of error production. The first studies completely dedicated to error detection are due to Allwood and Montgomery (1982, 1984) in the field of statistical problem solving who provide a description of 4 strategies of detection: "affirmative evaluation" where the subject controls or verifies his result according to his knowledge, the "standard check" where the subject checks his results without any specific suspicion, the "direct-error-hypothesis" where the subject reacts to a strange result and immediately makes a hypothesis about the type of error he may have made and "error suspicion" where some features of the results are considered suspicious but no explanation is suggested. More recently, Rizzo et al (1987, 1995) have developed a more refined and complete typology with 6 strategies of error detection, as follows. "Inner feedback": the subject finds his own actions unexpected, from information in working memory rather than feedback from either the action itself or its consequences on the environment. "Action feedback": the subject judges curious the way he has done the action but the information is directly related to action execution itself not to its results. "External outcome feedback": the subject sees unexpected results, information coming not from the actions performed but from their consequences on the environment. "Forcing functions": information comes from the environment and prevents the intended action or the attainment of the desired state of the world. "Intention uncertainty": the subject has the feeling of being unsure about what to do next. "Standard check": information is actively searched with the aim to control its status in respect to the frame of reference. These studies suggest also that detection rates are not the same for all types of error. Detecting slips (error execution) seems to be easier than detecting rule-based-mistakes, which are more easily detected than knowledge-based-mistakes.

As an operator is never alone in a professional situation of work, an analysis of the detection by another than the one who have produced an error (colleagues, collective work) appeared necessary.

Detection by another person

The literature does not offer a detailed description of mechanisms of detection in this specific context. But some hypotheses can be based on the knowledge of detection and of collective work. We will refer to a typology of collective activities (Rogalski, 1994). First, understand by the term "*actor*" the operator who directly acts on the system, and by *"observer"* an operator whose task varies according to his place in the situation. His place is defined along 2 dimensions: the level of context sharing by the actor and the observer, and the level of the possibilities to act on the situation and to share the same goals. These 2 dimensions give 4 types of situation:

- The observer and the actor share almost the whole context, goals and actions. Rogalski (1994) uses the term "distributed co-operation" to point out that the operators do not do the same but are organised to maintain a cognitive and temporal synchronisation (e.g. aviation pilots).
- They share a significant part of the goals but not the context. Although the operators are not in the same place they are involved in the same task so they try to be synchronised on the same goals (e.g. an air traffic controller and a pilot).
- They share the context but have different goals and possibilities of actions. The observer, whose goal is not to control the process, can sometimes detects the inadequacies (e.g. an instructor).
- Although sharing neither the same context nor the same goals and possibilities of actions, they are nevertheless related (e.g. inquiry commissions or distance educational situations).

These 4 positions have different consequences for the facilitating or inhibiting error detection. But a certain category of errors appeared to be detectable only by another person, namely rule and knowledge-based-mistakes (Woods, 1984).

Recovery stage

Little is known about the recovery stage, but it is possible to give a preliminary account. Return to a normal state can be more or less easy according to the situation (more or less degraded by the consequences of errors). Three levels of recovery can be distinguished: recovery based on an undo function; recovery based on a rule, when the operator knows a method for returning to a normal state; and recovery based on knowledge, when the operator has to create a complete procedure. Therefore, it seems clear that recovery has to take place early after the error production to avoid propagation of error into the system making recovery harder. It also depends crucially upon the visibility, the immediacy and the validity of feedback information (Reason 1990) and on the reversibility of actions and of unacceptable effects. To conclude, error management appears to be a significant part of human expertise and performance, even more than the production of error itself. This led to the idea that it seems interesting to reintroduce the complex and "natural" cognitive activity of error management in the whole cognitive activities, and in particular in a global model of the operator in a process control situation. In this way, we refer especially to the ecological safety approach where the abilities of error management are in the centre of the model.

TOWARDS A MODEL OF ECOLOGICAL SAFETY

Inspired by the ecological movement (Gibson, 1979, Vicente & Rasmussen, 1987; Flach, 1994), the concept of ecological safety introduced by Amalberti (1996) is based on the main idea that a natural safety exists through the cognitive activity of the operator. As he knows that he is resource-limited, the operator uses his natural and efficient cognitive strategies to manage and to protect himself from external risks and from his internal risks. Several components form this model (Wioland & Amalberti, 1996; Amalberti & Wioland, 1997). The targeted level of "performance" (operator tries to achieve his goal with the least effort), the mechanisms underlying "error management" as it has been presented early in the paper, and the "protections" against errors, defined as the strategies developed by operators to avoid their own cognitive deficiencies. The protections can be based on a feedforward activity (for example attention) or reactive (for example checking an action). To achieve his goal in terms of performance while keeping the situation under control, the operator has to choose dynamically a compromise between these several components. Management of human error is in the centre of the model because it could participate actively to the definition of this compromise. Error is considered as a signal allowing the operator to assess the quality of the compromise and to modify it if necessary. The components all interact together, and are directed by two upper levels, metaknowledge and confidence (Amalberti & Deblon, 1992; Valot and al, 1993).

PURPOSES OF THE STUDY

The first purpose of this study is to describe the components of the ecological model safety in a situation of process control. As the operator is seldom alone in a working situation, a second purpose is to introduce a discussion about the role of "collective" in human error management.

FIRST EXPERIMENT: STUDY OF THE COMPONENTS OF THE ECOLOGICAL MODEL OF SAFETY

This experiment took place in a micro-world which simulated an air traffic control situation (TRACON). Subjects have to manage planes, in a minimum time and in safety conditions. The planes can take off, land or simply transit the sector. For each of these tasks, a clear procedure is defined; if one step of the procedure is not respected then the task fails (but not all the scenario) (for a full description see Wioland (1997)). To succeed in their task, subjects have at their disposal commands to act on the planes and can have some information directly available on the screen or in the menu.

Subjects

Four professional air traffic controllers with some experience of the micro-world participated in the test phase and four novices with no knowledge about air traffic control of about TRACON, were trained before participating in the test phase.

Training and test phases

Four factors were controlled: number of planes, the task of the planes, the type of degradation (the reliability of the control equipment, the weather, and the qualification of the pilots), and a planned conflict between two planes. Over several weeks, four naive subjects were trained to control air traffic scenarios until they reached the same apparent performance as the four professionals. The strategies used by Air Traffic Controllers were elicited beforehand and taught to the subjects. We have checked that these strategies did not interfere with the natural and spontaneous activity developed by the subjects. The subjects were told to manage the maximum planes in a minimum time, and to describe their actions on-line and to think aloud. The test phase is composed of three sessions (each with three scenarios). The first session was focused on the recalling of the micro-world, the second session on the amount of the traffic, and the last session on the degradation.

Data analysis

For each scenario, verbalisations, actions and the display were video recorded. At the end of each scenario, the software recorded a score and the time taken, used to assess performance. Verbalisations, actions and information displayed were retranscribed using the MacShapa software (Sanderson, James & Seidler, 1989), coded in three separated columns, synchronised by a time base. The form of the coding was inspired by the one proposed by Hoc & Amalberti (1997). The coding of the verbalisations is oriented to the identification of the cognitive activity of traffic management with definition of predicates related to standard cognitive activity (information taking, decision taking, ...), predicates related to the identification of internal risks management (protections, detection and recovery), coding what the subjects do (commands sent or the movements of the cursor). The software displayed information which is also coded (for example the alarms).

Error identification

Errors are identified through deviations from the norm (procedure) or from the verbalised intentions of subjects. Each error produced has been noted and classified according to Reason's model (1990). For each of the errors produced, we have analysed whether and how it has been detected and whether it has been recovered. In the case of errors which have not been recovered, the presence or absence of consequences of the error is noted.

RESULTS

Performance

The scores of the 2 groups for the test phase were quite similar but the professionals took less time than the subjects.

Error production

The rate of error production observed for the professionals is significantly higher than the subjects trained (174 errors and 76; $t = 2{,}53$, $df=16$; $p<0.05$). The frequency of slips increased with expertise (from 0.08 per minute during training to 0.12 during the test), while the frequency of mistakes decreased (rule-based: from 0.11 during the training to 0.09 during the test; knowledge-based: from 0.02 to 0.005). For the professionals the same is observed, with a more slips produced (frequency of 0.13) and fewer mistakes (0.12 rule-based and 0.08 knowledge-based)

Error recovery

The percentage of errors recovered was about 72% (68% by the professionals and 74% by the subjects in the training and test phases). For the 3 groups, errors the most often recovered were slips (86% for the professionals, 85% for the subjects trained, and 95% during the training), then the rule-based-mistakes (57% for the professionals, 64% for the trained, and 60% during the training). Except for the subjects in training (60%), the less recovered were the knowledge-based-mistakes (17% for professionals and none for the trained subjects).

Error detection

The mechanism of detection most often used was external feedback (73% in the professionals group and during training and 94% for the trainees subjects). Second was verification (14% in the professionals, 7% during the training and none for the trained subjects). The least-used mechanism was internal feedback (5% for the professionals, 3% for the trained subjects and 10% during the training).

Undetected errors

The percentage of undetected and unrecovered errors is about 32% for the professionals and 26% for the subjects during the both phases. Of these, errors which have consequences on the situation were about 23% for the professionals, 18% for the subjects and 23% during the training. The professionals and the subjects tolerated more errors without consequence (9% and 8%) than the subjects during training (3%).

Protections

During the training phase, the subjects used protection and verification used with the same frequency (0.24 and 0.25 per minute). During the test phase, the subjects tended to use mainly verification

(0.32 vs 0.2) while the professionals seem to favour the protection (0.26 vs 0.17). The trained subjects developed or optimised reactive procedures (more verifications) rather than an integration of strategies of error management (rate of verifications increased from 0.25 to 0.32 between the training and the test phases while the rate of protection stayed the same).

DISCUSSION

For a same level of performance, the professionals have a local management of errors less optimised than for the trained subjects. This is linked to the level of familiarity with the interface of TRACON. The professionals have the same tools as in the real situation, but they do not know how to use them in detail in the experimental situation. They probably imported procedures and routines from their real work context, but the differences between the two systems led them to produce more errors and in particular more slips. These results agree with the slips literature: with expertise slips increase and mistake decreased (Anderson, 1983; Norman & Shallice, 1986) The high rate of recovery is explained by the conception of the micro world where action can be easily and quickly reversed, and the errors produced have a high visibility (through redundancy and error messages). The detection results also agree with the literature, Allwood (1984) and Rizzo (1987) having already shown that the mechanism most often used is based on the effects. With respect to protection, the task in TRACON turned out to be so close to the real one that the professionals brought from it a risk management strategy that was probably not very well adapted to the micro-world. The trained subjects developed a specific risk management strategy to use in TRACON and optimised it with training. They developed procedures to protect themselves which explained why they less often used the feedforward protections than the professionals. From a global point of view, expertise here is not characterised by an increasing of the feedforward activity, but by a reinforcement of the reactive mode. The subjects optimised their procedure. The tolerance of an important number of errors without consequence, is a strategy integrated in error management to save resources, because subjects probably know that these errors will have no consequence. Thus it seems logical that the rate increased with expertise and a better knowledge of the system and the risks.

SECOND EXPERIMENT: DETECTION BY AN OBSERVER

Since operators are rarely alone in a professional situation, the aim of the second experiment was to increase the background protection (here the human ones) to help the operator recover from errors that he neither detected nor repaired.

Experimental protocol and results

Forty pilots were asked to detect pilot errors while watching an eight minute movie of a routine commuter flight. The scenario included 14 non-ambiguous and non-catastrophic errors of various types (4 slips, 8 rule-based-mistakes and 2 knowledge-based-mistakes). There were 2 variables, level of expertise (20 trainees pilots vs 20 instructors) and level of instruction (aware vs unaware of risks). The viewing process was interrupted 3 times (with no possibility of going back) in order to record subjects' comments on the sequence they had just watched. More details can be found in Wioland et al (1995), Doireau et al (1997). The results are based on the analysis of the comments. For each "theme" introduced by the subject, one predicate was defined (for example one predicate related to the weather), and for each of these predicates 4 arguments were coded: the type of evaluation (positive, neutral and negative), the condition of the evaluation (certain or suspicious), the circumstances of the evaluation (contemporary, retroactive and anticipate) and the correction (presence or absence). Results indicate a low average rate of detection by the passive observers (30%) as compared to the rates found in the literature for actively involved subjects (between 70 - 80%). They reveal an effect of expertise (35% of detection for the instructors against 24% for the trainees) and no level of instruction effect. Among all the errors detected, the slips were least often detected (11%) and the rule-based-mistakes most often detected (32%), and intermediate, knowledge-based-mistakes (26%). Most of the detections were contemporaneous with the moment when the error was produced in the movie (85%), a very few are anticipated (2%) – never by the trainees, and some were detected retrospectively (13%). In the last case, among this type of detection, trainees detected more in this way than instructors (20% against 8%). The results showed that the subjects were quite sure of their evaluations, but the trainees were a little less sure than the instructors (52% against 64%).

Discussion

From a safety point of view, the efficiency of a "human" background protection" has been assessed in the worst position for the observer (absence of context sharing and no possibilities to act and to share the same goals). The results confirm that the position of the observer makes the detection less easy and efficient. It was found that the position of the passive observers significantly reduces their capacity to detect slips but enhances their ability to detect rules-based-mistakes and knowledge-based-mistakes. That means that from a quantitative point of view an observer is not very efficient, but from a qualitative standpoint that signifies the opposite. Indeed, the errors that an observer detects are precisely the ones which are least detected by the operator alone. From a safety point of view, the need to have another operator with the principal one is underlined. The idea that the rate of detection could be improved when the observer is in a better position can be assumed, but has also to be checked in future studies.

GENERAL DISCUSSION

In terms of the Ecological Safety Model, management of internal risks or errors, the operator has at his disposal several "safety nets". The first one is composed of "protections" whose goal is to avoid the production of errors. The errors which are mostly concerned are the ones which are "expensive" in terms of consequences. It refers to situations where the operator does not know how to recover from errors or when some resources are missing. In this case, these errors are probably considered to be highly risky by the operator because they could lead to a situation that he could not manage. With expertise and a better knowledge of the system and of the risks of certain errors (metaknowledge), some of these protections could be completed or replaced with some "verifications" oriented. This is efficient, because verifications seem to be less expensive in terms of cognitive resources (less attention than the feedforward protections). But more, it reflects also a strategy or an optimisation of natural safety. Indeed, experts learn from feedback that slips are not detected in a standard way (Allwood and al, 1982, 1984, Bagnara and al, 1987), but more often detected by checks. Then, in parallel with the increasing risks of slips, experts increase the checking. The second safety net when an error is produced is the detection itself. Of course, those mechanisms work in parallel. Several combinations of them can be envisaged depending on the context, goals, expertise, metaknowledge and self-confidence. The goal of the operator is not to avoid all errors but to control them. In fact, some of them could be useful and inform him about the efficiency of his strategy, choices and cognitive compromise. Errors can play the role of an alarm, meaning that the compromise to reach "the best performance with the least efforts while managing the risks" is not good. In other words, the operator has taken some risks which are not compatible with the situation. From a more global point of view, this could allow the operator to assess his level of control of the situation. Even if the mechanisms of management are efficient, all errors are not always detected, the remaining ones can be differentiated: errors undetected and unrecovered can be the result of the choice of the operator who tolerated them to save resources, because they know that these errors are without consequences on the situation. Some can have a worst meaning, and can lead to accidents.They are the ones that the operator failed to control (or detect). In this case of no detection where, errors get through the two first nets (protections and detection), we can imagine a third net: an observer or a colleague. The gain and the efficiency of this net depends on the position of the observer in the situation (on two dimensions, level of context sharing and possibilities to act). Here, the worst position has been studied. It appeared to have no efficacy from a quantitative point of view. But from the qualitative point of view it has been effective, because the errors detected by the observer are the ones which are less often detected when the subject is alone in a working context. The observer contributes to the safety from an external point of view but we have to be sure also that the situation will not lead him to reduce the flexibility and the global efficiency of the natural cognitive risk management (for example in the case where one operator compels the other to repair one error instead of tolerating it to save resources). This led us to assume that the performance of detection and recovery of a pair of operators in the same context and same task could be increased. However, the interaction between the operators can also be conflicting and lessen the natural management of safety.

CONCLUSION

From a safety point of view, the operator seems to have some robust and efficient cognitive ways to protect himself against their internal risks. In this context, the Ecological Safety Model has been presented. The comprehension of this natural safety is important because it could allow us to take it in account it in the design of systems. For example, the first conclusion which appears is that the technical systems have to avoid perturbing those natural mechanisms, otherwise, the role of the operator in the maintain of the safety is not kept. Instead of using principally the rate of error production to assess a system, we should look in more depth at the errors which are not detected. An increase in undetected or unrecovered errors could be analysed as a symptom of a negative interference between the logic of the system and the ecological safety. It is important to assist the detection of error so as to let the operators decide when and how they will recover their errors. But it is also important to consider the role of co-operation in a situation of work. For instance, the role of co-operation in human error management is not very clear, some new experiments have to be realised to identify exactly how errors can be managed by several operators, and the role of co-operation in the maintain of a natural safety to improve it.

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Narratran: a Tool for Authoring Discussion-Based Training Exercises in Emergency Management

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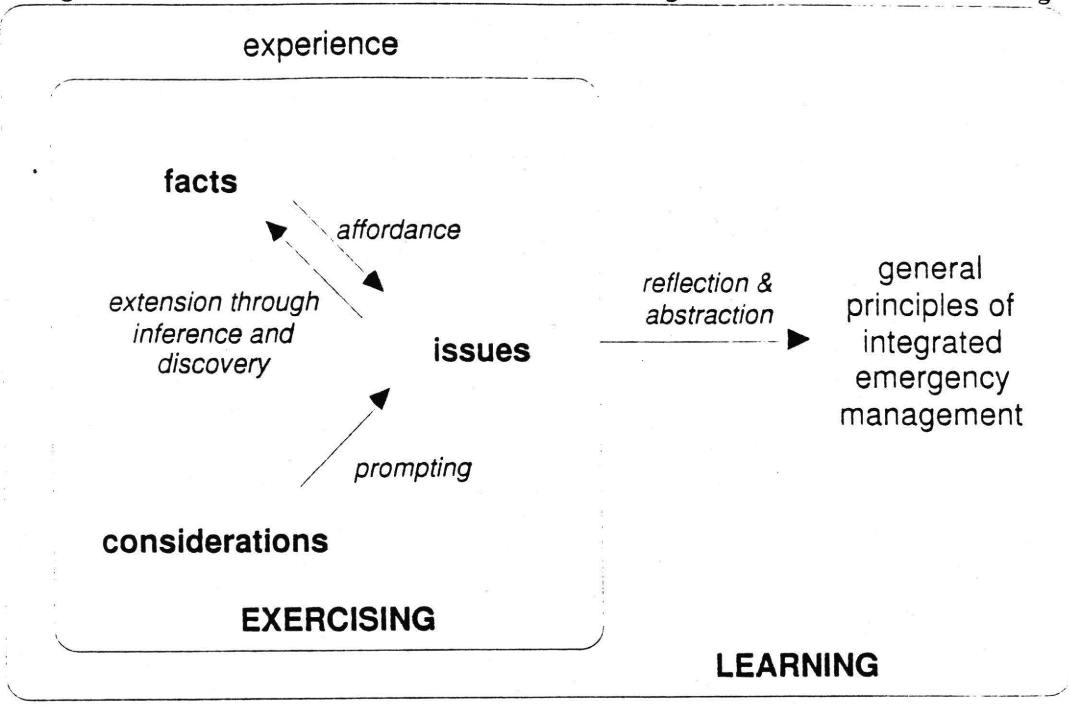
ABSTRACT
This paper reports the design and development of a prototype software tool called Narratran (standing for 'narrative training') intended to assist the authoring of 'discussion-based' training exercises in emergency management; in particular, for multi-agency response to disasters. Requirements for authoring support, derived from a training organization in the UK, are described along with an account of how they are met by the design of the Narratran tool. Finally, we conceptualise the cognitive engineering design problem underlying Narratran, and demonstrate how the tool offers the beginnings of a solution.

Key words
emergency management; training; experiential learning; authoring tool.

DISCUSSION-BASED TRAINING
Training for emergency managers in disaster response is a persistent problem because disasters occur infrequently, often require novel solutions, and rely on specialised inter-organizational procedures (e.g., Auf der Heider, 1989; Denis, 1995; UK Home Office, 1995). 'Discussion-based' exercises are one approach to providing such training in which trainees, organized into small groups called *syndicates*, discuss a disaster scenario presented in the form of a textual narrative; sometimes supplemented with maps, video footage or table-top models (Dowell, 1995). Discussion-based exercises are in widespread use throughout the emergency management community, and have a long tradition in management games (Wolfe, 1993). In some variants, participants role-play agents within the scenario, while in others they carry out disengaged commentary on potential courses of action. In either case, the composition of the syndicate is typically a partial analogue of some real-world disaster management team. For example, there might be one representative from each of the emergency services, re-creating the form of inter-agency exchange between incident officers at the forward control point of a disaster site, as used in the UK government's emergency management system (UK Home Office, 1995).

Discussion-based exercises, in common with 'live exercises' (involving the full-scale physical recreation of disaster situations; see Overy, 1993) and computer-based simulations like MINERVA; (Crego & Spinks, 1998; see also Dowell & Smith, 1998), are predicated on the value of experiential learning; that is, where trainees induce general principles from experience of the instance (Kolb, 1971; 1996). While discussion-based exercises lack both the surface realism of live exercises and the interactive 'real-time' properties of computer-based simulators, they nevertheless offer a number of potential pedagogical strengths. Through face-to-face discussion, trainees are exposed to each other's technical language, interpretative schemes, priorities and preferred solutions. The cognitive basis of cooperative work, essential to emergency management (Samurçay & Rogalski, 1993), may be facilitated through the promotion of a shared mental mental model (e.g., Cannon-Bowers et al., 1993) and the engendering of 'redundant' knowledge of each other's roles (Hutchins, 1995). Further, scenario-centred discussions support the development of the 'clinical

Figure 1. A model of discussion-based exercising and the associated learning



ability' (Miller & Leroux-Demers, 1992) of knowing when to apply certain principles and techniques to particular situations.

AUTHORING AND ITS SUPPORT

Training practice can be divided into three stages: the *authoring* of exercises; the *delivery* of exercises; and the *evaluation* of exercises (e.g., Bramley, 1991). This paper concerns the development of technology to support the *authoring* stage of discussion-based training. This is a different, but possibly complementary, focus to that of simulation technology development which seeks an alternative to traditional methods of *delivery* used by live exercises and discussion-based training.

Table 1. Exercise content represented by the Narratran tool

facts	The narrative statements of the disaster scenario. Two types are distinguished: **explicit facts** (given directly to trainees) •*At 0730, a lorry carrying chemicals collides with the bridge in the town centre.* •*The lorry catches fire and the bridge collapses.* •*People abandon their cars and retreat to a nearby factory site* •*At 0800, a member of the public reports a fire in a factory building.* •*A housing estate with 450 residents borders onto the factory site* •*At 0808, fire-fighters at the factory declare a major incident.* **implicit facts** (declared by the author, but withheld from trainees) •*The collapsed bridge blocks access through the town.* •*A shed in the factory site contains tanks of aviation fuel.*
considerations	The 'questions' given to trainees to focus and guide their discussion. For example: •*Where might the forward control pointand major incident room be established?* •*What resources should be requested immediately?*
issues	The general aspects of the scenario which the author intends for the trainee discussion to address. For example: •*Safety and access to the forward control point: the need to set up more than one forward control point, in each accessible area.* •*Evacuation of the public: the decision to evacuate residents; transport for evacuees; arrangements for a welfare centre; protection of abandoned property.*

To investigate how the authoring of discussion-based exercises might be better supported, we have developed a prototype tool called *Narratran* (standing for 'narrative training'). Narratran has been developed for a UK government training organization called the Emergency Planning College. The College carries out multi-agency training in disaster response for middle- and senior-ranking personnel of the emergency services, local government departments, and other agencies.

The first step in developing Narratran was to establish: (i) a model of the training delivery process used by the College, and (ii) high-level requirements for authoring. A study was carried out in which interviews with eight Course Directors were used to dissect and analyse the structure and development history of selected exercises.

The resultant model of discussion-based training is shown in Figure 1 and expresses the relationship between the *exercising* process and the associated process of experiential *learning*. Exercises involve three types of information: **facts, issues** and **considerations** (see Table 1 for examples). The textually presented **facts** are narrative statements which convey the disaster scenario. Textually presented **considerations** raise questions for the trainees to discuss in conjunction with the narrative **facts**. Withheld from the trainees, are **issues**, defined as general principles that the author intends for the trainees to discuss, either explicitly or implicitly. These three types of information are related in important ways, illustrated by the examples in Table 1. Firstly, **facts** *afford* the discussion of **issues**, and conversely the discussion may then raise new **facts** through *inference* and also through *discovery,* by asking facilitating staff. Secondly, **considerations** *prompt* the discussion of specific **issues.** The model in Figure 1 also asserts that the exercising process forms the concrete experience of an experiential learning process. This experience leads, through *reflection and abstraction*, to the learning of general principles of integrated emergency management, and the clinical knowledge of how those principles are applied to specific disaster situations.

Table 2 shows the high-level requirements for authoring that were identified in conjunction with the model of discussion-based exercising shown in Figure 1. Full descriptions of the requirements are given in Table 2, but it is instructive to make further comments on the constraints bearing on the authoring process. The skill of authoring is to create a set of **facts** and **considerations** which will, respectively, afford and prompt the syndicate discussion in a way leading to the experiential learning of targeted **issues**. Failure to elicit an important **issue**, or the elicitation of non-targeted and irrelevant **issues**, are undesirable outcomes to be avoided. Over the long-term, the College adapts its training to changes in legislation, new emphases on certain types of disaster, new managerial practices, and changes in the trainee population. The 'problem situation' of authoring, to borrow Checkland's (1981) term, concerns the generation and maintenance of exercises to meet these unstable demands. Exercises at the College are largely documented and stored in the form of the paper-based courseware given to trainees; that is, only the **facts** of the disaster narrative and **considerations.** Over time, through successive modifications by different authors, the rationale underlying the surface form of an exercise may become obscured. Why particular **facts** of the narrative are included, for example, or what **issues** should be prompted by a particular **consideration**, may no longer be apparent.

THE DESIGN OF NARRATRAN

We now turn to the design of the Narratran prototype before looking at how it addresses the requirements in Table 2. In software terms, Narratran is a database of materials for generating courseware for discussion-based exercises. It has been developed in Lotus Notes with the following data structure.

(i) *The document set.* Each exercise is stored as a standard set of documents: a **facts** document, an **issues** document and a **considerations** document.

(ii) *Itemization.* Within each document, material is itemized into discrete **facts, issues** and **considerations**. In the case of **facts**, itemization represents a departure from the existing prose form of the narrative.

Table 2. Requirements for the authoring of discussion-based exercises

integrity	to assess the coherence and completeness of each exercise, and to scrutinize its likely effectiveness
continuity	to enable authors to learn about the rationale underlying each others' exercises
evolution	to create new exercises based on existing ones, through: expanding one part of an existing exercise; modelling a new exercise on an old one; or, hybridizing components from different exercises
adaptability	to create exercises which can be rapidly tailored to short term needs, such as variations in trainee profile

evaluation	to enable better use of feedback from facilitating staff and trainees

(iii) *Categorization.* Items are categorized within each document. **Facts** and **considerations** are classified by *stage* of the exercise. (Typically an exercise narrative is presented in stages, with a discussion 'at each stage.) In addition, **facts** are classified by exposure, phase, theme and role. *Exposure* distinguishes between *explicit* **facts**, which are presented in the narrative to trainees, and *implicit* **facts** which are also part of the scenario, but are withheld from trainees. (Implicit **facts** may be given to trainees by facilitating staff in response to questions during the exercise.) *Phase* distinguishes **facts** concerned with: setting; prevailing conditions; disaster events; actions by the responding agencies; and aspects of the ongoing situation. *Theme* is a scheme created dynamically by the author to distinguish different strands of scenario content, such as an evacuation or an explosion. *Role* is also a dynamic scheme which allows **facts** to be associated with particular trainee organizations, eg. the police or fire service.

(iv) *Linking* (through data relations). Three types of link, or data relation, can be created between pairs of items: **fact-to-issue**, **issue-to-consideration**, and explicit-**fact**-to-implicit-**fact**. Through a rich set of links, many-to-many mappings can be created between the **facts** and **issues** documents, between the **considerations** and **issues** documents, and between the explicit and implicit parts of the **facts** document. Through itemization and linking, Narratran follows the form of a relational database.

(v) *Versioning.* Different versions of an exercise can be created by selecting and de-selecting items in each document. A large *core* of materials can thus be entered in the documents, only some of which are used for each version of the exercise.

To interact with this data structure, the Narratran tool provides interfaces for creating, browsing and manipulating **facts, issues** and **considerations**, and links between them. It supports the copying of linked clusters of items (for example, a set of **facts** with its associated **issues**) during the creation of new exercises, and the generation of courseware in the form of paper handouts. Trainee handouts contain only the explicit **facts** and **considerations**, organized by stages of the exercise. Handouts for course directors and facilitating staff can be specified by the author to include other material, including links.

MEETING THE REQUIREMENTS

We now consider how the Narratran tool attempts to meet the requirements for authoring outlined in Table 2. Each requirement is addressed in turn.

Integrity

Part of the data structure of Narratran embodies the model of the exercising process shown in Figure 1. **Fact-to-issue** links represent *affordance* relations, and **consideration-to-issue** links represent *prompt* relations. For example, the **issue** of *'evacuation'* (see Table 1) is afforded by, and might therefore be linked to, the **facts**: *'A housing estate with 450 residents borders onto the factory site'* and *'At 0808, fire-fighters at the factory declare a major incident'*. The tool allows the author to scrutinize the integrity of the exercise, by checking the role of each item with respect to others. For example, *prompt* links allow the author to declare and reason about the likely efficacy of each **consideration** for prompting the discussion of particular **issues**. Similarly, the distinction between **explicit facts** (those given to the trainees in the narrative) and **implicit facts** (those withheld by the trainers) support reasoning about the process of discovery and inference of new **facts**. Using Table 1 again, the implicit **fact** *'The collapsed bridge blocks access through the town'*, has to be inferred, in conjunction with maps, from the explicit **fact** *'The lorry catches fire and the bridge collapses.'*

Continuity

Analogous to the principle underlying the use of design rationale notations (e.g., Maclean et al., 1991), Narratran invites the author to document elements of the exercise 'logic' which might otherwise remain as tacit mental knowledge. Most significant are the facilities to document: **issues**; affordance and prompting relations; and, implicit **facts**. This extended documentation, relative to typical practice at the College studied, helps trainers to understand the original author's logic during subsequent re-authoring or use of the exercise. Thus the long-term continuity of training within the organization is promoted.

Evolution

Narratran's standardisation, through the document set and itemization, supports the development of new exercises from existing ones. Exercises are easily modifiable by editing, deleting and inserting items; and the appraisal of these modifications is assisted by links. For example, when considering the deletion of the **fact**, *'People abandon their cars and retreat to a nearby factory site'*, the author can be reminded of its role in affording the **issue** of *'Safety and access to the forward control point'* (abandoned cars may block the access and egress routes of the emergency services.) Thematic categorization of **facts** and their links to common **issues**, support the dissection of exercises into meaningful narrative components which may be carried forward into new exercises.

Adaptability

The need to adapt exercises at short notice is addressed by Narratran's versioning feature. Authors may prepare versions of each exercise for different trainee groups by selecting and de-selecting items from the core. Again, the transparency of exercise rationale encoded in links supports this tailoring of new versions.

Evaluation

A key part of the rationale of discussion-based exercises is that trainees learn from each other. Each trainee brings up-to-date knowledge of their own agency's formal and informal practices. Trainees often contribute important novel **issues**, or points of **fact**, which may need to be incorporated into future versions of the exercise. Itemization and versioning, allow these insights to be translated into new **facts, issues** and **considerations** to be added to the core for future selection, if desired. Exercise content becomes an infinitely extendable repository of incoming knowledge and expertise from the emergency management community.

As a caution against this unbridled optimism, we should note that use of the Narratran tool may have disadvantages over existing authoring practices. A chief area of concern is the shift from a rich prose narrative of the disaster scenario to a list of itemized **facts**. Categorization of **facts** by phase (setting, conditions, events, etc) was introduced to alleviate this possible problem, since phase can normally be flagged more naturally in a prose style. It is our intuitive belief, however, that a **fact** list may be superior to the prose format, for some exercises at least.

A COGNITIVE ENGINEERING BASIS

In this final section we examine the cognitive engineering basis of the development of Narratran (based on Dowell and Long, 1998).

First we conceptualise, a to-be-designed *authoring worksystem* as the interactive combination of authors and the Narratran tool. Second, the intended target of this worksystem is identified as the *domain of discussion-based training in emergency management*. The authoring worksystem and its domain can be further conceptualised as a chain of systems. Here, the cognitive behaviours of the authoring worksystem create exercises for use by a (discussion-based) exercising system with the aim of achieving learning by the individuals of emergency management system(s). Through transfer of training, these learned behaviours are carried forward to management system(s), in practice, which direct operational system(s) in response to the demands of disasters.

Thus the Narratran tool exists within a causal chain of systems with the direction of influence being: Authoring(a) → Exercising(e) → Management learning (ml) → Management practice (mp) → Operations (o) → Disasters (d). We can describe this as a *performance chain* in which each system enhances the performance of the system immediately down-stream, leading ultimately to improved quality of disaster response.

In general, cognitive worksystems carry out their tasks by maintaining and manipulating representations of their task domain. In the current authoring worksystem, performance depends on the 'experience' of the expert trainers; more specifically, it rests on their mental models of the performance chain: a → e → ml → mp → o → d. To design exercises effectively, trainers must reason (implicitly at least) about the impact of exercises, right through the performance chain to disaster response. As we have argued, the data structure of Narratran attempts to assist the author by embodying a simple model of e→ml; that is, a model of the discussion-based exercising system and its relationship with management learning (shown in Figure 1). The storage and manipulation of data within the tool thereby externalizes and extends authors' reasoning about this first part of the performance chain.

To pursue a cognitive engineering approach further, possible future developments of Narratran might attempt to address further components of the performance chain. One approach is the introduction of models of the management of the operational response to disaster; that is, models of m → o → d. These models might take the form of generic **issue-fact** relationships that embody principles of emergency management, and would serve as generic templates for exercise structure. The origin of the models would be case-study research into the management of specific disaster incidents. This could address the need to generalize the lessons learned by one-off disasters (see March et al., 1991) into a range of discussion-based exercises.

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The Politics of Information and Knowledge Sharing for Systems Management

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ABSTRACT

This paper reports on a case-study of introducing intranet facilities to improve co-operation by way of information support of a department that provides system management services.

Keywords

System management, Internet, Intranet, Information System, Requirements analysis, Management.

INTRODUCTION

This paper reports on a case-study of introducing intranet facilities to improve co-operation by way of information and knowledge management within the Distributed Systems (DS) department of a large international company that provides full IT services.

The main product of Distributed Systems is system management for distributed computer systems services built around VMS, UNIX and NT server platforms. In addition, DS provides expertise for special projects and it is responsible for the development of new services in its working area.

DS is part of the Technical Infrastructure Services (TIS) department which system management that may be characterised as: full services, around-the-globe, around-the-clock and high availability (well below .1% unplanned downtime). In practice, the main customers are large, internationally operating companies such as ICI and Philips who cannot do without and who are able to afford such services.

System management is a knowledge-based activity; to do this efficiently, you need a standing organisation of people to provide the knowledge where it is needed, procedures and standards to manage and possibly improve the process, and an extensive set of information sources to save the people from having to know everything.

Extensive growth caused problems in managing the organisation and the information, so a project "Design of an Information Infrastructure for Service Delivery" (DI2SD) was started intended to provide better information support.

Business Processes

Regarding procedures, system management is set up according to a methodological framework called ITIL (IT Infrastructure Library), originally a set of reference books on IT management written under the auspices of the British government for its Central Computers and Telecommunications Agency (CCTA, 1989).

ITIL or SMART as the local adaptation is called divides systems management into a number of services and processes such as Customer support (the helpdesk), Database management, Contingency services (disaster management), and Problem- and Change Management, etc. that describe what is delivered and how it is delivered.

SMART forms the conceptual layer in an ISO-9000 process quality system (ISO, 1987). Because ISO-9000 is limited to description only, elements from methods like TQM (Total Quality Management; Roa et al., 1996) and CMM (Capability Maturity Model; Paulk et al, 1993) are used in the quality system to measure and improve the processes.

The conceptual layers are further effectuated by a set of process descriptions and work instructions which relate the processes to the role assignments and responsibilities of the organisation, and a set of standards on e.g. operating system and database configuration that enable systems be managed in a uniform way.

Standing Organisation

Within the company there are four main business processes: Sales Acquisition, Portfolio Management, Contract Implementation and Service Delivery. DS is responsible for the Service Delivery in its working area, and actually provide the system management services. It is also involved in parts of Contract Implementation to prepare computer systems, organisationally and technically, for system management.

To provide services globally, DS is geographically distributed in one global, a few regional and several local sites. The local sites are responsible to the day-to-day activities, the regional sites add regular systems management 'following the sun', and the global site adds support by specialists.

The organisation of the global site is split horizontally and vertically. Horizontally there are platform specific groups (UNIX, VMS, etc.) and vertically there are layer specific groups with respect to both support level (helpdesk, system management, specialists) groups and support type (SAP using an Oracle database on a UNIX platform). A main problem for the organisation of DS are the growth figures, for some groups well over 100%. These show up in a constant struggle for resources between actual system management work, and the work required to address the growth by means of e.g. educating trainees, improved tooling and more usable information support.

Information Sources

Information support consists of a large number of wordprocessor-, paper and intranet documents, local office- and Lotus Notes databases, a globally accessible mainframe tool/database 'INFOMAN'[1]. In addition, the systems themselves can be seen as information sources.

Ideally, a paper and wordprocessor document describes the configuration of a particular system, and all the problems, changes and contract data should be managed in Infoman.

The **documentation** became troublesome when different groups started to use their own, to address their specific responsibilities, levels of skill and their own favourite places to store (and hide) them. Due to the workload and the need to update the same information at different places, maintenance suffered and inconsistencies between information sources were born.

Although **Infoman** is a good tool for managing mainframes where it provides for both, monitoring, problem and change administration and process automation. Within DS Infoman is only used as an administration tool with two main disadvantages:

- Infoman is not very suitable for the dynamic nature of distributed systems. Plugging in an extra diskdrive overnight is *not done* in mainframeland but common for DS, and whereas mainframes are generally dedicated to only a few processes, DS systems are used for general purpose.
- Infoman has a user interface from the stone age. Infoman is what Thoresen (1997) calls "Simple but Cumbersome"; it has a steep learning curve and it is not appropriate for 'occasional' usage, which is further deterred by a lengthy login procedure.

Because of the problems with Infoman several groups within DS developed their own solutions by creating local databases, document standards, etc. The general result is that information is not always accurate, available, easy to locate, and easily accessible. This problem is made more serious because system management often requires close co-operation between globally dispersed groups from DS and from other TIS departments.

THE DI2SD PROJECT

At this point the project entitled "The Design of an Information Infrastructure for Service Delivery" started with the aim to improve the efficiency and quality of the service delivery processes by using the intranet to actively, and more-and-less interactively exchange information between the parties involved in this process. Note that the software to control and monitor computer systems was not part of the project; only the information support system management was.

The project was formulated in two steps, first a requirements analysis part, after which a decision would be made about a subsequent design part.

REQUIREMENTS ANALYSIS

The aim or 'deliverable' of the requirements analysis should be a set of requirements for the structure and contents of an information system as follows:

- procedures, methods and tools to store, update and remove of information.
- an information structure to facilitates task-appropriate navigation.

Also, four technical requirements should be met:

- allow for global access to locally stored (distributed) information.
- facilities for user authorisation, access control and ownership
- document management facilities to prevent inconsistency and manual maintenance.
- facilities to search, retrieve and access information.

The approach followed in requirements analysis was threefold. First, following the idea that information should support formal procedures governing the service delivery process, an extensive analysis was made of the process quality documentation.

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[1] INFOMAN is the local name for IBM's "Information Management" tool that is now part of the TIVOLI framework of system management tools. See:http://booksrv2.raleigh.ibm.com/infoman/

Secondly, to become familiar with the 'way of working' beyond the formal procedures -which indeed proved much more important- a series of interviews was held. From each group the manager and one of the system managers was interviewed to determine which information was used from where, how, and for which purposes.

Finally, time was allocated for less structured observations during so-called "Severity Ones", crisis situations that clearly show acute information needs.

Some Observations

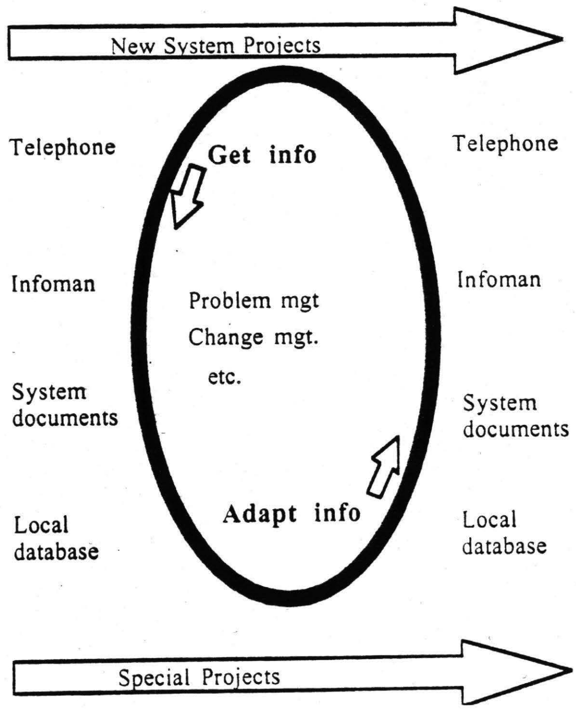
A number of general observations were made during the requirements analysis part of the project. These have been described elsewhere (de Haan, 1998) and will only be briefly described here:

- procedure-based business processes makes task analysis difficult: because role-assignments are dynamic and seldom explicitly laid down, process descriptions are not as helpful as might be expected to understanding the organisation's work structure. For example, whereas the documentation describes service delivery in terms of separate processes, in practice, each group has only one work queue.
- work instructions and task analyses are clear and simple but say little: work instructions for e.g. Problem Management describe the administrative process but not any of the actual steps taken to solve the problem, and problem solving activities only seems to have a generic observe-act-test cycle as a commonality.
- techies don't document: system managers like to invent but not document their inventions, and they are even less likely to maintain the documentation, or adapt it to the needs of less experienced people.
- information analysis requires that information management is in-place: apart from the problem that some documents do not exist when they should, it took considerable work to determine what information is available, and how to get it.
- wheels are constantly reinvented and no one seems to keep track of them. This is a common problem of every sizeable organisation. This often became clear since DI2SD was one of only a few department wide projects.
- the tacit knowledge problem (Evans, 1988): much information is kept hidden in people's heads because knowledge is difficult to verbalise and because people, and particularly the gurus, tend to take it for granted that everyone has to the same background knowledge.
- system management is a highly creative task: a large part of system management is rather dull but still many problems and changes require creative problem solving.
- for managers it may pay to keep information to themselves: in presenting a thesis about knowledge sharing at Origin, Karssen (1997) noted that "some managers (especially within TIS) tend to sit on their knowledge". This happens for genuine reasons but also for 'political' purposes. A financial department, for example, would only grant DS perusal of contract data for security reasons, but also to keep contract management within their responsibility.
- the need for management backing is a common observation for project success (Markus, 1983). Although systems for project ownership and resource allocation are used, these proved insufficient to ensure sufficient co-operation. DI2SD became "Trapped in Obsolescence" (Martin, 1991) when a strong DS manager left and was replaced by a rather unsupportive acting manager.

Some Results

The results of the analysis phase consisted of descriptions of the general information flow as regards the service delivery process and descriptions of the main information problems, both in general and in relation to the software used. A description of the information flow in full detail and a complete design specification could not be created because of large differences in the work process between groups, and because of lacking information.

Figure 1: System management processes



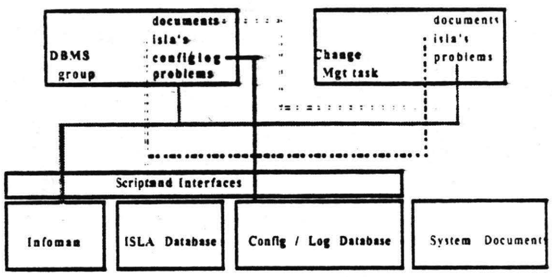
DS has three different processes; see figure 1. During a cyclic main process problems are solved, changes effectuated, etc. and a variety of information sources is consulted and subsequently updated. New systems are introduced in a linear process of planning, gathering information, documenting, installing software and handing everything over to the next group until the system is ready. A third process deals with all the projects not related to system management.

Requirements analysis did not go well. Although backed by the general manager of DS, not belonging to a group put me in an isolated position with insufficient means to get things done from the group managers. It was much easier to gather information, especially in unscheduled sessions, from the system managers who were less restricted in talking about 'all the things that go wrong'.
Although the business procedures say little about how the work is actually done, they proved helpful as a framework. Informal information gathering during severity one's was useful, also because the subsequent 'root cause analyses' provided the opportunity to verify the observations.

DESIGN

During the design phase, the top-down approach of the analysis phase was replaced by a bottom-up approach, driven by creating artefacts and demo's to actually solve the problems on the workfloor.
To make clear what the project was heading at, the results of the analysis phase were laid down in an information policy proposal and in a document explaining the possibilities of internet techniques to overcome any technical misunderstandings. In essence, the proposal suggested to use web-browsers to provide a uniform, group- or task specific interfaces to the different information sources, hiding information formats, storage places, and the particulars of databases and (legacy) systems such as Infoman. See figure 2.

Figure 2: Uniform information access



I will first discuss the main reasons to pursue a intranet-based approach, and continue with a description of the subprojects and their results.

Intranet Technology

There was ample reason for DS to make more advanced use of internet technology:

- web browsers exist for all the platforms used and managed by DS. Using plugins, MIME encoding and translation tools the file format problems and most of the storage-place problems can be resolved.
- the web only allows for lightweight document management (Rein, et al., 1997) that would, however, suffice until the arrival of the much awaited real solution.
- with a combination of HTML and client-site scripting it is easy may to create uniform user interfaces (Flanagan, 1996).
- server-site scripting may be used to access local databases (Fraternali, 1998) and data in (legacy) applications (Barta and Hauswirth, 1995).
- internet technology has gained the status of proven technology or standard business practice. As such, it would fit the purchasing policies of DS. In addition, it would "seamlessly integrate" with the office environment provided by a main business partner.

Organisational Issues

More important than the technical issues are the organisational advantages:

- an intranet, though mainly used as an elementary technical resource for e.g. Telnet, ftp and a variety of email and messaging systems, is readily available. New system monitoring software (CA TNG) had already replaced proprietary networking and hand-crafted scripts by a standard environment. As such, the logical next step would be to move information support and system activities themselves to the intranet (e.g. Pingleton and Fischer, 1994).
- the logically and physically distributed organisation of DS with many different parties involved in managing particular systems had already made it clear that the possibilities for co-operation by email, telephone and ftp were insufficient and counterproductive.
- DS is not meant to nor able to allocate resources to extensive development projects but it is able to provide the resources for the more incremental and piecemeal approach of internet development. The nature of internet development as low-key and anarchistic would also fit the user group and promote success.
- finally, the company's top management had recognised the need to use the intranet as a business advantage and supported this strongly. Apart from a slogan and a policy (see e.g. Telleen, 1996), staff and other resources had been allocated to provide expertise, tools, etc.

Projects and Results

Three and a half projects were started to put the design phase and the proposal into effect:

- a webteam projects with members from each group to develop the department's web site and create involvement for interactive use of the intranet,

- a project management project to create a demo to help solve the problem that at the department level no one exactly knew what was going on and who was involved in different projects,
- a document management project to provide uniform and controlled access to documents,
- a small project to demo and provide connectivity with various local databases and Infoman.

Generally speaking, these projects worked well. The webteam suffered slightly because several groups were represented by their most junior employee but this was -fortunately- counterbalanced by a senior manager who also represented the team in the management meeting. The team was a support for the web master in getting each group to produce the obligatory documents, and it worked well as a discussion platform and as a test forum.

The project management demo, a mere set of scripts running on a server, was a big success, also because it accidentally turned out useful as a tool to find expertise. The success of the projectbase and of a DS good-news page is best illustrated by the questions they raised to restrict access "*now that the whole company knows what we are doing*".

The document project was less successful because several group managers were reluctant to make the system documents accessible to all DS employees. A more advanced solution died during negotiations with the intranet management, who disallowed customer scripts. Earlier then expected, however, the document management software became available, and because DS was already working on it, the department was chosen for a pilot implementation.

The connectivity project had mixed success with respect to Infoman; the software was readily available but it required networking facilities far beyond the budget. As a workaround a script was used to dump essential data into a local database for read-only access. The project did deliver several working prototypes to access this and other local databases but before they could make it into the production environment, the DI2SD project was killed.

CONCLUSIONS

It may be risky to draw conclusions from just one project in one department in one company, nevertheless, the following five conclusions seem justified:

- Business procedures say little about how which information should be available.
- The quality documentation gives a very precise description of the business processes that looks like a perfect task analysis model but was often rather different to find again in reality because of the dynamic and implicit role assignments and because work instructions only lay down the administrative side of working.
- Even the most primitive information sharing facilities can make a big difference in improving information support and co-operation. Improving overall information access would require big decisions such as replacing Infoman, but this is not within the possibilities of a small department. The majority of problems existed because most groups used different formats, systems, platforms and, often inaccessible, places to store their information. Solving these problems, at least in a technical sense is trivial and can be done with standard off-the-shelf technology.

The main problem is in the organisation and the culture and not in the information. A good deal of the information used in system management is sensitive: information about contracts, employees, and tools is better kept hidden from competitors, even though this may hamper business itself. It is, for example, not possible to search the personnel database on special expertise (Karssen, 1997).

Information support, at least in this case suffered most from organisational factors, such as reward schedules that favour allocating resources to customers, extensive growth and the scarcity of resources, and the tradition of co-operation based on trading. As a result, group managers are stimulated *not* to share resources because that would simply undermine the trading position of their group.

Group managers are neither stimulated to use information sharing facilities, even if these would save resources, because that would leave them with less if anything to trade with.

The most advanced document and information management systems won't solve the problems. Sponsored by upper management, there are projects underway for document management and intranet development that may fail like a Lotus Notes project did before. In an organisation with powerful middle management, it seems that successful information sharing heavily depend on the proper incentives for this group, regardless of the importance of backing from the upper management (Markus, 1983) and perceived benefits among end-users (Grudin, 1988).

Information support should be approached bottom-up. The requirements analysis part of DI2SD was essentially a one-man show that began to look silly when management backing changed from support to indifference.

In this situation it was best to try to create a critical mass for change in a bottom-up fashion via rapid prototyping (Wilson and Rosenberg, 1988). Solving some of the most acute problems, if only by a demo, helped to create support among the system managers and to convince some group managers of the utility of the project.

Finally, as a more personal conclusion regarding my first year in industry, I might support a conclusion from Landauer (1991) that cognitive psychology should not stick too much to significance levels and focus on ways to make things better in everyday life.

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Ecological Modelling of the Air Traffic Management Task

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ABSTRACT

An ecological analysis of the air traffic management (ATM) task is presented in the dualism of a domain model and a worksystem model. The analysis is exemplified by its application to a simulation of the ATM task. This example supports the claim that ecological models provide complete and coherent analyses of whole tasks and of specific behaviours and structures. Ecological modelling is contrasted with alternative approaches to analysing cognitive work, and is identified as a feature of cognitive engineering.

Keywords

Cognitive design problems, air traffic management, simulation, cognitive costs, domain, worksystem

ECOLOGICAL MODELLING

Payne (1991) has distinguished three general approaches to modelling cognition of worksystems, according to whether the model is driven by concern for specific "usability phenomena", by the application of generic mental architectures, or by concern for the ecological relations with the cognitive environment in which users perform tasks. Payne observes that traditionally, cognitive ergonomics has been dominated by the first two approaches.

Within the phenomenon-driven approach, models of particular interaction behaviours, such as the varying recall of deep and broad menu tree structures, are often translated as design guidelines. But whilst such models may achieve completeness and coherence for their local interaction behaviours and structures, they do not contribute to complete or coherent models at the level of the whole task. Their scoping ultimately proves to limit the usefulness of the guidelines that may be produced. By contrast, the architecture driven approach aims to specify and apply generic, perhaps universal, architectures to modelling cognition of worksystems (Howes and Young 1998). This approach promises coherent and complete models at the level of the whole task, but the need for the architectures to be universal often leaves the resulting models incomplete at the level of specific interaction behaviours and structures.

The ecological approach uses the structure of the task domain to specify cognitive models of the worksystem. The resulting models are limited in generality to their specific class of domain, but within that domain, may achieve completeness and coherence at the level of the whole task and of individual behaviours and structures. And as suggested by Herbert Simon's much cited parable of the ant, because the domain licences a minimum of postulated cognitive entities, the ecological approach may be particularly suitable for modelling cognition in complex tasks.

Air traffic management (ATM) has proved an intractable task for cognitive modelling. Its extended temporal continuities, the interleaving of the controllers' activities, and the small set of overt behaviours relative to the set of mental behaviours, make the construction of satisfactory abstract models very difficult. These difficulties are compounded by the distribution of cognitions across the sector team.. Nevertheless, many different cognitive models of the ATM task have been developed and can be identified predominantly with the phenomenon driven and architecture driven approaches. Leplat and Bisseret (1965), for example, model the phenomenon of how controllers make conflict detection decisions. By contrast, Timmer and Long (1996) apply a framework for inductive reasoning, deriving from a computational architecture, to modelling the air traffic management worksystem.

In the following sections, an account is given of the ecological modelling of the ATM task. A model of the ATM task domain is first described. The domain model is then used to specify ecologically, a corresponding model of the ATM worksystem. The model is illustrated through studies with a laboratory simulation of the ATM task.

MODEL OF THE ATM TASK DOMAIN

The model of the ATM task domain is presented elsewhere in detail (Dowell, submitted for publication) and is summarised here for the purposes of making clear how the ATM worksystem model is established through ecological relations with the ATM task domain. The task domain model is specified in terms of the following four constructs:

Airspace and aircraft objects

The airtraffic management task arises over two classes of elemental domain objects: airspace objects, and aircraft objects. Aircraft objects are defined by type attributes, for example, laden weight and climb. rate. Airspace objects include sector objects, airway objects, flight level objects, and beacon objects. Each is defined by their respective attributes, for example, beacons by their location.

Airtraffic events

Airtraffic events occur in the conjunction of aircraft and airspace objects. Events are, in effect, a superset of temporal objects. They have their own attributes, centrally those of: Position; Altitude; Speed; Heading; and, Time. These events become the primary objects within the traffic management task.

Airtraffic event vectors

Sequences of airtraffic events arising corresponding with specific aircraft objects form trajectories over time called 'event vectors'. Each aircraft present within an airspace sector will be defined by an event vector. Event vectors have their own task attributes of: safety (in terms of aircraft separations); flight progress (i.e., duration of the flight through the sector); total of fuel used; the number of instructed manoeuvres; and achievement of sector exit height.
Three different sorts of event vector can be defined with regard to states of these task attributes, one describing the actual state of air traffic over a period, one describing the projected states over that period (ie, what the states would have been without the further interventions of the worksystem), and one describing a normative goal state.

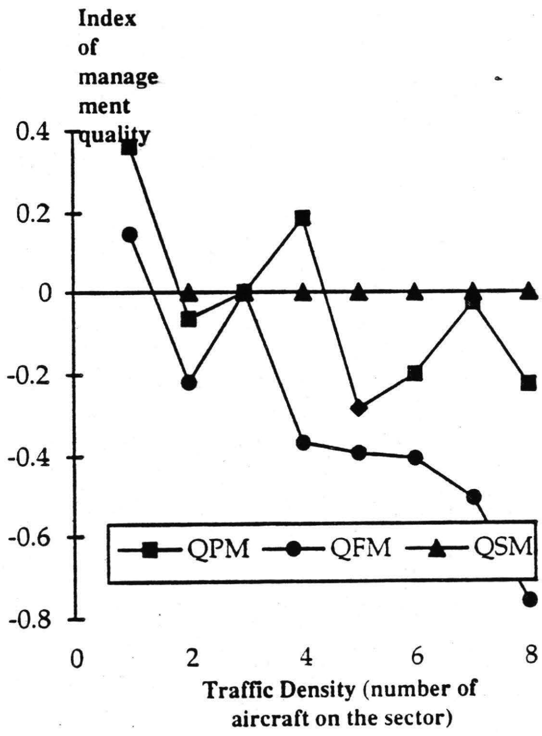
Quality of airtraffic management

In the relations between these three event vectors, the quality of management of the air traffic, by the ATM worksystem, can be established. Air traffic management quality is an assessment of the quality of management of each and all aircraft with regard to the attributes of safety, progress, fuel use, etc. Critically, air traffic management quality must assess the 'added value' of the worksystem's management of a process which is dynamic and self determining (Boudes and Cellier, 1998). It is able to do this by assessing the actual states of event vectors relative to both the goal states and the projected states. Dowell (submitted for publication) presents the method for computing these air traffic management qualities from a given set of air traffic data.

Modelling of the ATM domain is illustrated by application to a laboratory simulation of the ATM task. The simulation provides 'controller' subjects with the task of managing a set of aircraft within an en-route sector simulated by a dynamic computational traffic model. The simulation re-constructs the common user interface to an ATM suite, including a radar display and flight progress strips.

A model of the ATM domain can be constructed for this simulated task using a log of airtraffic events and the controller's management interventions. Figure 1 presents one form of assessment of airtraffic management quality achieved by a particular controller. The assessment describes the variation in management qualities with increasing traffic volumes. Qualities of safety management (QSM), fuel use management (QFM) and progress management (QPM) are shown. These management qualities are expressed by a unit-less index where zero represents a goal value, and negative values represent a sub-goal value. QPM and QFM are seen to decline with increasing traffic loads, whilst QSM remains constant (and optimal). This pattern is consistent with the trade-off between expedition factors and traffic volume observed by Sperandio (1978) in the performance of controllers at Orly Control Centre.

Figure 1. Traffic management quality achieved by a single 'controller' in a simulated ATM task.



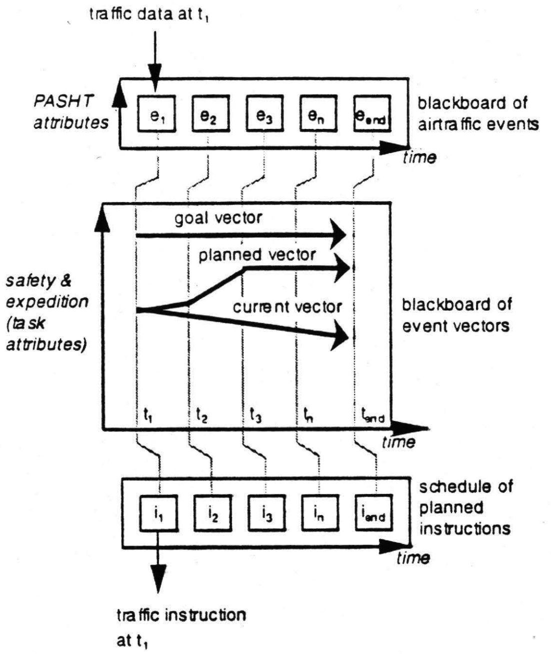
Model of the ATM worksystem

A model of the worksystem which performs the Air Traffic Management task can be generated directly from the domain model. The representations and processes minimally required by the worksystem can be derived from the constructs which make up the domain model. In this way, ecological relations bind the worksystem model to the domain.

Structures of the ATM worksystem

The structures of the ATM worksystem consist, at base, of representations and processes. The representations constructed and maintained by the ATM worksystem are shown schematically in Figure 2, contained within a blackboard (Hayes-Roth and Hayes-Roth, 1979) of airtraffic events, a blackboard of event vectors, and a schedule of planned interventions.

Figure 2. Schematic view of representations maintained by the ATM worksystem



The blackboard of airtraffic events contains a representation of the *current airtraffic event* (e_1)constructed from sensed traffic data. The blackboard has two dimensions, a real time dimension and a dimension of hypotheses about the PASHT attribute states of individual aircraft. Knowledge sources associated with this blackboard support the construction of hypotheses about the attributes of airtraffic events. For example, knowledge sources concerning the topology of the sector airways support the construction of hypotheses about heading attributes. As the ATM worksystem monitors flights through the sector, it maintains a representation of a succession of discrete airtraffic events.

A blackboard of event vectors contains separate representations of a current event vector, a goal event vector, and a planned vector. The *current event vector* expresses the actual values of task attributes deriving from the current airtraffic event, and the projected values of those task attributes at future events. A representation of the *goal event vector* expresses the goal values of task attributes for the current and projected airtraffic events. A representation of a *planned event vector* expresses planned values of task attributes for the current and projected airtraffic events. Critically, this vector is distinct from the goal event vector, allowing that the planned state of the traffic will not necessarily coincide with the idealised goal state.

The blackboard of event vectors has two dimensions, a real time dimension and a dimension of hypotheses about the task attributes of event vectors. The hypotheses then concern the attributes of safety and expedition of each vector, where the attribute of expedition subsumes the individual attributes of progress, fuel use, number of manoeuvres and exit height variation. Knowledge sources separately associated with this blackboard support the construction of hypotheses about the attributes of event vectors. For example, knowledge sources about the minimum legal separations of traffic, and about aircraft fuel consumption characteristics, support the construction of hypotheses about safety and fuel use, respectively. Other knowledge sources support the ATM worksystem in reasoning about differences between the current vector and goal vector, and in constructing the planned vector.

Apparent within the blackboard of event vectors are a distinct monitoring horizon and planning horizon. The current event vector extends variably into future events. The temporal limits of the current vector constitute a 'monitoring horizon' of the ATM worksystem: it is the extent to which the worksystem is 'looking ahead' for traffic management problems. Similarly the planned event vector extends variably into the future events. Its temporal limits constitute a 'planning horizon': it is the extent to which the ATM worksystem is 'planning ahead' to solve future traffic management problems. Both monitoring horizon and planning horizon can be expected to be reduced with increasing traffic volumes and complexities.

The planned vector is executed by a set of planned instructions. Planned instructions are generated by reasoning about the set of planned vectors for individual aircraft and the options for possible instructed changes in speed, heading or altitude. This reasoning is again supported by specialised knowledge sources. The worksystem maintains a schedule of planned interventions, shown in Figure 2 as a separate representation: intervention i_1 is shown executed at time t_1.

The complexity of the representations of the ATM worksystem is complemented by the simplicity of its processes. Two kinds of abstract process are specified: generation processes and, evaluation processes and can address the event-level and the vector-level representations. Two kinds of physical process are specified addressed to the event-level representations: monitoring processes and executing processes.

Behaviours of the ATM worksystem

The behaviours of the ATM worksystem are the activation of its structures, both physical and abstract, which occurs when the worksystem is situated in an instance of an ATM domain. Behaviours, whether physical or abstract, are understood as the processing of representations, and so can be defined in the association of processes with representations. Eight kinds of ATM worksystem behaviour can be defined, grouped in three superordinate classes of monitoring, planning and controlling (i.e., executing) behaviours:

(Monitoring behaviours)

- **Generating a current airtraffic event.**
  The ATM worksystem generates a representation of the current airtraffic event. This behaviour is a conjunction of both monitoring and generating processes addressing the monitoring space. The representation which is generated expresses values of the PASHT attributes of the current airtraffic event.
- **Generating a current event vector.**
  The ATM worksystem generates a representation of the current vector by abstraction from the representation of the current airtraffic event. The representation expresses current actual values, and currently projected values of the task attributes of the event profile. In other words, it expresses the actual and projected safety and expedition of the traffic.
- **Generating a goal event vector.**
  The representation of the goal vector is generated directly by a conjunction of monitors and generators. The representation expresses goal values of the task attributes of the event profile.
- **Evaluating a current event vector.**
  The ATM worksystem evaluates the current vector by identifying its variance with the goal vector. This behaviour attaches 'problem flags' to the representation of the current vector.

(Planning behaviours)

- **Generating a planned event vector.**
  If the evaluation of the current vector with the goal vector reports an acceptable conformance of the former, then the current vector is adopted as the planned vector. Otherwise, a planned vector is generated to improve that conformance.
- **Evaluating a planned event vector.**
  With the succession of current vector representations, and their evaluation, the ATM worksystem evaluates the planned vector and a new planned vector is generated.
- **Generating a planned intervention.**
  Given the planned vector, the interventions needed to realise the plan will be generated by the ATM worksystem, and perhaps too, the actions needed to execute those interventions.

(Controlling behaviour)

- **Executing a planned intervention.**
  The ATM worksystem generates the execution of planned interventions, in other words, it decides to act to issue an instruction to the aircraft.

These eight worksystem behaviours can be expressed continuously and concurrently. With the changing state of the domain, not least as a consequence of the worksystem's interventions, each representation will be revised.

Cognitive costs

Cognitive costs can be attributed to the behaviours of the ATM worksystem and denote the cost of performing the air traffic management task. These cognitive costs are a critical component of the performance of the ATM worksystem, and so too of this formulation of the ATM cognitive design problem. Cognitive costs are derived from a model of the eight classes of worksystem behaviour as they are expressed over the period of the air traffic management. The model of worksystem behaviours is established using a post-task elicitation method, as now described.

Following completion of the simulated traffic management task, the controller subject was required to re-construct their behaviour in the task by observing a video recording of traffic movements on the sector during the task. The recording also showed all requests the controller had made to aircraft for height and speed information, and it showed the interventions that were made for each aircraft. A set of unmarked flight strips for the traffic scenario was provided. As the video record of the task was replayed, the controller was required to manipulate the flight strips in the way they would have done during the task. For example, as each aircraft entered the sector they were required to move the appropriate strip to the live position. As the aircraft progressed through the sector, its sequence of strips would be 'made live' and then discarded. The controller annotated the flight strips with information obtained from each aircraft request made during the task, and with each intervention made. The controller was required to view the videotape as a sequence of five minute periods. They were able to halt the tape at any point, for example, in order to update the flight strips. However, no part of the videotape could be replayed.

At the end of each five minute period, the controller was required to complete a 'plan elicitation' sheet. The plan elicitation sheet required the controller to state for each aircraft, the interventions they were planning to make. The specific planned intervention was to be stated (height or speed change) as well as the location of the aircraft when the intervention would be made. The controller was asked to identify aircraft for which, at that time, no interventions were planned, whether because consideration had not then been given to that aircraft, or a decision had been made that no further interventions would be needed. When the sheet was completed it was set to one side and the controller then viewed the next five minute period of the videotape, after which they completed a new plan elicitation sheet. In this way, for each aircraft at the end of each five minute interval, all planned interventions were described.

This elicited protocol of sampled planned interventions was then compared with the interventions originally made, as recorded by the traffic model. The comparison indicated a number of executed interventions whose plan had not been reported in the corresponding previous sampling interval of the post-task elicitation. These additional interventions were taken to indicate planning behaviours wherein a planned intervention had been generated and executed between elicitation points. Hence, the record of executed interventions was used to augment and further complete the record of planned interventions obtained from the post-task elicitation. The result of this analysis was a data set describing the sequence of planned interventions for each aircraft over the period of the traffic management task.

The analysis was continued by abstracting the classes of planned interventions for each aircraft over the scenario, divided again into a succession of five minute intervals. Four different kinds of planned intervention were identified:

(i) interventions planned at the beginning of an interval and not executed within the interval.

(ii) planned interventions which were a revision of earlier plans, but which also were not executed within the five minute interval.

(iii) planned interventions which were also executed within the same five minute interval, plans executed exactly, and plans revised when executed.

(iv) plans for interventions made during the five minute interval, but where those plans were not described at all at the beginning of the interval.

Each of these intervention plans was identified by its instruction type, that is, whether it was a planned change in height or speed.

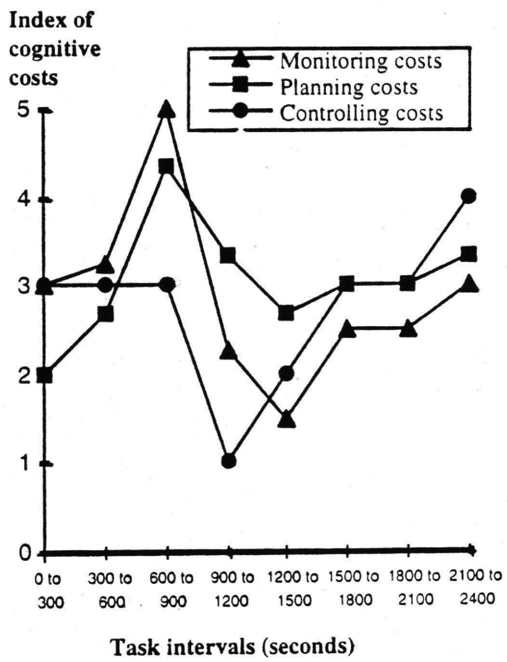
Representations of airtraffic events, planned event vectors, current vectors and goal vectors are implicit in the analysis of planned interventions. These representations were inferred from the analysis of planned interventions by applying a set of eight rules (Dowell, submitted for publication) deriving from the ATM worksystem model, of which the following are two examples:

> 1) the behaviour of generating a representation of the current airtraffic event was associated with any planned intervention for a given aircraft within a given interval, whether reported or inferred, except where those planned interventions were (a) reported rather than inferred, and (b) a reiteration of a previous reporting of a planned intervention, and (c) not executed within the interval.
>
> ... 3) the behaviour of generating a goal event vector was only associated with the first planned intervention for each aircraft.

The result of this analysis is a model of the eight cognitive behaviours of the ATM worksystem expressed over the period of the task. Cognitive costs can be derived from this model by applying the following simplifying assumptions. First, costs are atomised, wherein a cost is separately associated with each instance of expressed behaviour. Second, a common cost 'unit' is attributed to each such instance.

An assessment of the cognitive costs is given in Figure 3, relating to the same controller as earlier used to illustrate the assessment of air traffic management quality. This assessment is of all classes of cost over each sampling interval (300 seconds) of the task. For simplicity, the assessment is presented as the costs of the superordinate classes of behaviour of monitoring, planning and controlling over each interval. The assessment is produced directly from the number of expressed instances of each class of worksystem behaviour.

Figure 3. Continuous assessment of cognitive behavioural costs.



The assessment suggests that costs rose from the first five minute interval of the task to reach a maximum in the third interval. Because all the aircraft had arrived on the sector by the third interval in the task, the increase in cognitive behavioural costs might be interpreted as the effect of traffic density increases. However, since costs then fall to a minimum in the fifth interval, this interpretation is implausible.

Rather, the effect is due to an increase then decrease in monitoring and planning costs as the controller monitored the entry of each aircraft and generated a plan. Although the plan might later be modified, planning behaviours would predominate in the first part of the task. The plan would later be executed by the worksystem's controlling behaviours, and indeed, Figure 4 indicates that the cognitive costs of controlling behaviours predominated over both monitoring and planning costs in the final interval of the task.

The simplifying assumptions adopted in this analysis of cognitive costs need to be independently validated before the technique could be exploited more generally. As an assessment of cognitive costs based on a model of cognitive behaviour, the analysis contrasts with current methods for assessment of mental workload applied to the ATM task, methods which include concurrent self-assessment by controllers on a four point scale, and other assessments based on observations of the number and state of flight strips in use on the sector suite. Within the primary aim of this paper, the analysis exemplifies the incorporation of cognitive costs within the formulation of the cognitive design problem of ATM.

SOME OBSERVATIONS ON THE ECOLOGICAL APPROACH

The model of the ATM worksystem presented here was formulated on the basis of its ecological relationships with the model of the ATM task domain. Corresponding with the claims for ecological models, the ATM worksystem model achieves a completeness and coherence at the level of the whole task, as illustrated by its quantification of cognitive costs for the task. At the same time it is able to characterise individual behaviours, for example, the Sperandio effect, visible in the assessment of air traffic management quality (Figure 1) can be identified with characteristic changes in worksystem behaviour when cognitive costs increase. Specifically, characteristic changes would be expected to be found in the generating and evaluating of planned vectors with regard to safety and expedition.

To revisit the original distinction between the three approaches to modelling cognitive worksystems, it may be seen that the ecological and architecture driven approaches are perhaps less mutually exclusive than Payne (1991) indicated. The organisation of the ATM worksystem model (as opposed to its content), was not determined entirely by the structure of the domain model. Rather, the model drew critical structural constructs from the blackboard architecture. However the use of that architecture was within the requirements imposed by the ecological modelling approach. The relative contributions of domain model and architecture to the construction of the worksystem model contrasts with the model proposed by Timmer and Long (1998).

More generally, this model of the ATM task instantiates a conception of cognitive design problems (Dowell and Long, 1998). The conception proposes generic concepts of domains and worksystems necessary for formulating cognitive design problems. For example, the ATM domain model instantiates the concepts of objects, attributes, goals and task quality. Similarly, the worksystem model instantiates the concepts of behaviours, structures and costs. The conception operates then, as a high level framework for the modelling of the ATM task, to render the models in a form which can express the cognitive design problem of designing a worksystem to perform the air traffic management task effectively. Since the purpose of modelling the ATM task is to solve this design problem, the conception is an essential pre-requisite for construction of the models.

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Evaluation of a Virtual Environments-Based Training Tool through Trainer-Trainees Interaction Analysis

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ABSTRACT

This paper presents the evaluation of a virtual environments based visualisation system, a system dedicated to the training of nuclear power plants maintenance agents. The evaluation consists in an analysis of trainer-trainees interaction. The design objective was not to optimise information presentation but to facilitate interaction thanks to proposed information in order to support the teacher's work. Courses with the visualisation system or with traditional overhead transparencies are analysed from the trainer's point of view. Initial results support our hypothesis of a trainer's activity adjustment according to its interaction with the trainees, in opposition to a planned activity. Deeper analysis relying on communication theories shows the impact of virtual environments-based visualisation in comparison with OHP-based teaching.

Keywords

Evaluation, training, communications, human interactions, man-machine interaction, virtual environments, autonomy.

INTRODUCTION

As new three-dimensional visualisation media (virtual environments (VEs), virtual reality (VR), World Wide Web) expand, it seems possible to present information in a way that other technologies could not (movement, 3D, sounds...). Virtual environments appear as a way to enhance understanding, training, decision making of people who visualise. It may also facilitate the trainer's work. The advanced technical quality of such presented information is certain.

However the design and the evaluation of those tools raise many issues, i.e. :

- when is the use of this kind of visualisation relevant ?
- which information is it relevant to present ?
- what are the advantages and drawbacks of those tools in comparison with others ? (better understanding, better explanation, work facilitation...)
- how to evaluate those advantages and drawbacks ?

Our goal is to evaluate virtual environments' advantages and drawbacks for training from a user-centred point of view. This evaluation relies on trainer-trainees interactions analysis.

DESIGNING A VISUALISATION SYSTEM

Facilitating a mental representation or a working image

Facilitating process understanding or training through simulation is a major theme of ergonomics and especially cognitive ergonomics. The studies mostly based on cognitive psychology deal with this issue by trying to make the simulation fit the operator's mental representation.

The theoretical framework is that knowledge is an information processing : external information is internally processed and computation relies on symbolic representation. The operator is supposed to develop a mental model or a representation of the situation or of the process depending on the information presentation. This situation is externally defined in the pre-existing world. The mental representation includes plans to select information and rules to control the action (Richard, 1990). A good mental model is a consequence or a cause of understanding.

This theoretical framework gave rise to experimental studies comparing different kinds of information presentation (text, text with images, diagrams...).

More ergonomics-based researches try to consider the real activity of the operators in opposition with artificial situations. As De Montmollin argues (1991), *" operators working in natural life environments have to be distinguished from anonymous and universal human beings "*. Such studies deal with real work conditions and emphasise the operators' goals and actions in those situations. Mental representations are goal-oriented and allow the activity by planning and guiding action, thanks to a previous mental simulation of this action. Representations are not results of contemplative activities but are dependent on the action's aim. Representations are built thanks to interactions between the operator's actions and the environment. The external world conceptualisation relies on the relevant aspects of the operator's work. That's how representations become laconic and distorted (Ochanine, 1966).

From this point of view, the design of an information presentation system does not consist in adapting the presented information to a universal mental representation wholly corresponding to the real. It consists in systematising and adapting the information to the working image of the operators. The hypothesis is the similarity between external and internal representation makes the operator's work easier. Information must be relevant to goals and not exhaustive. It depends on the work and the operators' characteristics.

Knowledge acquisition supposes the addition of information in a pre-existing structure. The training system has to influence already existing strategies and task analysis in order to build new task related rules (Waern, 1990). Also, the aim of a training is to modify the trainees' mental representations thanks to the external presentation or to provide some new ones.

Facilitating the autonomy of the user

If the computationalist approach presented above gradually took account of the activity, this activity relied on mental models, plans and goals. According to this theoretical frame, our cognition is based on a representation of the characteristics of a predefined world. The presented information is an input for the cognitive processes.

The constructivist paradigm (Piaget, 1971) or the autonomy paradigm (Varela, 1980) deny any optimistic world representation supposed to fit to the human cognitive world. Knowledge is built through a perception-action cycle. There is no pre-existing mental representation or information amassing. Action interferes with a constantly elaborating understanding of the world. Knowledge is based neither in subjects nor in objects but in the interactions between them. Those interactions are caused as much by external stimulations as by the spontaneous actions of the subject (Piaget, 1971). The accent is on the interaction process not on the information processing. In this interaction process, the analysis is centred on the human acting in situation. The situated action theory (Suchman, 1987) emphasises that cognition is situated in interactions. The meaning of a situation is defined by the subjects in interaction. As Varela (1996) adds, the links between human and environment are situation, history, attitudes dependent. Information is no more an input but a disturbance for an autonomous organism and emerges from cognition. Knowledge and the one who knows are conversely determined.

Those theoretical considerations have at least three important methodological consequences :

1. action can't be studied in artificial situations,
2. action must be analysed from the actor's point of view in order to understand his different and varying interpretations in the dynamic process of interaction,
3. language is an important mediuk of interactions.

In a collaborative task as a training course with a trainer and a group of trainees, autonomy means the meaning of information comes from interactions between subjects. There is not one way to train or to learn from information. The course is built through interactions. Each act of a subject is a disruptive factor that forces eventually the other to adapt and modify its work. According to such an approach the design of a visualisation system aims at supporting an interaction between viewers and image or between viewers that allows them to elaborate their own understanding of the environment. The information presentation system has to promote interactive actions. Communications between subjects are important traces of this interaction.

EVALUATING A NEW VISUALISATION MEDIA FOR TRAINING

New technologies may enhance the learning experience in ways that other technologies cannot (better information presentation, real time interactivity, " learning by doing "). So, tools like virtual reality or www are often considered as a way of satisfying practice.

An evaluation of the benefits of the new tool

However, the benefits of the use of a specific medium to deliver instruction has to be evaluated in order to measure the advantages, drawbacks, cost/benefits ratio of this medium, particularly in comparison with other media.

This kind of evaluation is very difficult because as Clark (1983) suggests " *when examining the effects of different media, only the media being compared can be different. All other aspects of the treatments, including the subject matter content and method of instruction must be identical* ". Of course, those conditions are difficult to obtain. Ultimately then, the question is more to evaluate the respective benefits of each media according to the task.

Knowledge evaluation

A new training tool evaluation is supposed to measure the trainees' knowledge increase. It requires a measure scale. It requires also to be sure this increase is due to the medium. Although some methods like pre- and post-tests allow a knowledge evaluation, those tests are not always possible and do not give information about the acquisition of knowledge. They say nothing about which information was important. We need a method that appreciates the process of acquisition and the relations between that and the presented information.

Interaction as learning medium

Seifert and Hutchins (1991) have already reported data supporting the hypothesis of a positive effect of co-operative work on learning. First studies from Mugny and Doise (1978) on socio-cognitive conflict had already discovered the importance of interactions and social confrontations on learning. More recent studies (Bagnara, Marchigiani & Parlangeli, 1997) show that the collaborative learning is as important as the learning medium and changes the effects and the use of this medium.

VIRTUAL ENVIRONMENTS FOR TRAINING

Since Electricité de France needed new tools in order to train the maintenance agents of nuclear power plants, we designed a virtual environments (VEs) based system to teach them technical notions and a failure diagnosis method (Fréjus, 1997). VEs were chosen because they allow more information to be displayed in comparison with traditional instructional tools (like OHPs). The simulation showed a functioning nuclear power plant tap and its environment. The VR system had four characteristics : 3D simulation of the running of taps, real time interaction, integration of the real power plants' work constraints, use in a group. We substituted some parts of an existing training course with this simulation. Images were projected on a screen, the trainer handled the joystick (3D mouse) according to his objectives or the requests of the trainees. VR was mostly used not as an immersion tool but as a visualisation tool and as a trainer's work support. The trainees were approximately ten.

The objectives of the substitution of VR for OHPs were to test

- the possibility of inserting such a simulation in an existing course,
- the possibility for a trainer to teach with this kind of tool,
- the value of virtual environments as a help for the teacher in comparison with other educational media.

The course was an already existing course with the usual trainers and with trainees from nuclear power plants, not an experimental session.

We filmed three courses with VEs and two traditional courses with OHPs in order to achieve the comparison.

EVALUATING THE BENEFITS OF VEs-BASED VISUALISATION ON LEARNING

Hypotheses

Research on learning medium use and on autonomy both suggest that collaborative work and human interactions have to be taken into account in media evaluation as an important factor of the effectiveness of the medium.

Moreover, we assume that those interactions between trainees and especially between trainer and trainees during which visual information is presented are possible criteria for training medium evaluation.

The visualisation medium is designed in order to help the trainer's work. This trainer conducts his course according to his objectives, his experience and the trainees' feedback. To teach means to explain and eventually to show images facilitating understanding. We hypothesise that

1) the trainer's work is not goal-oriented and planned but situated, depending on the trainees' activity and realised through a dynamic interaction process.

2) the trainer's work adjustment depends on his own trainees' evaluation and gives information about their knowledge acquisition from his point of view.

3) the visualisation tool benefits are assessed by their role in the trainer / trainees interactions and therefore by the trainer's use of this tool.

Definition of an analysis methodology

In order to test our hypotheses, we needed to analyse the filmed courses : videos showing the trainees interacting together and with the teacher provide verbal data ; the trainer also interacts with the visualisation tool which provides behavioural data.

Data analysis should allow us to answer to three questions in order to test our hypotheses :

- how does the trainer adjust his work according to the trainees' work ?
- How does the visualisation system filter into this dynamic process ?
- What are the contribution of the different visualisation tools ?

Since we have to analyse the interactions between the trainer and the trainees and since those interactions are mostly based in this case on verbal communications, we must consider those communications and analyse them. Language and communication theories should also provide some methodological solutions.

The speech acts theory (Austin, 1962 ; Searle, 1969) considers speaking is acting ("*people act through language*", Winograd, 1988). Speaking contributes to modifying reality. This theory is based on plan recognition, doesn't consider interaction but only the speaker and isolates language from the rest of the situation. However, in man-machine interaction design or evaluation, this theory allows us to analyse language as well as behavioural data at the same level only as actions.

Roulet's architecture theory (1991) considers conversation is highly hierarchically-organised with units of different ranks : interaction, sequence, unit. Roulet adds conversation ends with a final agreement between speakers indicating they have the same understanding of the situation.

Ethnographic theories aim to discover the sequential organisation of speech (Sacks, Schegloff & Jefferson, 1974). They also emphasise words as means of action and the speech context importance. Context means the context for the speaker, from his point of view. His actions (verbal or not) have to be understood from his viewpoint of: his objectives, his history, his interpretation of previous acts. These theories, being based on autonomy or interaction, analyse the subjects' reciprocal actions in verbal and non verbal interactions. Speech is built by speakers. Each unit (i.e. act) in a conversation has to be understood in comparison with previous and following units and from the speakers' points of view.

Interlocutionary logic (Grusenmeyer, 1996) is also concerned with a constructivist view of verbal exchanges. The meaning of an utterance comes from the following utterance, i.e. the following act. This methodology of analysis (progressive and recursive) allows us to describe the construction of an interaction, interpreting each step according to the previous one. This description shows the dynamic process of interaction, speakers cognition and interpretations and understandings evolution.

According to those different theories, we decided in order to analyse our data to consider all verbal or behavioural data or even silence as an act each time this fact has a different meaning for the trainer. So, this analysis is not rules-based but is ocused on the trainer's activity: we separate interaction units according to the meaning of each action for the trainer, from his privileged point of view, because the trainer is the course's manager and the VR system user. So, contrary to interlocutionary logic, the analysis of the process of interaction is not based on the succession of utterances but on the succession of units of sense.

In order to extract the structure of each course and to analyse precisely the cognition evolution of the trainer, units having the same meaning for the teacher were pooled in the same sequence. Many sequences on the same subject give a macro sequence. Each unit represents each different objective or interpretation of an act (of the trainer or of a trainee) for the trainer. According to interlocutionary logic, the following unit allows the interpretation and validation of the meaning ascribed to the previous unit. Units, sequences and macro sequences were nominated for the trainer utterances with verbs, as task objective. Trainees' acts are coded from the trainer's point of view.

Example of interaction

(Context : trainees have had difficulties in naming which kind of tap is presented but agreed with the trainer on "gate-tap ")

Trainer:	So, this gate-tap, if we wanted to see how its lower part works (// : end of unit)
	So here we can open it, we will make an opening (starts " gate opening " simulation)//
	(the simulated tap is opening) Here is the tap opening (17 seconds) (centres the view on the lower part)//
	(sound for the end of the opening) Now that our tape is opened, what could we say ? As a gate-tap, which kind of tap is it ?//

Trainees : (together)	parallel seats
Trainer :	parallel seats//
Trainees :	free distension
Trainer :	free distension
Trainee 1 :	free distension//
Trainer :	parallel seats free distension//

Example of analysis :

Unit 1 :	Directing towards the lower part
Unit 2 :	Showing the opening tap by beginning the simulation of opening

Unit 3 : Showing the lower part opening
Unit 4 : Questioning about the kind of tap
Unit 5 : Answer a parallel seats : To confirm
Unit 6 : Complete with free distension : to confirm ; one repeat free distension
Unit 7 : Summing up the answers

Those 7 units constitute the sequence : " having trainees categorise the lower part of the tap " in the macro-sequence " having trainees define the equipment they will work on ".

This kind of analysis allows us to define

- the structure of the course thanks to sequences and macro-sequences : theme, organisation, order...
- the dynamic organisation : role of the trainees' feedback in the course evolution, resort to the visualisation tool, trainees understanding evolution for the trainer, trainer's reasoning...

RESULTS

Global analysis

Our global analysis of the five courses shows how the trainer adjusts his explanation to the trainees : the same topics are presented differently according to the trainees' feedbacks. When topics are the same, their order of appearance is different depending on trainees' knowledge and questions. The trainer does not plan his discourse to achieve pre-established goals but adjusts each explanation, question or advice to the trainee speech.

Three ways to carry on its course appear from the dynamic analysis :

- The trainer explains something, usually when they can't answer,
- He has trainee explain something : it's the trainer's favourite way to carry on its course,
- He replies to questions or failures to understand.

In line with Roulet, the change of one theme to another depends on the trainees' agreement on previous explanations. This agreement is voiced by some trainees or inferred by the trainer.

OHP-based courses analysis

The analysis of the two courses with OHPs shows the same global structure as the courses with VR. The use of OHPs involves many difficulties and limits : finding the appropriate transparency, showing it the right way, not having a transparency prepared in answer to a question...

OHPs are used in two main ways :

- to show what the trainer is talking about : it aims to localise, to know what we are talking about, to describe the relations between the tap's components
- to have the trainees name the pointed out parts.

OHPs are not an aid for explanation but for illustration. The trainer still has to gesture to support his explanation.

VEs based courses analysis

We noticed some difficulties in the use of VR (lack of knowledge of the system possibilities, 3D mouse use...). However, the system trial has been very successful, even without a lot of practice for the trainer (less than half an hour).

Depending on the kind of question, misunderstanding or on his own trainee knowledge evaluation, the trainer has the possibility to help students with images. VR as an explanation support for a trainer allows many uses :

- Ensuring the transition from a theme to another
- Resolving a lack of understanding or a contention
- Providing clues to answer (picture and sound)
- Developing or confirming a trainee's answer
- Illustrating from different angles
- Complementing the discourse
- Localising a component and its connections with other components
- Confirming what has been said
- Commenting rather than explaining.

In fact, VEs seem particularly relevant for complex explanations, movement and kinematics under-standing and to elicit their own knowledge. VEs provide a part of the explanation and not only illustration. When no simulation was able to answer, the trainer used to explain in a usual way like with OHPs. We noticed a change in the way of explaining ; the trainees were more involved and interacted more with the trainer when a simulation was presented in the course of an explanation.

Individual differences

Two trainers used the VEs based system : we noticed a different use of the support system according to how experienced the trainer was : VR acts as a substitute for explanations for the less experienced ; the structure of his course relies on the structure of the visualisation tool.

CONCLUSION

Our goal was to clarify how a virtual environments-based visualisation system helps the work of a trainer interacting with a group of trainees in order to teach them technical notions. Our experiment showed that the use of VEs did not disturb the trainer's course compared with the traditional course with OHPs. VEs are able to demonstrate topics that are difficult to explain because the visualisation ensures a part of the discourse. The use of VR is much richer than OHPs' possibilities. The choice between those tools for training must rely on the trainer's needs and objectives depending on whether he needed a visualisation tool to show and localise information or whether notions are too difficult to explain and need special help in order for the trainees to really understand and the trainer to easily explain some technical notions.

Moreover, our method permits us to analyse interactions in a group, to elaborate a model for computer based visualisation systems design and to describe the evolution of trainees understanding.

In accordance with our hypotheses, we noticed the trainer's explanation was co-built with the trainees. There is no optimistic representation but an adaptation to the trainees' needs and understanding. Cognitive processes as knowledge acquisition or explanation can be described through collective work analysis, indicating we should not consider co-operative work or teaching as a goal/subgoals oriented task but as an adjustment to disruptive factors (someone else's activity or visual presentation). In Varela's view, internal mental representation or universal representation of the world does not exist. We are interested in this adjustment phenomenon (between autonomous systems). This kind of approach allows us to design training tools that further people's interactions and confrontations instead of stimulating people with external input. General recommendations suppose a rich simulation in order to face the unforeseeable requests and difficulties (many possible views, real time interaction) and a strict architecture in order for the trainer to be able to build his discourse on the simulation structure. Tools' impacts are evaluated in the dynamic process of adjustment between operators. Of course, this approach applies to human computer interaction as well as to human interactions.

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Discriminating Task Solving Strategies Using Statistical and Analytical Methods

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ABSTRACT

We have recorded the behaviour of several users solving the same task with an interactive database program. Since the number of users exceeds that of strategies, multiple users will have a strategy in common. Our aim is to find groups of users sharing the same strategy. Following each of three methods (correlation, intersection and exclusion) we define a comparative metric among task solving behaviour. For multiple users, we represent these measures by a matrix system, to find groups of users with common strategies. Multidimensional scaling or analytic interpretation indicates distinct user groups.

Keywords

automatic plan recognition, task solving strategies, user behaviour

INTRODUCTION

The aim of this paper is to develop automatic methods finding task solving strategies. Such knowledge is of interest to understand how users behave in a newly designed system, and to thereby give them better support. Also, it may also help understanding how expert users behave in highly complex systems.

Under certain conditions, strategies may also be obtained by protocol analysis (Ericsson and Simon, 1984). Protocol analysis implies manual inspection of video and verbal utterances in addition to log files. With simple tasks, this work can be overcome. For more complex tasks, protocol analysis has proved cumbersome. Semi-automatic generation of process models was studied by Ritter and Larkin (1994). Guided by their work, further principles for automatic recognition of user strategies and plans will be suggested.

In general, a lot of task solving behaviour that is not strictly *task related* can be observed. It is hardly possible to single out the successful *strategy* from the *remaining behaviour*. One approach may be to study many users solving the same task. Since they all solve the same problem, it is likely that their common behaviour is what was required to solve the task.

A *strategy* is defined to be one (of many), possibly error free, successful task solving behavioural sequences for the current system and task. As soon as a complete strategy is accomplished, task solving is over. If users follow different strategies, a group of users may have one strategy in common, an other group a second one.

The *remaining behaviour* contains much information of how the successful strategy is developed. Unsuccessful trials, exploring the capabilities of the applied tools, repetitions and retries are components of a learning process, which may give insights to the cognitive structure of the knowledge about the computer system and the task.

We will investigate measures which relate task solving behaviour among one another and their suitability for grouping users with a common strategy.

In this paper the aim is to develop automatic methods purely based on observable task solving behaviour, applicable with simple as well as with complex tasks. Protocol analysis, human perception and verbalisation will only be used to validate the elaborated, automatic methods.

TASK DOMAIN AND STRATEGIES

An empirical investigation was carried out by Rauterberg (1992) to compare different types of user interfaces. Users had to solve different benchmark tasks with a character-based user interface (CUI) and a desktop user interface (graphical user interface, GUI) of a relational data base program. User behaviour was recorded with log files. In the present paper we use log files of 6 novice {N1,...,N6} and 6 expert {E1,...,E6} users solving the first task on the CUI system.

The task was to find out how many data records there are in a database consisting of files A, B and C. After the required results were found, task solving activity was finished. The goal was to operate the system, so the number of records for each of the files was displayed on the screen and could be read. Three basically different strategies could be used to reach this goal:

Strategy 1 (S1)

From the main menu the user goes to the 'Info' menu. There she or he selects the function 'Datei' by pressing key [d], which displays the number of records and other general information of the 3 database files A, B and C. The total number of lines that are output exceeds the size of the screen, so the first line indicating the number of records of file A is scrolled up and cannot be read. Therefore the user must halt the display by pressing the blank key, read the number of records of file A and continue the display process by pressing any key. Afterwards the requested data for file B and C can be read from the screen. This strategy was used by users N1, N4, N5, N6, E4 and E6.

Strategy 2 (S2)

From the main menu the user goes to the menu 'Liste' to generate a list. Then one of the database files A, B or C is selected. With the function 'Definition' the user defines which data fields shall be listed. After leaving the definition mode the function 'Erstellen' generates the list and displays it to the screen. The program automatically adds the number of records to the end of the list. The user reads the requested data and repeats the procedure with the other database files. This strategy was used by users N2, N3, E1, E2, E5.

Strategy 3 (S3)

From the main menu the user goes to the menu 'Daten' and selects the function 'Ausgabe' by pressing key [a], which is used to find specific data records. The user then enters a question-mark as search criteria, which is used as wild-card character. Pressing the enter key starts the search. As a result the program displays the first record which matches the search criteria and indicates at the bottom line the total number of matching records. Since all records match the wild-card criteria, this number equals the total number of records of file A. The user selects the next database file and repeats the procedure with files B and C. Only user E3 used this strategy.

Remaining Behaviour

All users in the experiment succeeded in solving the task. The effort measured by the number of keystrokes varied among the users, even if they applied the same strategy (Table 1). This indicates that the amount of their remaining behaviour varied among users, since the number of keystrokes is assumed to be constant for each strategy.

Table 1: Bandwidth of the number of keystrokes related to the strategies

Strategy	*User*	*# Keystrokes* *min.*	*max.*
S1	N1, N4, N5, N6, E4, E6	10	71
S2	N2, N3, E1, E2, E5	33	167
S3	E3	73	73

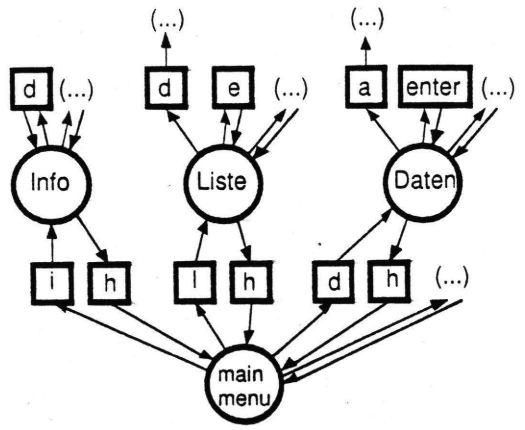
The remaining behaviour can be described as follows:

- *Correction of mistakes.*
- *Retries after unsuccessful trials with or without any changes of the action sequence.*
- *Repetitions.*
- *Exploratory behaviour to find some hint or trying functions which seem to be promising.*
- *Orientation, e.g. determining which mode is active or how to get back to the main menu.*
- *Attempts to apply other strategies, which were abandoned later on.*

DESCRIPTION OF TASK SOLVING BEHAVIOUR

The relational database program can be modelled as a system with 154 dialogue states and transitions which symbolise the possible succession of two states and the action associated with it. Figure 1 shows a fraction of the state transition model of the program. Circles represent dialogue states, squares represent transitions. The letter shown inside the squares indicates the key the user must press to activate the transition and go from one state to another. The same key might be used in different transitions. Specifying the preceding state and the action (i.e. the key to be pressed) identifies a transition unequivocally.

Figure 1: State transition model



User behaviour is represented as a sequence of transitions between system states. A *state-transition-vector* (STV, Formula 1) summarises a subject's task solving behaviour for one task. Each STV element represents the number of activations of a certain transition the user needed to solve the task.

$$\left\{e_i^p\right\} \qquad (1)$$

$e_i^p \in N_0$ — *STV component*

$p \in \left\{N_1, \ldots, N_6, E_1, \ldots, E_6\right\}$ — *user index*

$i = 1, \ldots, n$ — *transition index*

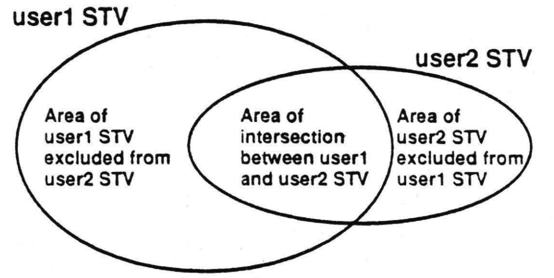
$n = 978$ — *number of transitions*

Since the order of activated transitions is not contained in the STV, the order of user actions is only partly conserved. It is stored implicitly, given by the potential sequences of actions which are possible by the system dialogue structure.

METHODOLOGY

The classical method to compare the task solving behaviour of two users is correlation, which is a measure of proximity. Analytical methods offer an alternative. In Figure 2 each ellipse illustrates the set of transitions activated by a user. The intersection area represents similarity (what do two behavioural sequences have in common), the exclusion areas difference (what two behavioural sequences do not have in common), between two STVs.

Figure 2: Intersection and exclusion between user 1 and user 2.



For each comparison method, we elaborate a metric (Table 2). The metric may be symmetrical or asymmetrical (the metric applied from user 1 to user 2 is or is not the same as the metric applied from user 2 to user 1). Application of the metric between all users results in a matrix. The matrix is then analysed by a grouping algorithm.

Table 2: The three methods, metrics, metric nature and grouping algorithms

Method /metric	*Metric order*	*Metric nature*	*Grouping algorithm*
Correlation	CORR	Statistical	Statistical
Intersection	$M_{p,q}^{IS}$, $M_{p,q}^{BIS}$	Analytical	Statistical
Exclusion	$M_{p,q}^{EX}$	Analytical	Analytical

CORR means Pearson correlation; the other metrics are defined by Formulas 2, 3 and 4.

CORRELATION METHOD

Correlation yields proximity of user behaviour. These values are analysed by multidimensional scaling (MDS, Systat, 1989) to indicate groups of users with resembling task solving strategies.

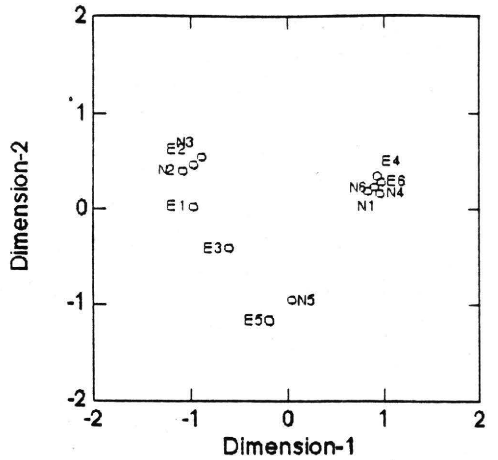
Metric

A Pearson mxm (m=12) correlation matrix relates all STVs with each other and has values between -0.003 (low proximity) and 0.948 (high proximity).

Grouping Algorithm

The correlation matrix interpreted by MDS (dimensions: 2; r-metric: 1; iteration: 50; convergence: 0.005; loss function: Kruskal, regression: monotonic) gives Figure 3, allowing for visual interpretation. The users may be grouped as follows: {N1, N4, N6, E4, E6}, {N2, N3, E1, E2} and {N5, E5}. It is not clear whether E3 should belong to the group {N2, N3, E1, E2} or if it constitutes a separate group. By proportion of variance (RSQ = 0.895), MDS explains some but not all the user data variance.

Figure 3: MDS plot with Pearson correlation matrix gives RSQ = 0.895.



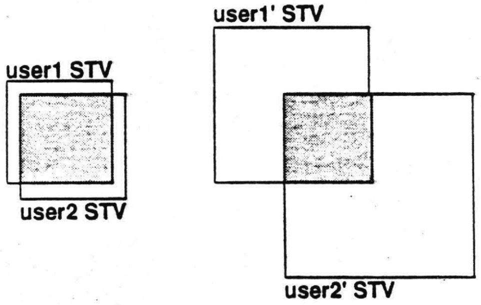
INTERSECTION METHOD

If two users follow the same strategy, the strategy will be within their intersection area which represents similarity.

Metric

Similar behaviour is measured by summing up the smaller STV element values of the two user STVs, thus considering the activation of transitions common to both users.

Figure 4: Userl and user2 STVs represented by rectangles.



In both situations, the intersection is the same, but the similarity between STVs are not. This indicates that a normalisation is required.

Userl and user2 STV can also be seen as sets, represented by *rectangles* (Figure 4). For the intersection area (measured quantity) to be a valid measure of similarity (desired quality), a normalisation is required. It is possible to scale degree of intersection by the larger (max.), the average (mean) or the smaller (min.) sum of the intersection areas. Scaling by the smaller of the areas corresponds to scaling by the maximum possible intersection. Expressed in the state-transition vector space gives the intersection metric of Formula 2.

$$M_{p,q}^{IS} = \frac{\sum_{i=1}^{n} \min(e_i^p, e_i^q)}{\min\left(\sum_{i=1}^{n} e_i^p, \sum_{i=1}^{n} e_i^q\right)} \qquad (2)$$

$p,q \in \{N_1,\dots,N_6,E_1,\dots,E_6\}, p \neq q$ *user indices*

These similarity values lie in the range of 0.078 (low similarity) and 0.929 (high similarity).

Ignoring repetitive behaviour is a means to reduce complexity. Replacing each STV component >1, by 1, results in a *binary* state-transition-vector. An intersection metric based on this vector is given by Formula 3. When comparing user behaviour with this metric, the similarity values lie in the range from 0.182 (low similarity) to 0.882 (high similarity).

$$M_{p,q}^{BIS} = \frac{\sum_{i=1}^{n} \min(e_i^p \cdot e_i^q, 1)}{\min\left(\sum_{i=1}^{n} \min(e_i^p, 1), \sum_{i=1}^{n} \min(e_i^q, 1)\right)} \qquad (3)$$

$p,q \in \{N_1,\dots,N_6,E_1,\dots,E_6\}, p \neq q$ *user indices*

Grouping Algorithm

Interpreting the *normalised intersection matrix* and the *binary normalised intersection matrix* by MDS (dimensions: 2; r-metric: 1; iteration: 50; convergence: 0.005; loss function: Kruskal, regression: monotonic), the users seem to represent three groups, {N2, N3, E1, E2, E5} and {N1, N4, N5, N6, E4, E6} and {E3} (Figure 5 and 6). According to the RSQ = 0.977 / 0.995 we can explain most of the variance within the user data.

Figure 5: MDS with a normalised intersection matrix gives RSQ = 0.977.

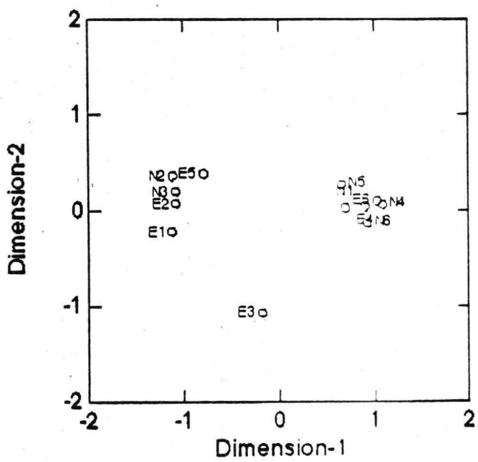
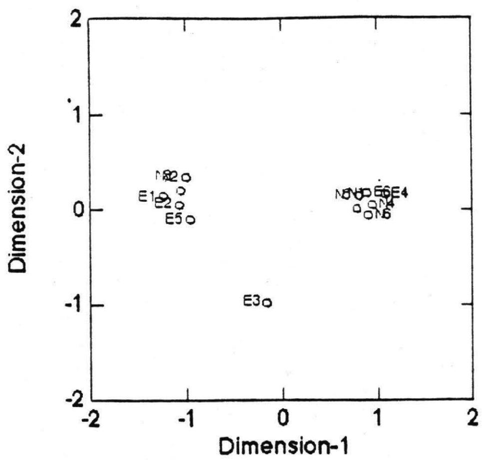


Figure 6: MDS with a binary normalised intersection matrix gives RSQ=0.995.



EXCLUSION METHOD

The exclusion method quantifies differing behaviour. Little difference between user behaviour might indicate that the users apply the same strategy. The difference is measured as the amount of one user's behaviour not shared by the other user. This measure is not symmetric since the excluded behaviour of two users is not identical (see Figure 2). So exclusion gives an asymmetric matrix of distances between users, calling for another grouping algorithm than MDS.

Metric

This method measures the difference between two STVs by estimating how much of one STV (column index in Table 3) is excluded from a second one (row index), giving an mxm (m=12) asymmetric exclusion matrix (Table 3).

$$M_{p,q}^{EX} = \sum_{i=1}^{n} \left| \min\left(e_i^p - e_i^q, 0\right) \right| \quad (4)$$

$$p, q \in \{N_1, \ldots, N_6, E_1, \ldots, E_6\}$$

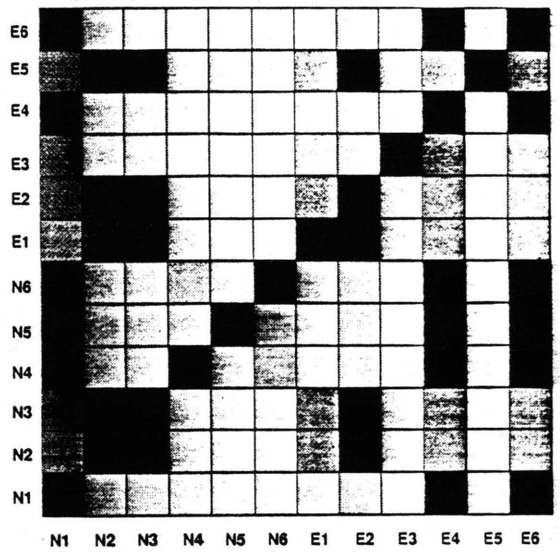
Table 3: Numerical representation of exclusion matrix.

	N1	N2	N3	N4	N5	N6	E1	E2	E3	E4	E5	E6
E6	6	43	47	51	70	50	47	35	73	5	171	0
E5	17	15	14	69	48	67	23	7	64	21	0	24
E4	9	44	47	56	70	55	47	35	73	0	171	8
E3	17	41	41	68	77	62	28	28	0	21	162	24
E2	17	15	16	68	81	67	19	0	66	21	143	24
E1	20	16	19	73	85	72	0	7	54	21	147	24
N6	3	41	44	28	48	0	47	30	63	4	166	2
N5	3	39	42	41	0	33	45	29	63	4	132	7
N4	2	41	42	0	55	27	47	30	68	4	167	2
N3	16	11	0	68	82	69	19	4	67	21	138	24
N2	18	0	15	71	83	70	20	7	71	22	143	24
N1	0	41	43	55	70	55	47	32	70	10	168	10

Grouping Algorithm

The grey-scale representation (Figure 7) is a visualisation of Table 3. Diagonal elements of Table 3 were directly mapped to the darkest grey-tone. Figure 7 shows to what degree a row user STV excludes a column user STV. Darker matrix elements correspond to lower degree of exclusion.

Figure 7: Grey-scale representation of exclusion matrix. Darker elements mean more exclusion of column STV from row STV.



Ignoring diagonal elements, small exclusion values (Table 3) indicate similarity, and we can derive four similarity relations (Table 4). The first three relations are interrelated, giving one group. Relation four gives a second group. One user is not related to any other user representing a third group. So three groups result: {N1, N4, N5, N6, E4, E6}, {N2, N3, E1, E2, E5} and {E3}.

Table 4: We can derive these four similarity relations.

Relation	*User STVs of each relation*
1	N1 is part of N4, N5, N6, E6
2	E4 is part of N4, N5, N6, E6
3	E6 is part of N4, N5, N6, E4
4	E2 is part of N2, N3, E1, E5

DISCUSSION

For method validation, we did a task based protocol analysis (Ericsson and Simon, 1984), grouping the users according to three distinct strategies (see Table 1).

The correlation method does not correspond fully to the protocol analysis, whereas the intersection and the exclusion method give the same grouping result.

The correlation metric differs from the intersection and exclusion metric particularly by the product of transition activations in the numerator of the formula. A high number of activations of the same transition strongly influences the weight of this transition. This is due to the quadratic quality the correlation metric. Users N5 and E5 illustrate this effect. To solve the task, they applied different strategies, but the correlation method puts them near to one another. Looking closer at their behaviour, it could be seen that both first tried to count the number of records manually by stepping through the whole file. This results in a high number of activations of the 'next record' transition, leading to a high correlation coefficient. However, this strategy was abandoned later on because of the large number of records.

The intersection method clearly groups the users according to their strategies. Contrary to the correlation method, remaining behaviour does not seem to have much influence on the grouping.

The exclusion method does not say anything about possible combinations or parts of strategies applied. For such questions, the statistically based methods seem more relevant. This is confirmed by Hanson et. al. (1991), treating class (or: group) assignment with Bayesian methods: "Such classes are also 'fuzzy'; instead of each case being assigned to a class, a case has a probability of being a member of each of the different classes".

CONCLUSION

For the present combination of system, task and user behaviour, it was possible to develop methods grouping users according to their task solving strategy.

FUTURE PERSPECTIVES

Results for one task only were acquired. To make the methods more reliable, it is necessary to evaluate several tasks. For each task the methods will be validated by manual protocol analysis. It is of particular interest to find out if the methods perform with other, more complex tasks.

It is also planned to study learning experiments, in order to recognise the acquisition process of strategies.

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A Method to Describe Human Diagnostic Strategies from a Cognitive Point of View

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ABSTRACT

Some primitive dimensions of the multidimensional space currently used to classify diagnostic strategies are extracted from the literature. A protocol analysis method is proposed to identify them. An application to a troubleshooting task is presented to illustrate the relevance of the method to the design of a computer tool able to cooperate with the human diagnostician during the progress of diagnosis.

Keywords

Diagnostic Strategy, Protocol Analysis, Human-Machine Cooperation

PROBLEM

Human diagnosis has been studied for a long time in ergonomic psychology, especially in troubleshooting tasks, but also in process control, as a way to access to cognitive mechanisms implied in maintaining situation awareness. However the classifications of diagnostic strategies vary from author to author and there is no consensus in this domain, except that there is no unique human diagnostic strategy and that we need some relevant tools to discriminate between many possible strategies.

[Several objectives can motivate the search for a cognitive description of human diagnostic strategies. For example, studies on operator training, comparing expert and novice performance, aim at defining the nature of expertise in diagnosis and at designing appropriate training (e.g., Munley & Patrick, 1997). Another objective may be the design of appropriate computer assistance to human diagnosis (e.g. Konradt, 1995), or better human-machine cooperation in diagnosis (e.g., Roth, Bennett, & Woods, 1988). In any case, identification of possible human strategies is crucial if one wants to avoid adopting a prescriptive approach, more often than not driven by a technical approach to diagnosis, which could be inefficient with human diagnosticians.

Several categories of human diagnostic strategies are available in the cognitive literature. In this paper, we will stress three approaches, since they are relevant to diagnosis work situations: Konradt (1995), Rasmussen (1986), and Reason (1990). Their relevance to the problem will be stressed, but also their drawbacks because each category implies the use of several primitive dimensions to be fully described.

The definition of primitives is required to cover the wide variety of human strategies and to have some chance to support them.

However, if one wants to take advantage of the joint functioning of the human and the artificial diagnosticians, some communication and cooperation should take place during the progress of diagnosis. Thus, the problem becomes: how can we have two very different strategies cooperate? or what kind of difference can we manage?

This paper proposes some primitive dimensions to classify diagnostic strategies and a method to evaluate them, aiming at identifying constraints on the design of computer supports to diagnosis in order to render human-machine cooperation possible during the course of diagnosis. A particular study on troubleshooting is presented to illustrate their relevance in relation to the results from which some recommendations were given to software designers, in terms of human-machine cooperation during diagnosis.

HUMAN-MACHINE COOPERATION

Recently, we have been confronted with this problem in a specific application domain — troubleshooting in a telephone company. The main aim of this study was to implement a protocol analysis method to identify diagnostic strategies used by operators called by clients to inform the company of breakdowns in their telephone lines. Some computer assistance was available — a computer program able to test the telephone line — but the opportunity of designing a more "intelligent" system was examined.

More often than not, technical diagnosis methods bear focus on search algorithms (e.g., Piechowiak & Rodriguez, 1993). Such algorithms navigate a tree of all the possible faults (pre-built hypotheses). They aim at eliminating as many leaves as possible at each step (e.g., split-half algorithm). In the telephone company, a prototypical version of an expert system to support operators had been developed before the beginning of our study. An informal study (questionnaires) done by the company had showed that operators rejected the software, except when the problem was complex. Our hypothesis was that such a rigid dialogue structure was inadequate for three main reasons:

- The logic behind the series of questions could be obscure for the operators, ignoring the rationale of the algorithm (information theory).
- This rigid series could be incompatible with the dialogue with the client.
- The operators could need a support only for certain steps of their reasoning processes and could not easily enter their present situation awareness into the computer.

The present study was done with engineering researchers interested in human-machine cooperation, especially in designing a computer support, at the same time understandable by operators and capable of cooperating with operators' diagnosis strategies. They were willing to open cooperation opportunities between the two joint cognitive systems (Hollnagel & Woods, 1983), not only at the end of the diagnosis process, but during the diagnosis development, at intermediary steps, to make mutual control deeper (one of the key aspects of human-machine cooperation in this context: Hoc, 1998).

In the present situation, for relevant calls, operators are expected to roughly classify the fault in one of three classes, in relation to their action repertory:

- Problem localised outside the client's home (cable or cubicle along a road, electronic automatic exchange, etc.): inform the relevant technician.
- Problem localised at the client's home, but not solvable remotely: arrange an appointment between the client and a technician.
- Problem localised at the client's home and solvable remotely.

This action repertory could appear as very poor, but even so some kind of non-trivial diagnosis activity is required. However, an enrichment of the operator task was also examined to improve information transmission to technicians who intervene at the clients' home.

Software which performs a technical check of the clients' telephone line is already available to operators. However no means are available to identify possible problems inside the houses. Thus the client is a crucial information source to determine this kind of fault.

Operators' activity was recorded during 24 hr distributed along one month. 508 calls were recorded and distributed by Sagar and Petit (1996) into 3 classes: 88 malevolent calls, 165 erroneous calls, and 255 relevant calls. Among the latter 255 calls, 26 calls were selected, eliminating trivial diagnoses (diagnosis done by the client, problem identified by the software on the line, problem concerning the client and not the telephone company).

A GENERAL METHOD

Considering diagnosis as a comprehension activity oriented toward decision-making (Hoc & Amalberti, 1995), the elaboration of our method has mainly been inspired by three theoretical sources:

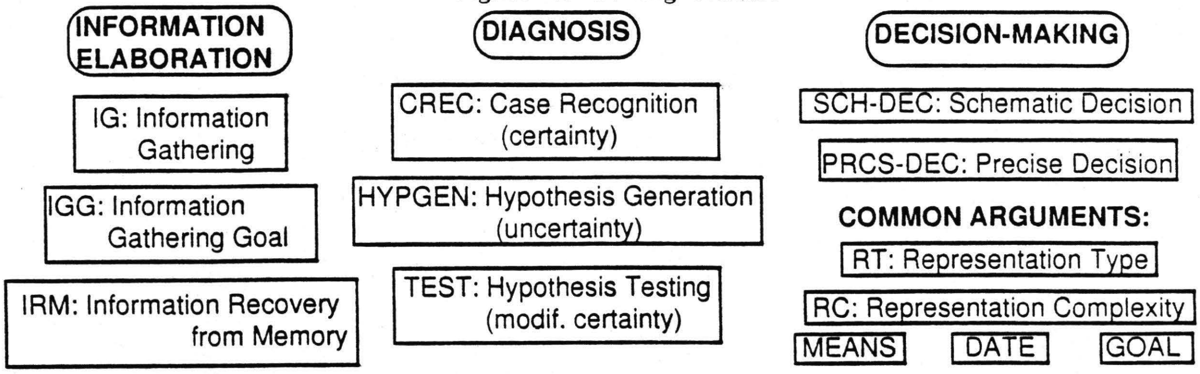
- The well-known approach to diagnostic strategies introduced by Rasmussen (1986, for a quite recent account), contrasting topographic, functional, and symptomatic search. Topographic search is described as guided by the representation of the system components and their relationships (e.g., mass or energy flow). Functional search is more abstract since it bears on knowledge of the system goals and means structure. It can guide a topographic search, helping to focus on the relevant components more rapidly.
- The recent and more extended classification proposed by Konradt (1995) with an approach to computer support for human diagnosticians, using 16 elementary and unstructured dimensions which are partly organised in this paper.
- The cognitive underspecification theory of Reason (1990) stressing two basic mechanisms which can be applied to diagnosis: similarity matching and frequency gambling. It is a schema-based theory of diagnosis stressing the role of overall structures accounting for syndrome processing in diagnosis.

It appeared to us that most of the classifications available in the literature make use of composite classes. For example, to contrast topographic and symptomatic search, Rasmussen actually refers to two different aspects, namely a contrast between representations of a topographic kind and other type of representations, on the one hand, and the use of knowledge on the correct functioning of the device as opposed to knowledge of faults, on the other hand. Symptomatic search can be supported by topographic representations too. Thus we have tried to identify more elementary dimensions, which are also appropriate for generating a larger range of possible strategies and to suggest computer support more precisely.

Protocol encoding was performed, using a general cognitive method introduced by Amalberti & Hoc (in press), already widely used in diverse application domains (blast furnace control, air traffic control, fighter aircraft piloting, and dynamic microworld studies). This method consists in inferring elementary cognitive activities (mostly covert) from the overt behaviour, the context, a general cognitive architecture, and knowledge in the application domain. More often than not, it makes use of thinking aloud (or simultaneous and as spontaneous as possible) verbal protocols (here, the recording of telephone conversations) and self-confrontation (comments made by operators in front of a video-replay of their behaviour with possible questions asked by the observer). The protocol collected during the task execution is decomposed into elementary units, on the basis of the inferred elementary activities, which are coded using a predicate/arguments format, with the help of the MacSHAPA software (Sanderson *et al.*, 1994). Self-confrontation data contribute to guiding the coder's inference process.

Predicates code activities and arguments specify these activities and the representations processed (Figure 1). For example, an information gathering activity is coded by the IG predicate, followed by 10 arguments specifying the information source, the time concerned, the representation type (functional, topographic, etc.), the representation complexity (is it only a simple fact or a meaningful structure?), the object, the variable measured on this object, its value, the level of interpretation of this value (raw or interpreted data), in what condition information is gathered, and with what aim in mind). Each predicate has its specific arguments, but some arguments are common to several predicates. The figure only shows the common arguments implied in the analysis presented in this paper. The predicates are classified into three classes: information gathering and recovery, diagnosis as a certain or uncertain inference, and decision-making.

Figure 1: Coding scheme



An excerpt of a coded protocol is presented in Table 1. The protocol is roughly decomposed into propositions. Each proposition is coded by one or several predicates according to the number of elementary activities inferred from the proposition and the context.

Table 1: Excerpt of a coded protocol

In each cell of the right column, the structure of the predicate is specified in italics before the coding.

Operator: How many apparatuses are connected to this telephone number?	*HYPGEN (Hypothesis number, Time concerned by this hypothesis, Representation type, Representation complexity, Object, Variable, Value, Condition, Goal)* HYPGEN(1, present, topographic, structure, apparatus, number, several, computer check, enrichment)
	IGG (Means, Time concerned, Representation type, Representation complexity, Object, Variable, Value, Condition, Goal) IGG (client, present, topographic, structure, apparatus, number, ?, hypothesis, test)
Client: On this number, there is only this one.	IG (Means, Time concerned, Representation type, Representation complexity, Object, Variable, Value, Level of interpretation of the value, Condition, Goal) IG (client, present, topographic, structure, apparatus, number, one, basic, hypothesis, test)
	TEST (Hypothesis number, Means, Time concerned, Representation type, Representation complexity, Object, Variable, Value, Result, Issue) TEST (1, client, present, topographic, structure, apparatus, number, several, invalidation, rejection)

DIMENSIONS OF DIAGNOSTIC STRATEGIES

The dimensions we introduced to classify diagnostic strategies were organised from three points of view, based on an opposition between the two dual aspects of cognition, namely, representation: what is processed? and processing: how is it processed? (Hoc, 1988).

Dimensions Related to Representation

- type of representation of the device (topographic, functional, etc.): RT argument (representation type);
- type of knowledge of the device (on the correct functioning or the faults): GOAL argument of the IG predicate (reference to faults is identified by a goal of testing or eliminating an hypothesis);

- representation complexity (elementary fact, like symptom, or structure, like syndrome): RC argument (representation complexity);

Dimensions Related to Processing

- type of search heuristics (based on similarity, frequency, typicality, least cost, etc.); this dimension was not evaluated because of our lack of knowledge in the domain;
- complexity of hypothesis processing (scanning, focusing): number of occurrences (if non zero) of the TEST predicate after the occurrence of the IG (information gathering) predicate.

Dimensions Related to Representation and Processing

- type of external support (client, computer, manual, colleague, etc.): MEANS argument of the predicate IG (information gathering);
- diagnosis certainty level (case recognition, hypothesis generation and test): CREC predicate for certain diagnoses and HYPGEN for uncertain ones;
- hypothesis proceduralisation level (pre-built hypothesis or *ad hoc* hypothesis): GOAL argument of the HYPGEN predicate (a pre-built hypothesis is generated with the sole aim of eliminating a branch of a tree);
- temporal span (observation or hypothesis concerning past, present, or future): DATE argument.

RESULTS AND DISCUSSION

Values of predicate arguments were defined to enable us to evaluate each dimension and describe strategies as patterns of such values. The results of this method assessment are threefold.

Completeness of the Dimensions

The dimensions considered were proved to be sufficient to fully describe the inferred strategies, but this do not imply that they are sufficient to described any diagnosis protocol. However the proposed structure can be enriched to cover a large range of strategies.

Completeness of the Cues

We were not able to evaluate one of the dimensions of our strategy classification with this method because of a lack of sufficient cues to infer its values. Identifying the type of search heuristics as a least costly strategy is quite impossible for an observer who does not know the diverse alternatives available to the operators at a specific stage of their search. The self-confrontation appeared not sufficient to access to this kind of information. Thus complementary data should be collected. However, such a classification can be of great help to enrich the protocols in the right direction, for example guiding a questioning of the operator by the observer during the self-confrontation phase.

The operators' strategies

The main results of this study are presented in Table 2, in relation to the dimensions, in terms of percentages of argument value occurrences.

Dimensions related to representation

<u>Representation type</u>

The representations processed by the operators are mostly functional, the rest being topographic. Contrary to well-known results in the troubleshooting domain showing that non experts are likely to use topographic strategies (Rasmussen, 1986), we have identified functional strategies. However, at this level, our result only concerns representation type and not the type of device knowledge (in the Rasmussen's terminology, topographic also refers to the use of knowledge about the correct functioning of the device). Clients and operators in this study are not expert in telecommunication. They have little knowledge in the technical domain, but they can use knowledge on a number of telephone functions. Thus, it is not surprising that they mainly communicate on functions.

<u>Type of device knowledge</u>

The type of device knowledge guiding the strategies deal mostly with the correct functioning as opposed to the knowledge of faults. In relation to this aspect of the topographic strategy defined by Rasmussen *(op. cit.),* our results are coherent with previous studies on non experts. Thus, the distinction between representation type and the kind of device knowledge is important to consider. Clients have no extensive case base on faults, nor do non technician operators. Hence they try to identify the problem by comparing the actual functioning of the telephone to what they know about its normal functioning.

<u>Representation complexity</u>

The complexity of the representations processed is fairly distributed between facts and structures.

Dimension related to processing

<u>Complexity of hypothesis processing</u>

The processing of the hypotheses is also similar to that of a non expert. Scanning is almost the sole strategy observed. Only one hypothesis is tested at the same time. Such a strategy is clearly far from a search algorithm through a tree of possible hypotheses with the aim of elimination as many hypotheses as possible.

Dimensions related to representation and processing

<u>Type of external support</u>

We can see that the client is the main information source. The role of the software (technical check of the line) is very limited and direct perception (e.g., crackle in the line) marginal. This show that clients possibly play a major role in determining the diagnostic strategy.

<u>Diagnosis certainty</u>

The diagnosis certainty is fairly distributed between hypotheses to be tested, thus uncertain, and case recognition with certainty.

Table 2: The main results

DIMENSIONS RELATED TO REPRESENTATION

Representation type: (N=674)	*Functional* 63.0% ± 8.3%	*Topographic* 37.0% ± 8.5%	
Type of device knowledge: (N=322)	*Correct functioning* 77.0% ± 5.7%	*Faults* 23.0% ± 5.15%	
Representation complexity: (N=674)	*Fact* 58.0% ± 7.9%	*Structure* 42.0% ± 7.9%	

DIMENSIONS RELATED TO PROCESSING

Complexity of hypothesis processing: (N=43)	*Scanning* 99% (*)	*Focusing* 1% (*)

DIMENSIONS RELATED TO REPRESENTATION AND PROCESSING

Type of external support: (N=322)	*Client* 80.0% ± 5.5%	*Computer* 15.0% ± 4%	*Direct perception* 4.0% ± 1.7%
Diagnosis certainty level: (N=79)	*Hypothesis generation* 54% ± 11%	*Case recognition* 46% ± 11%	
Hypothesis proceduralisation: level (N=43)	*Ad hoc* 95% (*)	*Pre-built* 5% (*)	
Temporal span: (N=674)	*Present* 85.0% ± 4.4%	*Past* 15.0% ± 4.4%	

X%±Y refers to a confidence interval at level α = .075

(*) *The confidence interval model is invalid.*

Hypothesis proceduralisation

Almost all the hypotheses are situation specific. There is no trace in the protocols of the use of pre-built hypotheses like those used by a search algorithm.

Temporal span

The history of the fault plays a minor role in coming to a decision. Most of information deals with the present status of the device.

In sum, these operators' strategies appeared to bear on functional knowledge of the correct operation of the device. They would be more adequately supported by functional representations than by topographic ones. Scanning *ad hoc* hypotheses was identified, that goes against a diagnosis support adopting a tree-based search algorithm. Assistance in reconstructing the history of the fault seems unnecessary. The role of the client is probably major and what should be supported is not the operator alone, but the operator-client multiagent system. Finally, from these protocols, it is impossible to show any symptomatic search which could be modelled by the schema theory. Hence, Reason's approach which has been proved to be very relevant in diverse diagnosis tasks does not appear of great use in this context.

CONCLUSION

The system designers were primarily interested in whether human-machine cooperation was possible for an operator of this kind and a software application implementing a algorithm following a predefined search tree. Such cooperation appears to be possible, since operators do not appear to use schemas (or syndromes) to guide their strategies. However, the major role of the client in the initial definition of the problem renders such search support somewhat cumbersome. Most of the features of the operators' strategies are probably linked to the action repertory available to them, as frequently shown in the literature (Hoc & Amalberti, 1995). Any improvement of these strategies as regards information collected to be transmitted to the technicians brings into question the present definition of the operators' action repertory and, only after that, the type of knowledge to be acquired.

The main limitation of this study is the difficulty encountered when trying to access to operators' search heuristics (e.g., least cost strategy). Although the operators did not seem to rely on a fault data base elaborated by experience, they are likely to use search heuristics which are not obvious in the protocols. As we have suggested it in this paper, this is one of the possible aims to devote to self-confrontation. This type of information is crucial when designing a support system that can jeopardise efficient and economical heuristics.

Proposing three classes of cognitive dimensions to describe diagnostic strategies, we have been able to discriminate dimensions related to representation — with implications on interface design — and dimensions related to processing — with implications on the design of cooperative computer systems. However, some dimensions concern representation and processing at the same time, which should be considered together during the design process.

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Mental Representation and Imagery in Program Comprehension

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ABSTRACT
This paper studies the role of imagery in program comprehension. With this goal we investigated whether theories of mental models from Psychology of Programming (e.g., Pennington's Two Stages Theory) could be expanded to account for the effect of imagery. Given the basic research in image processing, our hypothesis is that imagery would allow a quicker access to the functional (Data Flow) information of programs. Then, Visual Programming Languages should allow for quicker construction of a mental representation based on Data Flow relationships of a program than procedural languages. To test this hypothesis we ran an experiment where we accessed the mental model of C and spreadsheet programmers in different program comprehension situations. The results showed evidence that the spreadsheet programmers developed Data Flow based mental representations in all situations while C programmers seemed to access to a Control Flow based mental representation first.

Keywords
Imagery, mental model, Visual Programming Language, Spreadsheets, C, program comprehension, Pathfinder.

INTRODUCTION
Program comprehension is a complex cognitive skill which involves the acquisition of a mental representation of program structure and function. Imagery is a cognitive process that can play an important role in how this mental representation is acquired. Our research is aimed at studying this role of imagery in program comprehension by bringing together the data and methodology from Psychology of Programming and image processing research.

Basic research in image processing indicated that pictorial material would give faster access to semantic information than verbal material (Bajo, 1988). Also research on the effect of visual aids in text comprehension (Mayer and Gallini, 1990) and HCI learning (Navarro, Cañas and Bajo, 1996) has shown that visual aids enhance learning only when they could facilitate access to the meaningful information for a given situation. All together, these data support the hypothesis that visual aids could enhance computer use and the acquisition of mental representations because they would improve access to meaningful information.

In the last decade the mental model approach to text understanding (van Dijk & Kintsch, 1983) has been successfully applied in Psychology of Programming to explain the cognitive stages underlying program comprehension (Pennington, 1987; Corritore & Wiedenbeck, 1991; Burkhardt, Détienne, Wiedenbeck, 1997). According to Pennington's Two Stage Theory (1987) programmers go through two phases when they try to understand a program. In the first stage, they develop a knowledge structure representation (program model) based on the Control Flow relationships (i.e control patterns like loops or conditional patterns). In the second stage, under appropriate task conditions, programmers develop a plan knowledge representation (domain model) based on the Data Flow. This representation would contain the main program functions and the key information to understand what the program does. It also includes information about the programming situation.

Several variables from the situation influence how and when programmers go through these stages. Two of these variables are notations' visual characteristics (Scalan, 1989) and programming language (Gilmore and Green, 1988) Visual languages (VPLs) seem to facilitate program comprehension as compared to textual languages. This effect points to the role that imagery could play in program comprehension. However, not much research has been done in this issue that would allow us to expand text comprehension theories to explain how VPL programmers develop their mental representations.

Our hypothesis is that IF the role of imagery is to enhance the access to the meaningful information THEN VPLs should allow quicker access to the Data Flow information of a program than procedural languages. Therefore, visual programmers should more quickly develop a representation based on Data Flow relationships, even when performing a simple comprehension task, in comparison with other non-visual programming languages.

Recent research showed that the type of comprehension task that programmers perform influences the mental representation that they acquired. For example, Détienne (1996) has shown that reading-to-do (e.g. for modification) and reading-to-recall (e.g. for documentation) tasks affect differently the mental model construction. Pennington's theory could explain this effect of type of comprehension task. For performing a relatively easy task, like reading a program, programmers only go through the first stage. However, to modify the program they would go through the second stage, understanding the Data Flow structure.

We hypothesised that textual language programmers would access Data Flow information only when they perform a difficult task. However, visual languages programmers would access this information even when they perform an easy task.

To test this hypothesis we designed an experiment in which C and Spreadsheet programmers are assessed on their mental representations of programs, under different comprehension conditions. We are interested in studying how the visual format of spreadsheets affects mental model construction, both in a simple reading and a modification task. Among the VPLs, we selected spreadsheets for this study for two reasons. First because they are the second most important personal computer applications (Panko, 1988), and second (as we will see in the conclusions) because spreadsheets are a good candidate for the enhancement of collaborative working.

EXPERIMENT

Procedure

First, programmers were asked to fill in a questionnaire about their programming experience. Then, programmers of C or Spreadsheets were asked to read two programs (the 'Easy Task') and modify two other programs (the 'Difficult Task'). They were instructed to read the program until they thought they could understand the program (Easy Task) or could make the required modification (Difficult task). The time limit for both types of comprehension tasks was 10 minutes After reading or modifying a program, they performed two tasks designed to elicit the mental representation of the program's structure that they have acquired:

Primed Recognition task: This task has been widely used in image processing research. The motivation for using this task is that it has been shown to be effective in testing whether the subject's mental representations are based on a hypothesised relationship. In each trial of this task, subjects were presented with a program segment (target) taken either from the program that they had read or modified, or from a different program. Their task was to decide as quickly as possible whether or not the segment was part of the program they had already seen. The target segment was preceded by another program segment (prime). The underlying assumption is that knowledge is organised in networks where the activation from one node spreads to nearby nodes. Therefore if the prime and target are related in the mental network, the activation of the prime would facilitate the activation of the target. The critical manipulation is the prime-target relationship. To test whether the mental model developed by the subjects was based on data or Control Flow relationships, two theoretical networks were constructed for each program (one Control Flow network and another Data Flow network). Then, there were four priming conditions:

1. Data Flow related Condition: A target segment in the test is preceded by a prime close in the theoretical Data Flow network, and far in the Control Flow theoretical network.
2. Control Flow related Condition: A target segment in the test is preceded by a prime close in the theoretical Control Flow network, and far in the Data Flow theoretical network.
3. Unrelated condition: the target segment is preceded by a segment from the same program, but hypothesised to be far away in both the control and Data Flow theoretical networks.
4. Non-Program condition: the target segment was from a different program than the prime segment.

Half of the targets were part of the original program. The other half were not from the program, therefore the subject should reject them as not belonging to the original program. These non-program targets were constructed by modifying some program segments, so that the information in the modified fragment did not correspond with the information shown in the original program. In order to be sure that the Data Flow related condition is not affected by Control Flow information, and the other way around, two controls were done with the material. First, in the Data Flow conditions, we replaced the operations in these segments with dots. Following the same reasoning in the Control Flow conditions, information about the name of the variables were replaced with dots. Second, a distractor code fragment was presented with every target. The target and the distractor were identical except in an operation, in the case of the Control Flow condition, or a variable name in case of the Data Flow condition or one of these options for the rest of conditions. Therefore, the recognition decision had to be based on the exact recognition of the Data or Control Flow information from the program.

Primes were presented for 10 seconds, because we wanted to be sure that the subject had time to read them. During this time, no answer was required from the subject, who was instructed to carefully read the prime fragment. This time was calculated in a pilot study as the maximum time needed to read our fragments. After the prime disappeared, the next screen presented the target and distractor fragments until the subject responded. In this screen, subjects were asked to click on the fragment/s that they thought were from the original program, or if neither of them was from the original program, click the OK bottom to go to the next trial.

Recognition accuracy and time were recorded. We predicted a priming effect. Response times to the target segment preceded by a prime close in the network structure should be faster than response time (and with better accuracy) to the same target preceded by a prime which was not as close in the cognitive structure. This priming effect would be observed in the control and/or Data Flow conditions depending on the knowledge acquired by the subject.

Sorting Task: This task has been used successfully to access a subjects' mental model in programming (e.g. Robertson and Yu, 1990). The subjects were presented with a program that they had read or modified previously, and were asked to group together the lines of code or the cells that they though were related to each other. To make a group they just needed to click on the lines/cells that they wanted to select. They could do all the groups that they found important. They were given some practice trials to this task with names of fruits and mountains.

Sixty-four subjects with different experience levels participated. Thirty-two subjects were C programmers and thirty-two were Spreadsheet programmers.

Results

The data from the experience questionnaire were quantified by two expert programmers. We wanted the experience data from each subject to be sure that our results were not interacting with this variable, which has been shown to be important in developing mental representations in programming (Corritore & Wiedenbeck, 1991).

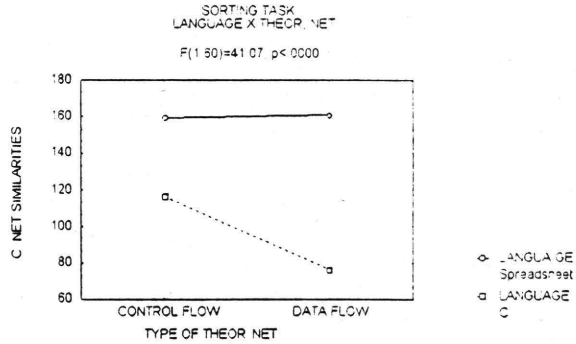
Sorting task results

Raw sorting data were transformed into proximity data by calculating how often two segments of the program were grouped together by one subject. Therefore, for each subject there were four proximity matrices, one for each program (two belonging to the Modify Condition and two belonging to the Read Condition).

Those matrices were submitted to a Pathfinder analysis, resulting in networks with links among the segments, representing relationships in the subjects' mental representation of the programs. The theoretical Control Flow and Data Flow networks were our criteria for measuring a subject's level of comprehension of Control/Data Flow information in the program. The PathFinder analysis provided us with a measure of the similarities among networks, called C (which range goes from 0 to 1). We calculated the C between each subject's network for each program and our theoretic control (four Cs) and Data Flow networks (four Cs). We averaged the Cs between the two modified and the two read programs for each subject. In total four C measures were calculated for each subject. The statistical analyses were done on these C values.

A factorial design, 2 X 2 X 2 (Language X Control vs. Data Flow Network X Comprehension task) was used. Language was a between-subjects variable and Control vs. Data Flow Network, and Comprehension task were within-subject variables.

Figure 1. Sorting Results



Closeness (C parameter) of the C and Spreadsheet programmer networks to the Control and Data Flow theoretical networks.

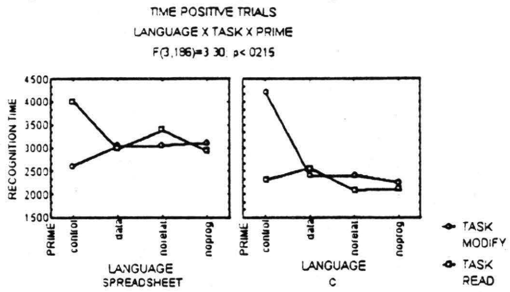
Our results show significant effects of the programming Language ($F(1,60) = 108.934$, M.S.E $= 0.0023$, $P<0.001$), the Prime Condition ($F(1,60) = 35.1022$, M.S.E. $= 0.0006$, $P<0.001$) and the interaction between them ($F(1,60) = 41.75$, M.S.E. $= 0.0006$, $P<0.001$, Fisher's Test of the Least Significant Difference (LSD) $= 0.013$). Spreadsheet programmers' representations were closer to both the control and Data Flow criteria ($C = 0.16$) than C programmers' mental representations ($C = 0.09$). Overall, control primes were closer to the theoretical networks, but that was due to the C programmers. As we can see in Figure 1, according to our hypothesis, C programmers have better networks for Control Flow information compared with Data Flow information. So, C programmers learned the Control Flow information better than Data flow information. On the other hand, Spreadsheet programmers seem to have developed good mental structures for both control and Data Flow information.

Primed recognition task

The number and average time of correct responses were recorded for positive and negative trials (where the target segment was or was not part of the studied program respectively) separately for each subject. A factorial design, 2 x 4 x 2 (Comprehension task x Prime Condition x Language) was used. Language was a between-subjects variable, and Comprehension Task and Prime Condition were within-subject. The level of experience of the subjects was again a covariate.

Positive Trials (in which the target segment was from the studied or modified program)

Figure 2. Priming Recognition Results



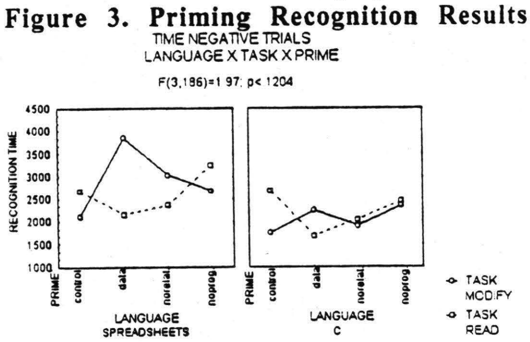
Response times to positive trials, second order interaction: Programming Language by Comprehension Task and by Prime Condition.

Recognition Time: The effect of Language was significant (F(1,61)=7.332; p=0.008). C programmers were faster (Average=2542 ms.) than Spreadsheet programmers (Average=3137 ms.). Close to significant was the interaction between the Language and Comprehension Task (F(1,61)=3.49, p=0.067), where C programmers showed larger differences between tasks than Spreadsheet programmers. However, this interaction was modulated by the effect of the significant second order interaction of Prime Condition by Comprehension Task and Language (F(3,186)=3.30; p<0.021, LSD = 1265). When C programmers modified a program, Control primes slowed down recognition times compared with Data, Program Unrelated and Non Program. There were no differences among primes when C programmers had to read a program. For spreadsheet programmers the data followed the opposite pattern, although the differences were not significant. Control primes tended to slow down recognition after reading, and made recognition faster after modifying a program faster.

Accuracy: There were no significant effects of any of the manipulated variables.

Negative Trials (in which the target segment was NOT from the studied or modified program)

Figure 3. Priming Recognition Results



Response time to negative trials, second order interaction: Programming Language by Comprehension Task and by Prime Condition.

Recognition Time: The effect of Language was significant (F(1,61)=14.6; p=0.0003). Again, C programmers were faster (Average=2135 ms) than Spreadsheet programmers (Average =2768 ms). The interaction of Prime Condition by Comprehension Task was also significant (F(3,186)=10.72; p<0.001). The data showed that when programmers read a program, the Control Flow condition slowed down the recognition process in comparison with the other conditions. In the opposite way, when programmers had done a modification task the Data Flow targets needed more time for recognition. It seems that programmers had acquired the Control Flow information in the reading task, and activating this information in the Control Flow condition made it more difficult to refuse the incorrect target. The same interference effect seemed to happen with the Data Flow information for the modification task.

Again the effect of this interaction seemed to be modulated by a second order interaction close to significant, of Language by Prime Condition and Comprehension task (F(3, 186)=1.97, p< 0.1204, LSD= 671). When C programmers had to read the program there was an inhibition effect of the Control Flow conditions in comparison with the Data Flow conditions. On the other hand, when C programmers modified the programs, there was a tendency for the Data Flow conditions to increase the time needed for recognition although this difference was not significant. With regard to the Spreadsheet programmers, they also performed differently depending on the task. There were no differences among prime conditions when they had to read a program. On the contrary, after modifying the programs, Data Flow and Control Flow conditions had the opposite effects. Data Flow conditions slowed down the process of rejecting a fragment, in comparison with the Control, Program Unrelated and No Program conditions. Control Flow conditions seemed to need less time to take the correct decision in comparison with the Data Flow and Program Unrelated conditions.

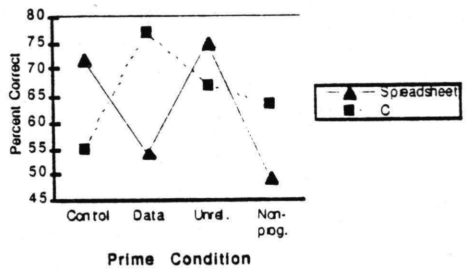


Figure 4. Priming Recognition Results: Percentage of Correct Responds to Negative Trials, second order interaction: Programming Language by Prime Condition.

Accuracy: There was a significant effect of Prime Condition $F(3,186)=5.20$; $p< .002$). Target segments that belonged to the studied program (Data and Control Flow conditions and Program Unrelated condition) were recognised better than targets that belonged to different programs.

The interaction of Language by Prime Condition was also significant ($F(3,186)=11.91$; $p<0.001$; M.S.E.=811.5, LSD= 10). For C programmers Control Flow conditions decreased accuracy compared to the Data Flow and Non Program conditions. On the other hand, for Spreadsheet programmers Data Flow conditions decreased accuracy compared to Control Flow or No Program conditions. So, Control Flow conditions inhibited recognition for C programmers and Data Flow conditions inhibited recognition for Spreadsheet programmers.

As a conclusion from all these data, we found a facilitation effect in the recognition task from our priming conditions. These facilitation effects in recognition time were not due to a trade off with accuracy as we could see in the accuracy data.

We also found strong inhibition effects both in time and accuracy. Inhibition data have been more informative than facilitation data in psychological research. This inhibitory effect has been explained as interference from the subject's mental representation with the information presented to them. In our case the interference shown specifically for the Control Flow conditions in C programmers, and for Data Flow conditions in Spreadsheet programmers gives evidence that programmers develop different mental representations based on Control Flow or Data Flow respectively. The interference effect is also modulated by the Comprehension task. These data are congruent with the previous literature. Specifically, there seems to be a general tendency by C programmers to have a stronger Control Flow based mental representation after modification than after reading a program. The same reasoning seems to apply to Spreadsheet programmers with the Data Flow information.

GENERAL CONCLUSION

Our conclusions are derived from the two tests that we used to access a subject's mental representations. Our data indicated that using these methodologies together could give us complementary information which allow us a deeper understanding of both the mental representations and the processes beneath them.

In general, our results showed evidence that imagery influenced programmers' mental representations. Specifically, we found differences in the information acquired by the programmers depending upon the Language and the comprehension task. The data from the sorting task showed that the mental structure of the spreadsheet programmers has more information about both Control and Data Flow structures. However, C programmers seem to have a better mental representation for the Control Flow information. With regard to the Priming Recognition task, we found strong interaction effects when the programmers had to reject a target that was not from the program. C programmers seemed to be more influenced by the Control Flow primes, so their representation was more strongly based in Control Flow information. For Spreadsheet programmers it seemed to be a different pattern depending on the task. When Spreadsheet programmers read programs, they were more influenced by the Control Flow primes. However, after modifying the program, the Data Flow primes showed a stronger influence on recognition. These results are congruent with previous research showing differences in the program representation depending on the task and programming language (Pennington, 1987, Burkhardt, Détienne, Wiedenbeck, 1997).

Furthermore, these data together gave support to our hypothesis that the Spreadsheet, with its visual characteristics, helped programmers to develop a representation of the program based on Data Flow structure. The sorting data clearly showed that the Spreadsheet programmers develop a Data Flow mental representation even in the easiest tasks, while C programmers seemed to need to have special task conditions (e.g.- more difficult) to acquire this information. Therefore our data with C programmers replicates the results of Pennington (1987), supporting her Two Stages theory for procedural languages. On the other hand, based on the effects found for Spreadsheet programmers, we claim that it is necessary to add a factor to this theory to account for the role of imagery in programming. Programmers will go through the stages that have been proposed depending on the variables that enhance the processes underlying these stages. One of these variables seems to be imagery, which enhances access to Data Flow information.

Finally, in connection with the goal of this conference of exploring collaborative work and cognition, we would like to add a reflection about the repercussion of studying cognitive processes underlying Spreadsheet comprehension. Because it has been observed that spreadsheet development and usage is mainly a non solitary activity, in the last few years, this new issue has got some attention. Nardi and Miller (1991), using case studies, discovered that collaborative spreadsheet development appears to be commonplace, and interestingly follows a strong pattern of sequential work. Panko and Halverson (1994) empirically tested the differences between developing a spreadsheet alone or within a group (two and four people). Their results showed that 'dumb' mistakes and errors about which everybody would agree when somebody points it out, were drastically eliminated in group working, especially in groups of four people. These results, which have not been found for any other programming language, seem to indicate that spreadsheets are a good candidate for the enhancement of collaborative working. It could be suggested that enhancing access to the main information by all the members of the group is why Spreadsheets are especially good in collaborative work. In any case, spreadsheet programming has shown to have some special characteristics that, added to the fact that it is one of the two most important personal computer applications (after word-processing, Panko, 1988), make its study an important goal for further research.

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The Role of Working Memory in Measuring Mental Models

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ABSTRACT

There is no agreement on what a mental model is and how to infer the mental model a person has. We are conducting research aimed at solving these problems by developing a model of Mental Model formation. Our basic hypothesis is that a Mental Model is a dynamic representation created in WM by combining information stored in LTM (the Conceptual Model) and characteristics extracted from the environment. Two experiments tested hypotheses derived from the model. Implications for individual and group research are discussed.

Keywords

Mental Models, Working Memory, Knowledge Elicitation.

INTRODUCTION

When a person learns to interact with a system it means she/he acquires a knowledge of its operation and of the structural relationships between its components. Researchers have called this knowledge the 'Mental Model' of the system (Moran, 1981). The existence of Mental Models and its importance during the interaction with the system have been demonstrated in numerous experiments (e.g., Kieras and Bovair, 1984; Cañas, Bajo and Gonzalvo, 1994). Research on group co-operation has also acknowledged the importance of mental models. When members of a group share similar and accurate mental models of group interaction, the group interacts more efficiently and performs more effectively (Cannon-Bowers et al, 1993; Tindale et al, 1996). The concept of Mental Model is particularly important for research on Team behaviour. Teams are groups in which the members work together on the same task to solve a common problem and there is no division of work responsibilities (Cannon-Bowers et al, 1993). To perform the task members of teams must develop a common knowledge that has been called Team Mental Model (Klimoski and Mohammed, 1994).

Because of this, in the current investigations on design, learning of new interfaces, group co-operation, etc., it is common practice to try to infer what is the mental model that a person or group has.

The investigation of mental models is blocked at present by two problems. Firstly, a theoretical problem exists, which is reflected in the great confusion concerning the definition of a Mental Model. Though this problem has been stressed for a long time (Rouse and Morris, 1986) it still has not been solved satisfactorily. Secondly, a methodological problem exists that, in part, is a consequence of the definition problem. Although many methods have been proposed for inferring which model users has, all have been critiqued as being unreliable (Sasse, 1991).

The research project we are conducting is aimed at solving these definitional and methodological problems by developing a model of Mental Model formation. The basic hypothesis behind our model is that a Mental Model is a dynamic representation created in Working Memory (WM) by combining information stored in Long-Term Memory (LTM) and characteristics extracted from the environment. Methods that are proposed to infer the Mental Model that a person hold must consider that. The methods that are currently used require that the persons perform a task that is different from the real task they perform when interacting with the system or co-operating with other team members. We assume that the person being tested with these methods simulates the real task in her/his WM to perform the elicitation task. Therefore, what it is inferred is the result of this simulation.

This model could explain a common and unexpected result found in Mental Model literature: experts in a field who are supposed to have a good and similar knowledge seem to have different Mental Models (Cooke and Schvaneveldt, 1987; Navarro, Cañas and Bajo, 1996). For example, Cooke and Schvaneveldt

(1987) found that expert computer programmers had less similar mental representation of computer concepts than novices. This result could be explained from our model: even when two people share the same Conceptual Model, they can appear as having different Mental Models because when tested individually they execute different tasks in their WM.

The model could also have implications for the improvement of group discussion. The first step in co-operation is always the elaboration of a common knowledge space (Sauvagnac and Falzon, 1996). However, during group co-operation two people who shared the same Conceptual Model could be cued by the discussion process so that different portions of their knowledge are brought to their WM, making the above elaboration more difficult.

Theoretical Rationale

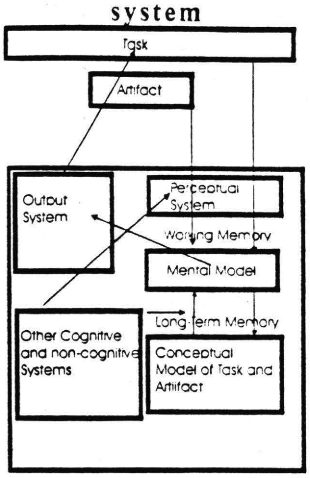
The definition problem

The definition problem is due to the fact that the term Mental Model has been used by researchers who work in different areas and study different tasks. Johnson-Laird has formulated his mental model definition in his attempt to explain the reasoning processes in tasks of syllogisms and language comprehension. To execute these tasks, a person forms in WM a mental representation of the world combining the information stored in LTM with the information of the task characteristics extracted by perceptual processes. This representation is called in this context Mental Model and it is, by its nature, dynamic. Though the information retrieved from LTM, the knowledge that a person has about the world, is important, Johnson-Laird (1983) gave greater importance to the information extracted by perceptual processes of the characteristics of the task (Rasmussen, 1990).

Research on the interaction with physical systems also considers that a person forms a representation in WM combining the knowledge stored in LTM, and the extracted information of the task characteristics (Gentner and Stevens, 1983). However, in this case the information stored in LTM that is relevant for these researchers is related to the knowledge of the structure and the operation of the physical system. Therefore the emphasis is on this representation, which is called Mental Model of the Physical System, and the efforts are placed on investigating how it is acquired and extracted from LTM.

It would be possible to unify both definitions if we make clear the distinction between the information stored in LTM, the Conceptual Model (Young, 1983), and the dynamic representation that is formed in WM combining the information stored in LTM and the extracted information from the environment (task), the Mental Model (see Figure 1). In this way, the unified definition of the Mental Model would emphasize the common characteristic of both definitions: the function of a Mental Model is to simulate the reality in WM.

Figure 1. The role and place of Mental Models during interaction with a physical system



The methodological problem

The dynamic nature of the mental models has an important consequence when considering the methods that we use to measure them. As Staggers and Norcio (1993) have indicated, if a Mental Model is a knowledge structure that is simulated in WM, we must speak of the Mental Model as a process and as the result of that process. When we measure the Mental Model of a person we are measuring the result of the simulation process. This result we take as reflection of the knowledge structure that it is stored in LTM. However, the simulation is accomplished selecting the part of the permanent knowledge that it is relevant for the task. That is to say, all the knowledge is not selected. The part that is selected will depend on the task, the context, the intentions, etc. It is also possible that the mental model as measured might be affected not only by selection but also by transformations performed on the knowledge in order to comply with the elicitation task

An additional problem with the knowledge elicitation methods that we use is that subjects are requested to accomplish a different task from the one that they would accomplish in the real situation. Therefore, when we measure the mental model with a knowledge elicitation task, the person simulates the real task in her/his WM and responses are given based on this simulation. Therefore we do not measure the knowledge stored in LTM but the knowledge which is put in WM depending on the elicitation method we use.

Take for example a knowledge elicitation task such as relationship judgements. This task has been widely used in interface design (Cooke, 1994). Subjects are asked to judge how related two components of the interface are. We know that objects could be compared along different dimensions. For instance, the USA and Cuba are very closely related when we compare them taking their geographical location. However, they are unrelated when we think of their political regimes (Tversky, 1977). We could assume that the dimension on which two components are judged to be related would depend on the task the subjects simulate in their WM.

Experimental Rationale

If we teach several people to interact with a system in such a way that all of them are capable of accomplishing any task that we give them, we can assume that they will all have stored the same knowledge (Conceptual Model) of the components of the system and of the relationships among them in their LTM. Then when we request the subject to perform a task in which we infer their Mental Model, e.g., to give us a relationship judgement between two components, they will simulate a task in their WM where those two components are implicated. Their judgement will reflect the relationship of the two components as a function of that task. However, in many occasions two components are implicated in several tasks and in each one the relationship between them will be different. Therefore, judgements will be made based on the particular task that subjects simulate on their WM.

In our experiments subjects learnt to interact with the system until they performed without any error. They also passed a declarative test in which we asked them a set of questions regarding all aspects of the system. Then they performed a knowledge elicitation task (relationship judgements) in which changes were introduced to affect the operation in WM. If performance in the elicitation task depends on these changes, we will be able to say that it was the result of what happens in WM and not of the Conceptual Model which the subjects have, the Conceptual Model being perfect and the same for all the subjects.

Experimental Procedure

Description of the system

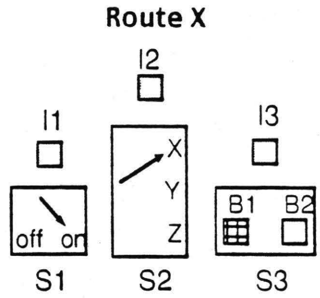
In our experiments, subjects learnt to operate a control panel device displayed on the computer screen. The device was a modified version of the one used by Kieras and Bovair (1984) consisting of switches, pushbuttons, and indicator lights (Figure 2). We said to the subjects that the device was a control panel for an electrical circuit. Their task consisted of making the current to flow from panel S1 to panel S3. They were instructed in the possible three action sequences that allowed them to complete the task:

1. Route X: press button ON in panel S1 (light I1 turned on); switch toggle switch in panel S2 to X (light I2 turned on; press button B1 in panel S3 (light I3 turned on) .

2. Route Y: press button ON in panel S1 (light I1 turned on); switch toggle switch in panel S2 to Y (light I2 remained off); press button B2 in panel S3 (light I3 turned on).
3. Route Z: press button On in panel S1 (light I1 turned on); switch toggle switch in panel S2 to Z (lights I2 and I3 turned on).

This system was sufficiently simple so that the subjects could learn it easily in a short period of time.

Figure 2. Device set for Task 1



The Learning Task

In the first phase of the experiments the subjects learnt to operate the system until they were capable of executing the three action sequences two times without committing any mistakes.

The Declarative Task

Then, subjects undertook a test in which they answered ten questions on the operation of the interface. The purpose of this test was to have a measure of the declarative knowledge that subjects had and to assure us that actually they had learnt to interact with the interface and that, therefore we could suppose that they had acquired the conceptual model of the system.

We eliminated from the experiments all subjects who failed in more than one question of the questionnaire.

The Elicitation Task

In the two experiments that we describe here, subjects completed a relationship judgements task concerning 11 interface items. Subjects were to assign ratings to pairs of items according to how related they thought the items were. The scale ranged from 1 to 6. A rating of one indicated that the items were unrelated, and a rating of six indicated a high degree of relatedness. The subjects were to indicate their responses by pressing the numbers corresponding to their ratings on the keyboard. The instructions emphasised that they should work fast, basing their ratings on their first impression of relatedness.

The judgement matrices were transformed into network representations using the Pathfinder algorithms (Schvaneveldt, 1990). Pathfinder is a graph-theoretic technique that derives network structures from proximity data. The Pathfinder algorithm takes proximity matrices and produces a network in which concepts are represented as nodes and relations between concepts are represented as links between nodes.

Experiment 1

In the relationship judgement task, item pairs are presented in a sequence. The subject sees a pair and judges it, then sees other pair and judges it, etc. The sequence in which the pairs are presented can have an effect on the judgements. According to our model, when a pair is presented the subject simulates in her/his WM a tasks in which that items pair intervene, and depending on the task that she/he simulates will issue her/his judgement. After issuing the judgement a trace of the simulated task remains in WM. When the following pair is presented, the subject resumes simulating a task in her/his WM. However, the task simulated to judge this second pair would depend on the task simulated for the first pair. For example, let us suppose that we are evaluating the mental model of two MSWORD experts. Then, we present two sequences, one to each expert:

1. Expert One: 1. "Print-File" ; 2. "Search-Edit"; 3. "Search-File"
2. Expert Two: 1. "Save-File"; 2. "Open-File; 3. "Search-File"

We could predict that expert Two would rate "Search-File" as being more related than expert One would. File is a menu and an object. The first sequence would lead the expert to think on the relation "is in the menu". However, the second sequence points to the relation "things that you can do with a file".

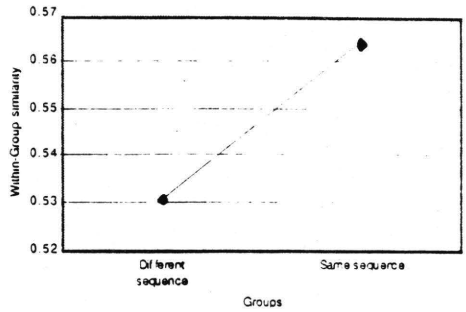
This task is similar to the classical similarity task. Researchers who have worked in the topic of similarity know that the context in which the similarity between two concepts is judged influences the judgement that a subject gives (Goldstone, Medin and Halberstadt, 1997). For example, Medin, Goldstone and Gentner (1993) had groups of subjects rating the similarity of *sunrise and sunset* and *sunrise and sunbeam*. In one condition of their experiment one group of subjects rated the pair sunrise-sunset and another group rated sunrise-sunbeam. In this condition sunrise-sunset was rated as less similar than sunrise-sunbeam. However, in other condition of the experiment, subjects rated both pairs simultaneously. In this condition, sunrise-sunset was rated as more similar than sunset-sunbeam. Medin et al argued that since sunset and sunrise are antonyms they are considered to have little similarity when they are judged in separation. However, this same characteristic causes them to considered closely related when they are judged in the context of sunrise-sunbeam. Therefore, the context influences how we judge the similarity of two concepts.

In this experiment we manipulated the presentation sequence of the system's pairs of components which the subjects were giving relationship judgements on. For one group the sequence was random and different for each subject. For another group each subject were presented with the same random sequence. Our hypothesis was that the group that had the same sequence would show greater within-group similarity in their judgements than the group with different sequences.

Subjects

Fifty-six subjects participated in the experiment. After eliminating those subjects that did not pass the declarative test, results from forty-three subjects were analysed. Eighteen subjects performed the elicitation task in the same sequence condition and twenty-five in the different sequence condition.

Figure 3. Within-group similarity as a function of sequence of presentation



Results

Pathfinder analysis provided us with a measure of the similarity between two networks called C. This value reflects the degree to which the same node in the two graphs is surrounded by a similar set of nodes. A C value of 0 corresponds to two complementary graphs and a value of 1 corresponds to equal graphs.

We calculated the network similarity between all pair of subjects within one group. Then those C values (253 from the same-sequence group and 300 from the different-sequence groups) were submitted to a one-way ANOVA.

The results of this experiment showed that when subjects judged the concept pairs in the same sequence their ratings had more similar network representations than when they judged them in different sequences, $F(1,451) = 8.25$, $MSe = 0.013$, $p < 0.01$ (see Figure 3). Therefore, we can say that the task simulated to judge a pair left a trace in their WM that influenced the rating of the following pair.

Experiment 2

If the result of the first experiment could be explained by the trace left in WM of the task simulated to judge to a pair of items, we could eliminate that trace by introducing an interference task after subject's response to one pair.

In this second experiment all subjects were presented with the same sequence of pairs. However, one group of subjects saw one number on the computer screen after they rated one pair of concepts. They had to count backward from that number for 2 seconds. Another group performed the task without counting backward.

We hypothesised that counting backward would erase the WM trace. Therefore two subjects that rate the items with this interference task would have less similar network representation than two subjects that perform the elicitation task without counting backward.

Subjects

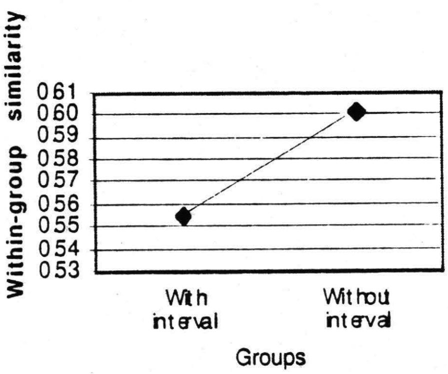
Forty-eight subjects participated in the experiment. After eliminating those subjects that did not pass the declarative test, results from forty subjects were analysed. Twenty subjects performed the elicitation with the retention interval and twenty without the interval.

Results

As in the first experiment, we calculated the network similarity between all pairs of subjects within each group. The C values (190 from each group) were submitted to an One-Way ANOVA.

As shown in Figure 4, the group that performed the elicitation task without counting backward showed more within-group similarity than the group that performed the task counting backward, $F(1,378) = 16.28$, $MSe = 0.013$, $p < 0.001$. Therefore, counting backward after rating a pair of items erased the trace that the simulated task had left in WM. Then, when a new pair of items had to be rated, the probability that two subjects simulated the same task decreased.

Figure 4. Within-group similarity with and without retention interval



CONCLUSION

The variables that we introduced to affect the contents WM had an effect on the [erformance of the subjects in the elicitation task. Though all subjects learnt to interact with the system perfectly and they were capable of answering questions that were put to them on this, their ratings of relationship were affected by what occurred during the elicitation task. Since the inferences that we make on the mental model are based on these judgements, our inferences would be affected by these variables.

Therefore, we claim that what we measure with our elicitation tasks is the content of WM, the Mental Model, and not the Conceptual Model stored in LTM. Research on Mental Model should be conducted with a model of the elicitation task that is used. This model would take into account the tasks that subjects simulate in their WM. Also, several elicitation tasks should be used in conjunction to get a better picture of the Conceptual Model.

Implications for Team Mental Model Research

Klimoski and Mohammed (1994) have called attention to the great confusion that exists about the contents of Team Mental Models. Researchers have used the concept to mean indifferently: artefacts that team members use; the task to be performed; a particular problem facing the team; the knowledge, skills, abilities, etc. relative to team functioning; and representations of environment events and projected future states. Our definition would include all these contents. A team Mental Model would be constructed by combining a conceptual model of artefacts, world and technical knowledge, skills and abilities (procedural knowledge stored in LTM), with information extracted from the environment. What is combined depend on the task to be performed by the team to solve a particular problem and it is used to project future states of the environment and artefacts.

Klimoski and Mohammed (1994) have also addressed the question of what does it mean to "share" a Mental Model. Team members could have identical representations, a distributed configuration of representations (no overlap), or a configuration of overlapping representations. Although most researchers would agree that a shared Mental Model does not imply identical representations (Cannon-Bowers et al., 1993), the question of how much overlapping would allow us to say that team members shared a common Mental Model remains open to research.

Our results suggested that we cannot answer this question with methods of measuring Mental Model that test subjects individually. We should think of the Mental Model considering the task that team members perform. Mental Models are created while team members interact with the system to reach a common goal (Orasanu and Salas, 1993). Therefore, we should develop methods that capture the representation that team members share when working on the co-operation task.

Problems of validity of measures have been also addressed by researchers on Team Mental Models (Hinsz, 1995). However, proposing a new method (e.g. belief association matrix) without considering the dynamic nature of Mental Model and that tests subjects individually would not solve the problem. We need a method that captures the content of , let us say, the 'Collective Working Memory'. Our goal for the future should be precisely that one.

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Team Situation Awareness using Graphical or Textual Databases in Dynamic Decision Making

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ABSTRACT

In this experiment we explore the effects of using a graphical and textual database for sharing information within a team that are to control a dynamic system. The task involves fighting a simulated fire. Four people are to co-operate in a layered organisation, with one layer being the operative and the second layer the supervisory. The operative layer involves two fire chiefs who are commanding two fire units each. The supervisory unit consists of two persons that are to co-ordinate the fire chiefs. The supervisory unit receives all information from the fire chiefs but has to construct an overall picture, a so-called situation awareness, of the development of the whole area. The supervisory unit constructs this situation awareness which is meant to be supported by the graphical and textual databases respectively. We hypothesised that the graphical condition would be more successful than the textual database in registering the current situation, since the graphical database allows direct mapping. On the other hand, we hypothesised that the textual condition might be better in supporting the future planning and prediction of system dynamics. We analyse 18 quartets, 72 subjects by both performance measures and a questionnaire. There were no significant performance differences between conditions, but there is a major learning effect, especially for the textual condition. In accordance with our hypothesis we found that participants in the graphical condition did better mapping the map with the "real" world, at least in the first session. More successful groups worked more ahead of the fire than did less successful groups. From the questionnaire it seems that the subjects learn more about co-ordination and trusting their fellow team members than about the internal dynamics of the simulated fire. In fact, the teams learn things about system dynamics that are wrong. We therefore suggest that team SA might be more of a co-ordination problem than a problem of acquiring knowledge about system dynamics.

Keywords

Situation awareness, Dynamic Decision Making, Micro-world studies, Co-operation, Co-ordination

INTRODUCTION

With the development of more powerful tools the extent to which we can control dynamic systems increases dramatically. Information technology makes new representation media, as well as automated analysis and prediction possible. But information technology does not only amplify the control system's cognitive powers, it is also a way of co-ordinating between agents. With new communication technology we can communicate quicker and with more accuracy in the transmission. This is of course of great importance as many dynamic systems such as forest fires and emergency situations are so complex and/or geographically large that they requires co-operation between several actors.

A useful theoretical concept, associated with dynamic decision making is situation awareness (SA). SA is an intermediate state in the decision making process, and involves the current comprehension of dynamic systems which is required if an appropriate decision for future development is to be taken. SA becomes especially complex when we consider teams. How is information to be distributed and shared between agents so that they can construct and develop appropriate common goals for the emerging situation? How can we, with the aid of information technology, support such collective constructs? What kind of media representations will best aid such joint cognitive accomplishments?

Endsley suggests that Situation Awareness (SA) involves the following levels (Endsley, 1995).

1. Perceiving elements in the environment
2. Comprehension of the current situation
3. Projection of future status.

These states have correspondence also on a team level. The team as a unit must, in order to achieve SA in one way or another, collectively process information on these levels. We therefore introduce a new concept, team situation awareness (TSA) (Salas, Prince, Baker & Shrestha,1995). The problem in TSA is that if the team is to act together as a unit towards a common emerging goal and with concerted actions, must information be shared. Otherwise each and every individual may interpret the situation in relation to independent goals. Many goals must also be shaped in the process. So team situation awareness must be constructed on the spot, rather than perceived or inferred from system characteristics. We define TSA as the active construction of a situation partly shared and partly distributed between two or more agents, from which one can anticipate important states in the near future.

BACKGROUND

The present study is based upon observations from a field study of an Emergency Co-ordination Centre (ECC), partly reported in Artman & Wærn (1998) and Artman & Garbis (this volume).

In an ECC unit different operators have different responsibilities. One operator is responsible for knowing where medical services are positioned, and what they are currently doing; others are responsible for fire brigades, helicopters etc. An emergency unit can, of course, never know when and what kind of emergencies will be reported, so it is not possible to stick to a strict, expert task allocation which, for instance, lets the paramedics responsible take medical inquiries only, the ambulance responsible take ambulance calls only, and so on. The caller will be answered by any of the operators who then will take care of the incident and despatch the appropriate resources. This means that the operator must co-ordinate with other operators as soon as the resources needed are out of the operators responsibility, as well as in other circumstances, e.g. when there is need for parallel task execution. This also means that each operator must know to a certain extent what incidents are going on, otherwise too many resources could be sent to a single incident, and this could be hazardous for the possible next incident. It is not uncommon that several persons phone to the ECC and report the same incident, especially now when mobile telephones are common, so the possible threat is real. Resources are scarce and have to be carefully allocated.

At present the operators share a textual database where they can and should register the incidents and what they have done about it. This database is accessible to all operators, and constitutes a kind of collective memory of the units actions. The unit has recently been equipped with a new database system, a Geographic Information System (GIS), which visualizes the ambulance's location in the area for which the team is responsible. Thus the dynamic cognitive task of knowing where the ambulances are located has shifted from listening to other operators and looking in the database to update one's SA, to directly perceiving the location on the screen. In the future all the operators may have a screen where they directly can see where the ambulances are and thus can more easily decide which ambulance is suitable for the incident in question.

In the experiment reported we explore the implications of the use of textual or graphical databases for sharing information within a team.

A graphical database is obviously better in that it directly affords the mapping of the state of the system if it is adequately updated. That is to say, a graphical database is better on the first of Endsleys three levels. Still, integration of information as well as future projection has of course to be interpreted and cannot simply be picked up from the graphical representation. If it is easier to create the first level representation the second level might be easy to infer. However, the third level of future development may be constrained by the possible interference between perceptual impressions gained from the graphical interface and the conceptual reasoning required for predictions.

A textual representation is less direct as it requires more mental transformations in order to be useful for understanding the state of the system. Text demands or affords more reflective thinking as one must constantly update one's mental model of the spatial relation (Norman, 1993). This may be the main advantage of the textual representation since a reflective cognitive mode of control may stimulate representations of higher order mental models and to stimulate the use of mental simulation (Klein, 1993).

Even so, the advantage of enabling exact graphical mapping may be compensated by the possibility that textual expressions can be vague and allow for interpretation. A reflective mode of operation may well provide the basis for a feed-forward mode of control, looking beyond the immediate future in problem solving, level three of situation awareness. We suggest that these processes are important in developing an appropriate plan of future development.

Consequently, our general hypotheses are that the team using the graphical database will have more a higher correspondence of SA with the state of the world. The reason for this is primarily because it takes less time to perceive, update and analyze the state of the current situation when using the graphical database. Furthermore, we propose that the textual database will stimulate the formation of reflective modes of operation and thus promote relatively more feed-forward oriented modes of control.

We think that these two modes of support will be more or less successful for controlling the dynamic environment. We hypothesise that the graphical database condition will perform better initially, while the textual database condition will be harder to learn but could also give rise to better performances in the long run.

METHOD

Subjects

Seventy-two computer-literate undergraduate students were paid 200 SEK each to serve as subjects. There were a total of 18 quartets, 9 within each condition. The subjects were randomly assigned to each condition. They received general instructions and opportunity for practice.

Experimental task

The questions are approached by an experiment, performed in a micro-world, which is a development of the D³Fire (Distributed Dynamic Decision) micro-world paradigm by Svenmarck & Brehmer (1991). D³Fire simulates a series of fires. The task is to extinguish this fire with four fire fighting units. The problem is that each person in a fire fighting unit only can see a limited window, 3 X 3 squares. The whole area is 20 X 20 squares. This calls for co-operation and co-ordination. D³Fire has been developed to investigate the co-ordination of dynamic distributed decision making and investigates how people with individual tasks within a common goal co-ordinate their actions. The development of D³Fire which we call C³Fire (Communication, Command and Control) is more explicitly made to investigate how a team assesses the situation and how the team gain control within different information conditions as well as how and if a second time-scale constituted by a team affects the outcome (see Granlund, 1997; Artman, 1997). C³Fire thereby corresponds to co-ordination centres that are detached from the environment they are to control, since the commanding layer does not receive any direct information from the operative level (see Artman & Garbis, this volume, for a more detailed account of such units).

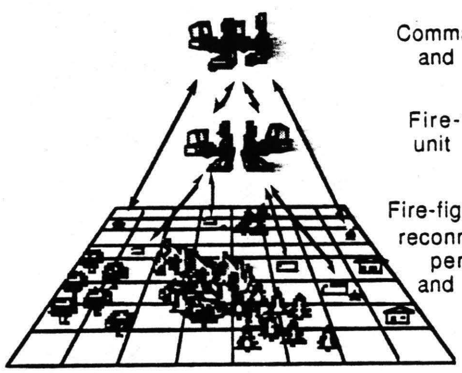

Figure 1. The C³Fire organisation.

Of the four persons in C³Fire, two are assigned to be at the second layer staff, corresponding to emergency co-ordination centre operators. These are regarded as superior in rank to the other two persons, called fire chiefs, in C³Fire who are to control all four fire engines as ordered by their superiors (see fig. 1). When a fire chief sends a mail to the staff it is randomized to whom it reaches. This constitutes the requirement to co-operate and share information and resembles the situation at the ECC. The second layer staff who are located at different places can communicate by electronic mail and via the database.

The fire chiefs are to report to the staff and supply possible proposals or findings from the operative level (the playing field). The staff will not have any operative information about the field status other than that supplied via electronic mail from the fire chief and from some computer simulated reconnaissance troops. They receive information regarding wind and weather from the game, and they are equipped with a map which corresponds approximately to the actual area. They are given no other direct information concerning where the fire is or how it is spreading, etc.

Reconnaissance troops are also added to the game and these tell the fire chiefs and supervisor unit what is happening outside of their known area. These troops are designed as autonomous artificial agents and are there to enable the players (on the one hand, the fire chiefs, on the other hand, their superiors) to obtain information about the course of the fire and to engender a richer flow of information. These autonomous agents simulate hierarchically lower agents and are considered to correspond to someone who phones a co-ordination centre or who tells about their findings with regard to an area out of sight of the units. The players can give the agents reconnaissance tasks and receive information via a simple mail based command language.

The goal is to fight the fire(s) with a minimum loss of squares. A trial ends when the fire(s) has been put out, or after a maximum trial duration of 30 minutes. When the fire has started the commander team is informed via electronic mail from the co-ordination centre, and must then in turn inform the lower decision-makers and command them to a chosen position. We have included three sorts of forests, one slow burning, one fast burning, and one which is regarded as normal (thus mixed). Furthermore, we included houses and told the subjects that these were to be prioritized. These extra conditions were added as we wanted the staff team to be able to choose between interconnected goals (e.g. minimise forest fire and save houses) and induce them to set strategic goals.

Design

As mentioned above, the experiment was designed to compare quartets utilizing either a graphical or a textual database. In both conditions the quartets received three trails. Thus the design of the experiment was a 2 (graphical versus textual database) by 3 (trials) design with repeated measures.

The trials were exactly the same scenarios except that the objects and fires were mirrored from session 1 to 3.

Procedure

All quartets were informed about the general nature of the task, their respective individual roles, how their database functioned, about the fire, wind, the different types of forests, and were instructed that they should try to save the houses as well as extinguish the fire. They were given thorough training in how to use the interface and were then allowed to familiarize themselves with the display and the electronic mail. Between the trials they were given a survey about how they experienced the fire, the co-ordination between team members, some questions related to situation assessment as well as to the interface. The subjects could agree to disagree with a given statement in a 4-graded Likert scale.

RESULTS

Several dependent variables were derived from the data that C3Fire registers on a trial. We computed the statistics derived from the survey to see if the conditions had any effect on their experience of the fire, co-operation and SA. In this paper we analyse only the first and the third sessions. The subjects were not given the impression that the scenarios in the sessions were the same (m over sessions=2.58).

Effectiveness over conditions

We calculated effectiveness in two ways. First, the single goal of saving unburned forest. Then the multi goal calculation were saved and unburnt houses were incorporated into the statistics were analysed. There were no significant differences between the graphical and textual conditions in either session or calculation. However, there is a dramatic learning effect ($F = 42.8$, $p < .01$). If we look at table 1 we can see that the textual conditions learning is most dramatic.

Table 1: Shows the average number of squares of green forest saved in the two conditions and in the two analyzed sessions.

	Map	*Text*
Session 1	237	189
Session 3	323	327

We could not find any significant differences between the conditions as regards communication between the subjects in the quartets. There is significantly more electronic mail communication between the two staff operators in the third session than in the first ($F = 14.92$, $p < .01$).

We also dichotomised between the successful and the less successful teams irrespective of condition but could not see any quantitative differences in communication.

There is no correlation between the use of agents and how successful the team is on the above measures.

There are no differences between conditions in how they experienced the interface. Most found the interface quite easy to use (over sessions the arithmetic mean was M=1.67, where 4 stands for difficult). They subjects also found it more easy to use over sessions ($F = 19.11$, $p < .01$). The subjects did nor experience it difficult to write electronic mail in order to communicate. The staff team members in both conditions found that the databases made them unanimous, and even more so over sessions ($F = 11.757$, $p < .01$). The graphical condition found their database to be more important than the textual condition to be able to understand 'what is going on' (session 3. $F = 4.71$, $p = .05$). Both conditions found the database quite easy to use (Mean over sessions = 1.64, where 4 stands for quite difficult). All this strengthens us in our view that there is no problem in handling the computersystem at the interface level.

This result indicate that for effectiveness neither textual or graphical database support is superior, but that the subjects feel that they are supported by each one.

Situation Awareness

In order to explore how well the graphical or textual database did support the teams to develop situation awareness, we have both analysed their actual use of the shared databases as well as asked questions where they could estimate their Situation Awareness.

Level 1. Situation Awareness

By comparing the actual area with the information in the constructed database we could observe how well the staffs had perceived the current state of the system. The results are presented in table 2. In session 1 there is a great difference between the conditions, and this is significant ($F = 23.13$, $p < .01$). However, in session 3 this difference has disappeared.

Table 2. Shows the average percentage of correct registered fires relative to how many fires each team could have registered.

	Map	*Text*
Session 1	16.7	2.8
Session 3	25.3	15.7

It takes less time for the graphical condition to register a fire in the database than for the textual condition (Session 1. $F = 8.288$, $p = .01$ / Session 3. $F = 6.365$, $p = .02$).

The survey tells us that the subjects get more confident over sessions in that others know where the fire is ($F = 14.351$, $p < .01$) Their own estimation of their individual awareness of where the fire is, is also becoming more confident over sessions ($F = 71.05$, $p < .01$). This is not so surprising because in the absence of a visual field, staff members are not as confident as the fire chiefs are about where the fire is in the first session (session 1. $F = 5.14$, $p = .05$), although this difference disappears in the third session. Successful teams were more likely to think that they knew where the fire was, at least in the first session (session 1. $F = 3.867$, $p = .05$), and they were also more likely to agree that one must construct a picture of how the fire spreads (Session 1. $F = 3.746$, $p = .05$). These differences between successful and less successful teams disappear in the third session.

Level 2. Situation Awareness

The two conditions differ as regards the way in how the team members experience how the fire develops. It is significant that in the third session the team using the graphical database tend to think that the fire spreads less when there is little wind ($F = 3.89$, $p = .05$). This is in fact wrong. Thus it seems that the teams, in general but specifically in the context of the graphical condition, learn the wrong dynamics of the way systems develop ($F = 4.47$, $p = .05$). When faced with the question of whether if the fire spreads faster at the beginning they are uncertain (Mean over sessions 2.47 where 4 means very uncertain). Despite these misunderstandings, the subjects think that it is most important to construct a picture of how the fire develops (m over sessions = 1.32). It is also getting easier to predict the fire's developments if we are to believe the subjects ($F = 34.45$, $p < .01$). After the third session they are getting more confident that their team members understand the development of the fire in the same manner ($F = 60.14$, $p <.01$). Most of the subjects did agree completely or partly that the different vegetation did make a difference to how fast the fire spreads (Mean= 1.81, where 4 stands for disagree on difference).What is very interesting is that there is no significant difference between fire chiefs and staff members in all these questions. This is interesting as the staff members do not have the visual window on the actual fire.

Level 3. Situation Awareness

In order to see if the teams performed as if they have had a situation awareness level 3, that is, to foresee future developments, we perfromed a quite elaborate analysis. We took as a starting point the square where a actual fire started. We then observed when the team noticed the fire by reporting it to the database, we accepted a first observation to be 5X5 squares away from where the actual fire started. The next coming reported fires must be within 7 X 7 squares from this first reported fire. In order to be counted as being a future observation we only counted a marked fire on a actual non-fire square. Such reporting into the database would make the representation to be ahead of the actual development. We could not find any differences between the conditions in their registering of such fires that are ahead of the actual development. That is to say, we cannot say that either the graphical or textual database is better suited for registering a dynamic system. Still, teams in session 1 that have been more successful in saving green squares tend more often to register fires that are ahead of the actual development ($F = 13.09$, $p < .01$). In session 3 teams that are more successful had a close strategy in that they registered more fires than less successful teams ($F = 4.445$, $p = .05$). Interestingly enough, however these teams were not so successful in registering the right current situation (SA level 1). These seemingly contradictory results be explained simply by the fact that the teams that was successful also worked on a second timescale relative the actual development.

The survey suggest that the subjects over all conditions do not feel so confident in estimating how a fire spreads within five minutes, but they think they are getting better at it (session 1. mean = 2.88 / session 3. mean = 2.43 where 4 means 'not confident' / repeated measure $F = 21.74$, $p < .01$).

Co-operation

For team SA co-operation and co-ordination becomes an important aspect. As we have seen, the different conditions do not differ in their communication frequency with different units. Furthermore, we have shown that most subjects form the wrong impression of the details of the target system's dynamics. The learning effects must be understood in terms of other aspects than these. From the questionnaire we can see that the subjects start to form conceptions of their team members as well of their own functioning.

The subjects think that they need to know what others are doing (M over sessions =3.75, 4: necessary to know). The more successful teams are more likely to do not think it is as necessary as the less successful teams (Session 3. $F = 4.78$, $p = .05$). The more successful teams think they know what others are doing without others telling them than is the case with less successful teams (Session 3. $F = 5.524$, $p = .05$). Thus, successful teams seems to care less about what others are doing, or / and can infer this from other information. It could be that successful teams rely more on silent co-ordination.

The teams' answers suggest that they are telling others more about their intentions and plans especially after the third session ($F = 9.636$, $p < .01$). Thus they have learnt to articulate their future actions for others. There is also a difference between the fire chiefs and the staff where the stafftend not to think they told others about their plans (Session 1. $F = 11.04$, $p < .01$ / Session 3. $F = 8$, $p = .05$). At first sight this may be remarkable, as the staffs' work is to direct the fire chiefs, but as the staff is always dependent upon information from the fire chiefs, the problem for them is to be able to plan for their own work. The staffs can plan for the fire chiefs, but have problem to plan for themselves, and therefore cannot impart their intentions about their own strategic actions.

The subjects experience that they are communicating much more effectively in the third session ($F = 72.48$, $p < .01$). They also have more trust in others to do their best in the third session ($F = 7.61$, $p < 0.1$), at the same time as each person's own role is also more secure over sessions ($F = 13.33$, $p < .01$).

We also asked to what degree the participants considered one single person responsible for the co-ordination. It was found that the fire chiefs favoured this to a higher degree than did the staff members ($F = 4.27$, $p = .05$). That is to say, the fire chiefs have not experienced any difference in the staffs' actions, while the staff themselves were more inclined to think that one of them took command.

CONCLUSIONS

The results could not provide any answer to the question of whether a graphical or a textual database would be a better support system for dynamic decision making. Shared situation awareness seems to be less a consequence of the actual support system than a consequence of practice and most possibly of a socially shared co-ordination model. What exactly this shared model or practice contains is not revealed, but the survey suggest that many subjects are getting more confident in their own roles in the team work, as well as others roles, knowledge and actions. Thus, we might say that co-ordination and trust in others are important factors in dynamic decision-making.

Our data show that the teams form a wrong impression of how the fire develops. This might indicate that SA is not about "correct comprehension of the system" or about being a model of the system. Rather than to understand the dynamics of the target system it might be important understand in what way one's actions affect the development. That is to say, to understand the interactions or consequences of the team actions rather than some internal dynamics of the system to be controlled. This might be a subtle and in part confounding distinction. In team work where there is a collective responsibility this of course means understanding not only one's own actions but rather the team's collective actions. This then comes down to co-ordinating activities between team members. As we have seen the subjects become more and more confident in their communication endeavours. We now think that team SA consist more of awareness of co-ordination than perception of system dynamics. Team SA seems to be composed of both an understanding of how the team's actions *affect* the systems development, as well as co-ordination between the distributed units.

It is often claimed that to control a dynamic system the operator needs an understanding of the system, and also have a model of the system We question this. In the emergency centre we have observed the system's dynamics is seldom discussed. The discussions in critical situations are most often centred around whether the description of the incident is correct and what can be done about it. Similar tendencies have been noted in these micro-world studies and so we think that successfully controlling a dynamic system depends on the co-ordinated activity between agents. This does not change the need for adequate situation awareness but it may direct attention away from the situation of the system per se to the resources and practices needed to support co-ordination.

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Situation Awareness as Distributed Cognition

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ABSTRACT

In this paper we argue that the predominant models of Situation Awareness (SA) are inadequate for the study of systems operated by teams. The reason for this is that these models are based on mentalistic assumptions focusing almost exclusively on individuals. We suggest that, to study the control of dynamic systems, it is necessary to shift the unit of analysis from the individual to the whole cognitive system comprising a team of people as well as the artefacts which they use. Thus, our vantage point is the theoretical framework of distributed cognition. Through two field studies we try to demonstrate how team situation awareness is actively constructed via the communicative practices which the team uses in its work.

Keywords

Situation Awareness, Distributed Cognition, Dynamic systems, Co-operation, Co-ordination.

INTRODUCTION

Situation Awareness (SA) is an intermediate state in the decision-making process of dynamic systems where one should be able to comprehend the situation in order to make an appropriate decision for future development. One of the more general and widely agreed upon definitions of SA is "the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future" (Endsley, 1995:36). Endsley is treating the phenomenon in quite traditional cognitive science models with the general focus on attention, perception and memory. SA becomes another box in the individual's mental machinery, "an individual act bounded by the physical facts of the brain and body" (Resnick, 1991:1). The strong mentalistic and individualistic bias in cognitive psychology combined with the primarily focus on the aviation domain (Vidulich, Dominguez, Vogel & McMillan, 1994; Carretta & Lee, 1995; Wang & Houck, 1995) has led SA studies to focus on first person experienced perceptions. These constraints in theory and practice have reduced SA to be an individual mental skill or ability (McMillan, Bushman & Judge, 1995). In the pursuit of a method to unfold this skill or ability, sense-making negotiation and interactive processes as well as technological support are forgotten. However, in most situations involving dynamic decision making and control of dynamic systems the task is undertaken by a team. Domains such as surgery, air traffic and underground line control, process industry and military command all constitute examples of dynamic systems where teamwork is essential and where non-individual-centred approach is also necessary.

DISTRIBUTED COGNITION

The predominant individualistic and mentalistic perspectives take the individual's mental capacity as the starting point. Failure to retrieve information from the long-term memory, or misunderstanding the meaning of representations and the limited capacity of the working memory, are all taken to be the innermost explanation of human error. The human actor becomes a passive recipient of information or an information-processing unit which encodes and retrieves information from memory. However, by adopting the distributed cognition approach (Hutchins, 1990, 1995, 1996) we instead shift our focus from the individual actor to "how information is represented and how the representations are transformed and propagated through the system" (Hutchins, 1995:287). According to this view the people as well as the artefacts they use are regarded as constituting a cognitive system, where cognition is the product constructed as a consequence of co-ordinated work between the units of the system. Cognition thus is a dynamic and emergent construct, rather than a static feature and mental architecture.

Furthermore, cognition is not formed in a social vacuum. Many practices and notions have been formed by earlier practitioners over time, only to become incorporated in the operators' situated actions. Using a distributed cognition approach the task is to describe how cognition is distributed and co-ordinated. However, adopting this framework does not mean, as some antagonists assume, that the individual is abandoned but rather that the individuals' roles are confined to "providing the internal structures that are required to get the external structures into co-ordination with another" (Hutchins, 1995:131).

Distributed cognition requires the analyst to analyse interaction rather than mental properties. Whether we focus on people interacting with an artefact or interacting team members we must understand that cognition is constructed and formed as consequence of the resources and information provided by agents combined with the information and resources the individuals themselves provide. This means that much of the cognitive content and co-ordinated negotiations will not be bound to one single person but will rather tend to be distributed between individuals.

Thus the deficiencies of the traditional approach are overcome by a distributed approach. This approach takes the *system* as the basic unit of analysis instead of the individual. It focus on practices of sense-making instead of mental constraints, and it allows the analysis to see co-operating individuals as a cognitive system.

SITUATION AWARENESS AS DISTRIBUTED COGNITION

As already mentioned most co-ordination centres of dynamic systems consist of a team where each individual has some specific responsibility and roles (see Heath & Luff, 1992; Hutchins, 1990). However, the currently predominant models of SA have little to say about the co-ordinated effort of teams. Some efforts have been made to shape a theory of Team SA (Salas, Prince, Baker & Shrestha, 1995; Wellens, 1993) but no agreed upon theory has so far been formulated.

Most co-ordination centres do not only consist of teams with access to many technological devices, they also tend to be detached from the actual environment they are supposed to control. This means that the operators at co-ordination centres are often connected to the dynamic system via information obtained indirectly. Thus they have no first-hand experience of the actual situation, and consequently no direct feedback. Therefore, they rely on other persons or on artefacts, protocols and descriptions of the situation, and have to actively construct an understanding from the information presented to them. In addition, the different team members have different domain knowledge, as well as different information resources, which must be combined and co-ordinated. Furthermore, time-constraints often apply which call for parallel task execution. The situations confronted are seldom alike and therefore cannot be dealt with by routine methods or by a static prescriptive organisation. Consequently, teamwork calls for negotiation between team members, and we would overlook an essential feature of the team's situation awareness if we attributed the sense-making process to a single individual. The distributed cognition approach, which takes the interactional and negotiational practices as its primarily unit of analysis, avoids reducing team practices to individual or social attributes.

Wellens (1993:272) defined group SA as "the sharing of a common perspective between two or more individuals regarding current environmental events, their meaning and projected future", and Salas, Prince, Baker, Shrestha (1995:131) defined team SA as "at least in part the shared understanding of a situation among team members at one point in time". Although we do not fully disagree with these definitions we would like to stipulate a definition that puts more emphasis on the interpretative and distributed nature of team SA; "The active construction of a model of a situation partly shared and partly distributed between two or more agents, from which one can anticipate important future states in the near future." This accomplishment emerges in a context where artefacts and information technology partly structure the possibility to share and distribute information.

CENTRES OF CO-ORDINATION: TWO FIELD STUDIES

The empirical data through which we will here revisit SA are drastically different from data obtained from the aviation domain. The operators in these settings rarely have visual contact with the scene where a problem may have arisen but which they nontheless have to deal with. In the following we will describe how two teams co-ordinate their assessment of the situation through distribution of tasks and interpretations.

Emergency Co-ordination Centre

Sweden has 20 emergency co-ordination centres (ECC) in which several operators work around the clock receiving emergency phone calls from the public. When a case is identified as being an emergency the operators send out the appropriate resources such as medical help, the fire brigade, the police etc. The emergency centre thus distributes the execution of tasks and is responsible for the co-ordination of the organizations involved until a command unit arrives at the incident and takes over responsibility for co-ordination.

We will here look at a example of how the ECC operators take care of a very complex situation. It is a Friday evening around 8 p.m. and at this time the unit is loaded with calls as, is usual on Fridays. A person calls in and describes, for almost 30 seconds, to operator 1 that she is depressed and has been feeling very ill. Feeling bad or being depressed is seldom an acute state, and in addition it is an awkward way of introducing oneself to an emergency centre if one expects to receive quick help. Therefore it is no surprise that the stressed operator responds in a rather reserved but polite way[1].

Time	Operator 1	**Operator 2**
0.00	SOS-Central (inaudible)	[Works with another case]
	And how do you feel now?	
0.28	Ω [listens through headphones]	
	Have you done it yourself	[Hangs up]
0.32	Why?	
	Ω	
0.38	*[Call for Assistance]*	*[Looks around]*
0.47	Ω	
0.49	It is still in your arm now, is it?	[Takes assistance]
0.54	Ω	Ω
	Huh, it a big knife then?	
0.58	Ω	
1.00	Let it stay there till the ambulance comes	*[1]Let it stay there do not move anything!*
1.02	Ω	Ω

We can see how operator 1 is polite and answers the 30-sec.-long statement of being depressed by asking how the caller is feeling now. The caller replies by saying that she driven a knife in her arm. Operator 1 maintains his composure while he responds. Usually, when something like this happens the operator who has taken the call recites aloud significant words uttered by the caller, thereby making it possible for a second operator who is not busy, to pay attention and become aware of the existing problem. At the same time operator 2 is looking around in the room by mere routine, not paying any attention to the particular call or to operator 1. He does not seem to get the impression that the call is urgent. Shortly thereafter operator 1 calls for assistance and operator 2 directly 'taps in' to the call and is then able to hear the caller through his headset. Note that does not, when he taps in to the telephone call operator 2 know anything about he actual emergency since he lacks the information from the caller. The first operators' suspicion can be explained by the primacy effect where what comes first still affects the interpretation of later information. However, when hearing about the knife in the arm but having not heard the beginning of the conversation, operator 2 is not suspicious. Instantly he reacts to the latest information by telling operator 1 to tell the caller not to move the knife. This illustrates how the team SA develops as different operators with different domain knowledge and information contextualisations get involved.

In the subsequent episode the operators become startled by what the caller tells them; the knife has been in the arm for about 20 hours! Could this really be true? Operator 2 asks about the described situation to operator 1, and the latter in turn nods vigorously. Then operator 2 undertakes the process of deciding which ambulance to send. He therefore involves operator 3, who is responsible for the information of the location of the ambulances.

Time	**Operator 1**	**Operator 2**	**Operator 3**
1.11	And you did this last night, did (..)		
	Ω		
1.16	*[Nods]*	*Uhuh, [towards 1] Is the knife still there?*	
1.17	Ω	Ω	
	[Writes the phone number into the	ooh, damn it	
1.28	database]	Ω	
		[3]What do you think [3] What ambulance do	
1.30	Yes	*we have in town?*	
	Ω	*[3]Should we take ambulance 4?*	
1.31	[repeats phone number]	Ω	
	Ω	Ω	
1.34			*[2]Yeah, we could, yes uhu You..*
1.35	Yes, and what is your name then?	*[3]Do you have contact? No.*	
1.37	Ω	Ω	
1.40			*[2]No, [town], u'know No, take 941 then*
1.41	Door... Are you able to open the door?	*Uhhuh*	

Operator 1 asks the caller for her 'phone number and name in order to match those with the information on a 'phone number database. This matching procedure is yet another way of establishing the identity and credibility of the caller. By using the database to do this we can say that the assessment of the situation is distributed between the operator and the information contained in the database he accesses. While operator 2 is asking operator 3 about the status of the ambulances the former is at the same time listening via the headset to operator 1 who is asking the caller further questions. Operator 2 must send an ambulance instantly, but must first also co-ordinate with operator 3 about the availability of ambulances in the area.

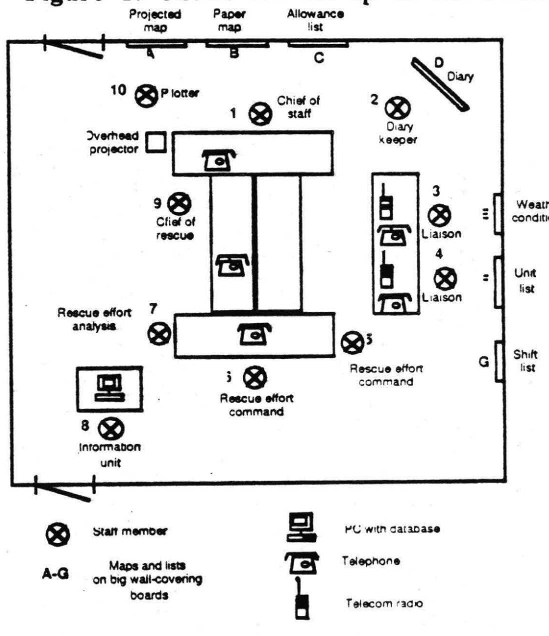
However, matters get more complicated! It turns out that the caller, who is almost unconscious, has locked the door of her apartment from within. Without access to spare keys, the emergency management operators will have to arrange to breakdown the door to the apartment. Again it is operator 2 who lets operator 1 understand what must be done. Operator 1 in his turn notifies the caller that the door has to be forced to enable medical help to reach her. The awareness and anticipation of the situation is once again distributed between the operators and must be co-ordinated by communicative acts. Operator 2 then calls the ambulance which has been suggested by operator 3. While the fire brigade was sent to force the door so that the paramedics could enter, the police were also notified of the action taken by the fire brigade. Once again this notification procedure was distributed and conducted in parallel; operator 1 called the fire brigade while operator 2 simultaneously called the police. The cognitive tasks of co-ordinating the many items of information - already known information, the information given by the caller, the information provided by the other operators, the information accessed through the database, the allocation of resources, the aspects of the personal status, the information order etc. - are all indeed emergent, cognitive co-operative accomplishments.

Team situation awareness through public representations

The second field study, which we will present here, is based on a staff command training session at the Swedish Rescue Services Agency. The purpose of the training was to practice staff command strategies and techniques. The participants in the training session were all highly skilled professionals, meaning that many of them had several decades of experience from their particular domains. They represented professions such as coast guard, fire chief, police inspectors, local and provincial authority rescue services etc. During the training session the team members were constantly given information from a special 'simulator group'. This group consisted of people from the National Rescue Services Board, all experienced in training rescue control. The simulator group closely monitored the activity of the team and fed it with the appropriate information according to a prepared scenario. Thus the members of the simulator group simulated the fire brigade, police, ambulance etc. at the scene of the accident.

The scenario which the rescue command group was faced with during this particular session was a leaking valve on a train wagon filled with 45 tons of LPG (liquefied petroleum, commonly referred to as bottled gas). The increasing temperature at the leaking valve in combination with the high pressure created a major explosion threat. Considering the fact that the rest of the train consisted of similar wagons also filled with LPG, the team was faced with the potentiality of a gigantic catastrophic explosion. The set-up of the rescue command room is illustrated in Fig. 1. As can be seen from figure 1 the rescue command room contained a lot of different artefacts all of which were essential to the work of the staff, though in quite different ways. However, we would like to maintain that all of these artefacts are not simple filters of reality but rather active elements in the construction of the operators' model of what is happening at the scene of the accident. In other words, these artefacts are essential in the process where the team members construct a model of the system they control and are responsible for.

Figure 1: Shows the set-up of the room



In the upper right corner in the layout of the control room we find a diary (artefact D). The diary consists of a big paper pad which the diary keeper (nr 2) constantly updates. The role of the diary is twofold. First, the information coming to the staff from the units at the scene of the accident is taken down. Second, all the decisions taken by the rescue command team are recorded. The diary is updated on a temporal basis so that the exact time is written in front of each incoming piece of information or decision taken. Ten minutes after the staff has come together the delayed chief of rescue (nr 9) arrives to the staff. While the chief of rescue is taking his position, the chief of staff (nr 1) starts to brief him on the situation. But just as the chief of staff starts doing that, he pauses, turns round and takes a long look at the diary (artefact D). While he is still looking at the diary the chief of staff begins the briefing. Eventually, the chief of staff takes his eyes from the diary and faces the chief of rescue and continues the briefing.

Analyzing this situation from a distributed cognition point of view, we can say that the chief of staff, *together* with the diary briefs the chief of rescue. The chief of staff does not, and cannot, keep in mind all the events that have occurred at the scene of the accident, as well as the decisions taken by the rescue staff in the preceding ten minutes. There is simply too much information. Due to the time pressure the diary denotes only a brief sentence of every event. This means that the diary as such contains only the necessary but not the sufficient information on the decisions and events. When looking at the diary, the chief of staff has to actively interpret the information displayed on it and construct a history of the situation so far. Thus, in this particular instance the diary contributes to the team's *retrospective situation awareness*. It helps the team to understand how they got to where they are at the moment.

Moving over to artefact F, on the right hand side wall, we find a list including all the units which the rescue command team disposes and which are sent to the scene of the accident. Responsible for updating this list are the two liaison operators (nr 3) and (nr 4). When they receive information about the units they add it to the list. By doing that the liaison operators also make the information accessible to all their team members, so that everyone in the room can easily obtain the represented information on the unit list by looking at it. For example when the rescue effort analyst (nr 7) needs to know how many police units and which ones are commissioned to the area around the accident site he does not have to ask the liaison operators who have quite a hectic time. Rather he takes a look at the unit list and thereby retrieves the information he needs. Through its public representations, meaning that they are immediately available and accessible to all members, the unit list becomes one of several artefacts which contribute to the formation of the team's *contemporary situation awareness*. Of course each team member could have had his own list containing the information about the unit status which is relevant only to his own sub domain. But then each individual list would have looked different since the staff members would have had to find a way of constantly updating each others' lists in order to obtain a shared understanding.

Finally we will briefly examine artefact A, at the top of the figure, which is a line-art map of the accident area. This map is projected by an overhead projector on a whiteboard. The map is relational and only indicates the position of the train with the leaking gas wagon, a nearby plant as well as urban areas which could be threatened by the gas cloud that would follow from an explosion. Furthermore, the line-art map contains specific representations only for that particular context, and is thus stripped of other sorts of information such as a street grid of the residential areas around the accident scene. The plotter (nr 10) can draw movements of units, weather conditions or any other features that he wishes to display on the whiteboard where the map is projected. The very fact that map A is projected on the whiteboard makes it possible write on the projection and thereby add or remove information in an easy, flexible and quick way.

About an hour into the work of the rescue command team we find a 'bubble' drawn on the line-art map. This bubble represents the spread of a gas cloud, which would follow an explosion under the current weather conditions. Thereby, the current information on this map indicates the most possible future state of the accident scene within the time scale which the team has chosen to work with. We have to remember that part of the work of rescue management control is to try to predict the future situation and to suggest necessary actions in order to limit any deterioration of the emergency and prevent further damage from taking place. Therefore the team need to work on a different time scale than the ones 'out there'. Quite a few times during the team's work we find several team members in front of this future status map engaged in serious discussions accompanied by a lot of pointing on different spots on the map. In other words the line-art map helps the team members constitute a *prospective situation awareness*.

The three artefacts which we have used as examples in our analysis indicate that they do indeed play an active role in the formation of the teams situation awareness. Their role in the propagation of information around the rescue command cognitive system can be described as acting as *cognitive catalyzers*. That is because the artefacts contain the necessary but not the sufficient information. The team members must in addition interpret the information and make sense of it. Therefore we can also say that the artefacts must be considered as equally important parts in the process of building up a model of the situation 'out there'.

CONCLUSION

It is interesting to notice that in an environment where the process as well as the information is truly distributed no single team member or artefact can be said to constitute an information hub in its on. All team members and artefacts should be considered as integral parts of the rescue command cognitive system. This also means that there can exist a collective state of mind which is not represented in any single locus (Weick & Roberts, 1993). We also want to point out that it is as possible to identify the temporal aspects of team situation awareness when adopting the distributed cognition as it is when considering individual SA (Endsley, 1995).

In the illustrations which we have provided it was evident that the teams' model of what was going on in the system was clearly distributed. In the first example this is done through extensive discourse and a delicate practice by which operators anticipate each other and the future situation. In the second example we examined the role played by the publicly represented information displayed on the artefacts which they used. We found that the artefacts are integral parts of whole cognitive system and the way it works. In both our field studies we found that discourse as well as artefacts have to be actively and collectively interpreted by the team members in order to make sense and so contribute to the construction of shared SA. We suggest that the future development of the concept of SA must take into account the distributed nature of cognition. Otherwise it will fail to provide essential insights into how people control dynamic systems.

Footnote

[1]The transcription is a simplified version and only includes talk between the operators that is connected to this incident. Some of the facts of the incident have been changed to make it anonymous. Text in italics signifies co-ordination and communication between the operators. The omega sign (Ω) is used to signify the caller's remarks (not transcribed) which reach the operator though the headset. [1-3] means that the talk is directed to operator 1-3.

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Reconsidering Advisory Work in Agriculture

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ABSTRACT

We studied various situations of interactions between farmers and advisors in order to determine how to adapt advisory work to the new challenges agricultural sector has to face. To analyse these situations, we drew a framework based on the hypothesis that advisory activity can be seen as a mediating activity that the advisor exerts between the farmer and the farm he (she) manages. Our first results show a variety of styles of interaction as well as few co-operative activities between advisors and farmers. We now plan to use these analyses to discuss with advisors how to increase co-operation between them and farmers as this seems to be necessary to face the new needs expressed by farmers.

Keywords

Human-human interaction, decision support activity, farm management.

INTRODUCTION

In agriculture, during the last 30 years, advisors played a key role in technological transfer. Their role is nowadays reassessed due to new requests expressed by farmers in terms of farm management support. According to these requests, their role is less to behave as an expert than to be able to adjust their style of co-operation to the situation, e.g. to the problem to be handled and the farmer to be advised.

Few researches have been undertaken in order to describe the way farmers and advisors co-operate in problem solving. Anthropologists studying the interaction between farmers and showed that farmers and advisors have different conceptions of farm management and livestock husbandry (Darré, 1994). They found that such discrepancies were due to different norms of actions issued from different knowledge systems: a technical one for the advisors, a practical one for the farmers. Sociologists showed that the way advisors interact with farmers is related to the way the advisor conceives his (her) work: some conceive it as local development support, others as farmer education, ... Such analyses do not help really in identifying which activities advisors have to develop in order to adjust their co-operation style to the situation of interaction.

Therefore, we propose to consider that advisors have a mediating role between the farmer and the process that the farmer manages (a farm, a crop, ...), meaning that, to exert their role, advisors have to combine two different skills: (i) technical skills which include knowledge about the management objects, about the actions to be undertaken to control the production process, and about the way farmers manage their farm; (ii) communication skills which include know-how about discourse organisation so that advisors are able to understand farmers' problems and to help farmers in their solving.

Moreover, the combination of these skills for a management support activity implies that the advisor adapts his (her) own point of view on management to the farmer's one in order to capture farmer's management style and problems. Therefore, we suggest that farmers and advisors have to develop co-operative activities allowing them (i) to detect and solve interference between their management goals, (ii) to build a common framework of reference, (iii) to build a model of oneself and the other agent as suggested by Hoc (1998).

MATERIAL AND METHODS

Using this framework, we analyse the way advisors and farmers interact while different management support activities. Table 1 sums up the number of different situations we followed. The situations of interaction not only differ by the object of management (crop *versus* farm), they also differ by the number of farmers interacting with the advisors (a group of farmers *versus* one farmer), by the location (indoors *versus* in front of the process) and by the timing (before any action has to be done to control the process *versus* time of action).

Table 1: Classes of observed situations of interaction

Situations of interaction	Observed Number
Collective advice (50 farmers), before action, crop management support, indoors (RMS)	3
Collective advice (15 farmers), time of action, crop management support, indoors (TDPS)	6
Collective advice (15 farmers), time of action, crop management support, outdoors	6
Individual advice, before action, farm management support, indoors (TDPP)	3

We recorded the exchanges occuring during these meetings. We also analysed 40 documents written by advisors after individual meetings, and had self-confrontation interviews about the way advisors filled these documents. Data collected during interactions have been processed using the grid of analysis presented in table 2, and data collected during self-confrontation interviews have been analysed to detect the way advisors use the information they store on the documents.

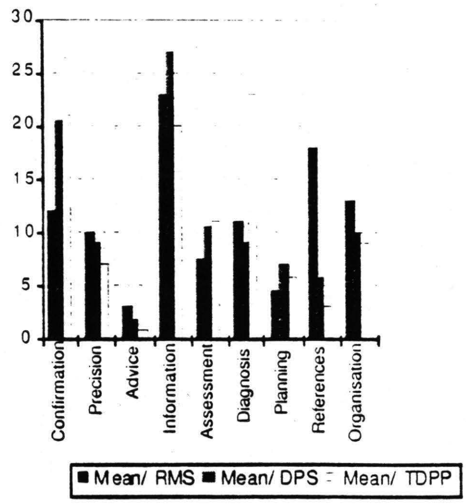
Table 2: The grid of analysis of the discourses collected during interactions

Coded category	*Explanation of the category*
Organisation	Anticipation of next interactions
Information	General rules of action, general knowledge, circumstantial data
References	External sources of data on crop production or on farming systems
Assessment	Established facts or appraisal of farmers results
Precision	A specification of a previous statement
Diagnosis	Analysis of a cropping or farming situation
Planning	List of actions to be realised on a crop or on the farm
Advice	Advisor commits him(her) self
Confirmation	(yes, no, I don't know, repetition of the last words said by a agent)

RESULTS

For collective advice, we observed that most of the interactions are devoted to exchanges of what we called "information" whether looking at each recorded situation or at the mean for the various situations we identified (RMS, TDPS, TDPP). Still on a mean basis, few differences appear between these various collective situations of interaction: we notice an increase of farmers participation during TDPS and TDPP interactions and a reallocation of "references category" to "diagnosis one" when the meetings occurred outdoors (figure 1).

Figure 1: respective parts of each category for the various collective situations (% of total coded category for all the advisors)



The recorded individual advisory situations also allowed us to point out different styles of interaction. Some advisors act more as experts, coming onto the farm to collect data in order to prescribe management improvements, while others act more as consultants trying to catch the farmer's opinion. The self-confrontation interviews showed that advisors also differ in the information they store: some only keep data on the problems they have detected, while others try to keep all the information given by the farmer.

These results suggest that that styles of interaction are more linked to the advisor's personal features than to other factors such as those above. We now plan to use these results to discuss with advisors the difficulties they meet while interacting with farmers and about the interest of improving advice efficiency through developing more co-operative interactions.

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Diagnosing ineffective performance in the domain of Emergency Management: performance modelling and its decomposition

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ABSTRACT

The Emergency Management Combined Response System (EMCRS) is the co-ordination system which plans for, and controls, agencies, such as fire, ambulance and police, when they respond to emergencies, such as explosions, aircrashes etc. An initial combined agency (CA) model of the planning and control of the EMCRS describes its overall 'actual' performance, as concerns its plans. This model supports the diagnosis of co-ordination problems between agencies. However, at present, it fails to take individual agency plans into account. This paper describes an attempt to improve diagnosis of co-ordination problems by decomposing the EMCRS into its parts and modelling each individually, with respect to their plans. The CA model is then used, with individual agency models, to re-interpret overall EMCRS performance. It is concluded that EMCRS decomposition supports more accurate diagnosis of the effect of the co-ordination problems on its overall performance.

Keywords

Planning and control, emergency management, performance, co-ordination.

INTRODUCTION

This paper presents work to develop a model to diagnose the ineffective planning and control performance of the EMCRS, as occasioned by co-ordination problems between agencies. Section 1 describes the EMCRS and the initial CA model thereof. The need is identified to decompose the system into its parts and to model each individually. Section 2 outlines the single agency models for the fire and ambulance agencies, with respect to example co-ordination problems. Section 3 relates the CA model to the single agency models. This relationship provides a more accurate expression of EMCRS overall planning and control performance, and so more accurate diagnosis of the effect of the co-ordination problems. Section 4 presents a summary of the work and future plans.

EMCRS AND THE INITIAL CA MODEL

The EMCRS is composed of agencies required for a disaster response, and has a three level planning and control structure. The EMCRS has objectives (plans), common to all agencies, not withstanding their individual responsibilities. These objectives are (in descending priority): to save life; to prevent escalation of the disaster; to relieve suffering; to safeguard the environment; to protect property; to facilitate criminal investigation and judicial, public, technical or other inquiries; and to restore normality as soon as possible (Home Office, 1994). The EMCRS was set up to support better co-ordination between agencies responding to disasters, such as explosions, aircrashes etc.. The individual agencies relate their own plans by means of those of the EMCRS, to interact effectively with each other. Each agency plan specifies a set of functions, for example: fire service - rescuing trapped casualties; preventing escalation of the disaster; providing a cordon around the immediate hazard etc..

An initial CA model of EMCRS planning and control has been developed elsewhere (Hill and Long, 1996) from the Planning and Control for Multiple task work (PCMT) framework (Smith, Hill, Long and Whitefield 1997), and data from an EMCRS training exercise. This model distinguishes the interactive worksystem (here the EMCRS, comprising one or more users and computers, devices or equipment), from its domain of application, constituting its work (that is stabilising a disaster). The effectiveness (performance) with which work is carried out, is a function of: the quality of the task (i.e. whether the goals have been achieved), and the resource costs to the worksystem (i.e. the effort etc. required to achieve the work goals) (Dowell and Long, 1989). Overall EMCRS performance thus expresses whether goals, e.g. preventing escalation of the disaster, have been achieved.

The CA model has been used to identify planning and control co-ordination problems between agencies, by identifying 'conflict' behaviours. These conflicts constitute the 'co-ordination problem'. A behaviour conflict may reduce overall EMCRS performance by either hindering goal achievement, and/or by rendering resource costs un-acceptable. However, defining accurately effects of these problems is difficult, due to trade-offs between individual agencies' performances. For example, the police service wish to preserve the disaster site as a 'crime scene' (vandalism is suspected), and to catch the criminals, and so require the fire service not to trample the site; and the fire service, who slow the rescue of casualties, and are less effective in fire prevention, if they do not trample the site. The CA model describes the 'actual' overall CA performance with respect to EMCRS common objectives. The co-ordination problems identified thus do not take account of the performance trade-offs between agencies. Here, the CA model describes an overall EMCRS performance deficit which derives from the police and fire services. Trampling by the fire service reduces the chances of the vandals being caught. Carrying out minimal trampling reduces rescue of casualties and control of the fire. These overall deficits derive from the common objectives, i.e. to save life (casualties not rescued); prevent escalation of disaster; (fire not controlled); and to facilitate criminal investigation (vandals not caught).

However, each agency has its own disaster plan. These plans describe agency functions/tasks and their priorities. To express accurately overall EMCRS performance, account must be taken of these plans. For example, the fire service plan states: 'Investigation work will not take precedence over the necessity to rescue casualties, fight fires, or the protection of lives and property from fire or further deterioration. Every effort must be made by the Fire and Rescue Commander to preserve the scene intact.' (Chief and Assistant Chief Fire Officers' Association, 1994). The fire service should keep their trampling to a minimum, to preserve other fire service behaviours. Thus, for this co-ordination problem, there is no fire service performance deficit, as the actual performance effected by minimal trampling, is equal to the planned performance, which allows effects of minimal trampling. Thus, although there is still a police service performance deficit (minimal trampling still reduces vandal apprehension), the overall EMCRS performance deficit is less than was identified by the CA model.

There is a need, therefore, to decompose the EMCRS into its parts and each agency to be modelled individually with respect to its plans. These single agency (SA) models describe planned individual agency performance with respect to CA actual performance, that is, overall EMCRS actual performance. The CA model can then be re-interpreted with the help of the SA models, to diagnose more effectively overall EMCRS performance, as concerns planning and control co-ordination problems.

SINGLE AGENCY MODELS

SA models have been developed for the fire, police and ambulance agencies. They describe 'planned' performance of an individual agency with respect to the CA 'actual' performance. The data are a subset of the CA data. Six training exercise behaviour conflicts have been identified as co-ordination problems. The models describe only planned performance, as it relates to behaviour conflicts and their effects. Only two behaviour conflicts are described here, involving fire and ambulance services, due to space limitations.

Behaviour Conflict 1: Trampling

The police declare the site a 'crime scene', because there is some suggestion of vandalism. The fire service and the ambulance service are thus expected not to trample what might be evidence. The CA model describes 'actual' behaviours of fire and ambulance services as minimal trampling, without affecting their other behaviours (and so the associated performance). For the fire service performance is: expeditious rescue of casualties, and effective fire containment; and for the ambulance service performance is: expeditious casualty access and subsequent transferral to hospital. The fire service SA model shows that actual performance (P_A) is equal to planned performance (P_p), as their plan specifies that minimal trampling may be carried out, but should not hinder rescue or other fire service behaviours. Such behaviours are not hindered, hence $P_A = P_p$. In contrast, for the ambulance service $P_A < P_p$. Their plan does not mention trampling, so minimal trampling reduces their performance to less expeditious casualty access and transferral to hospital.

Behaviour Conflict 2: Inner Cordon Restrictions

Severe structural damage has occurred within 30 metres of the disaster. The CA model describes 'actual' fire service behaviours of setting up an inner cordon to contain the disaster. The fire service are responsible for personnel safety therein. Entry to the cordon requires regulation safety equipment. The cordon, however, was set-up without informing the ambulance service. The CA model describes the 'actual' ambulance service behaviours of arriving at the scene, without regulation safety equipment and so refused entry. Without entry, they cannot carry out triage and so cannot prioritise casualty transfer to hospital. The fire service then have to move casualties to the edge of the cordon, for ambulance service triage.

The SA model for the fire service shows $P_A < P_p$. The cordon was set up without informing the ambulance service, which is not in accordance with their plan. Additional casualty movement had to be carried out as a result, reducing their primary function of fire containment. The SA model for the ambulance service shows $P_A < P_p$. According to their plan, they should have been informed of the need for regulation safety equipment, to enter the cordon, allowing triage etc. The SA performance expressions are now related to those of the CA performance for the two behaviour conflicts.

RELATING THE MODELS

Behaviour Conflict 1: Trampling

The initial CA model describes CA PA < CA Pp, as a performance deficit is identified for both police and fire services; and police and ambulance services. The overall performance deficit can be re-interpreted using the SA models as follows:

Trampling (fire service)

If SA1 PA = Pp and SA2 PA < Pp,

then CA PA < CA (SA) Pp

and (CA PA < CA (SA) Pp) < (CA PA < CA Pp)

If the fire service (SA1) actual performance equals its planned performance (their trampling behaviours not reducing their effective fire containment and casualty rescue), but the police service (SA2) actual performance is less than its planned performance (their crime scene preservation behaviours hindered by fire service trampling, which reduce their effective vandal apprehension), then CA actual performance (CA PA) is less than the CA planned performance, given SA planned performance (CA (SA) Pp). However, the performance deficit (CA PA < CA (SA) Pp) from the CA(SA) model is less than the performance deficit (CA PA < CA Pp) of the CA model (the CA(SA) model identifies only the police service as having a performance deficit). Thus, the overall EMCRS performance deficit is less than originally identified by the CA model above.

Trampling (ambulance service)

If SA1 PA< Pp and SA2 PA < Pp,

then CA PA < CA (SA) Pp

and (CA PA < CA (SA) Pp) = (CA PA < CA Pp)

If the ambulance service (SA1) actual performance is less than its planned performance (their trampling behaviours reduce expeditious casualty access and recovery), and the police service (SA2) actual performance is less than its planned performance (their crime scene preservation behaviours hindered by ambulance service trampling, reducing their effective vandal apprehension), then CA actual performance (CA PA) is less than the CA planned performance, given SA performance (CA (SA) Pp). The performance deficit (CA PA < CA (SA) Pp) of the CA(SA) model is equal to the performance deficit (CA PA < CA Pp) of the CA model. A deficit occurs for both the police and the ambulance services. Thus, the overall EMCRS performance deficit, identified by the CA model, in this instance, is accurate. However, the ambulance service SA model has identified that trampling behaviour is not specified in their plan. Were trampling behaviour to be specified, as in the fire service plan, then their performance would not be in deficit.

Behaviour Conflict 2: Cordon Restrictions

The CA model describes CA PA < CA Pp, as a performance deficit is identified for both fire and ambulance services. SA model re-interpretation follows:

If SA1 PA < Pp and SA2 PA < Pp,

then CA PA < CA (SA) Pp

and (CA PA < CA (SA) Pp) = (CA PA < CA Pp)

If the fire service (SA1) actual performance is less than its planned performance (their failure to inform the ambulance service of the cordon's set-up reduces fire containment, as they have to move casualties, instead of fire fighting), and the ambulance service (SA2) actual performance is less than its planned performance (their casualty access behaviours reduced, (fire service failure to inform them of the cordon set-up), and so also casualty assessment and prioritisation), then the CA actual performance (CA PA) is less than the CA planned performance, given the SA performance (CA (SA) Pp). The performance deficit (CA PA < CA (SA) Pp) of the CA(SA) model is equal to the performance deficit (CA PA < CA Pp) of the CA model. A performance deficit occurs for both fire and ambulance services. Thus, the overall EMCRS performance identified by the CA model, in this instance, is accurate.

SUMMARY AND FUTURE WORK

This paper has described an attempt to improve the diagnosis of overall EMCRS performance by decomposing the system into its individual parts (agencies) and modelling each, with respect to their agency plans. It is concluded that EMCRS decomposition supports more accurate diagnosis of the effect of the co-ordination problems on overall EMCRS performance. Future work will acquire additional data to validate further this modelling and decomposition technique.

Acknowledgement

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The Coordination Mechanism and Cooperative Work

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ABSTRACT

The paper describes an attempt to integrate coordination into an HCI framework, within a discipline of cognitive engineering. This attempt should also reconcile better the different traditions of HCI and CSCW.

Keywords

Coordination mechanism, speech act, cognitive engineering, worksystem, structure, behaviour, domain, effective/ineffective work.

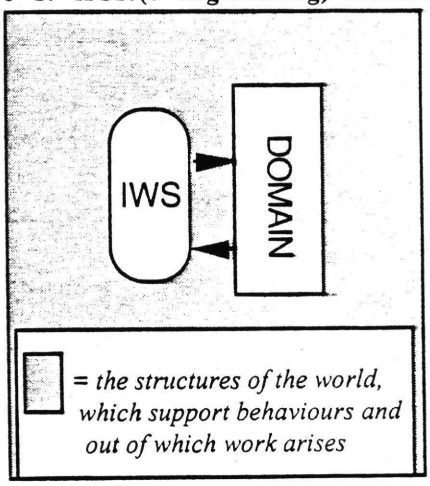
INTRODUCTION

Our research derives from a proposal (Dowell, Pigeon & Long, 1995) which rests on the recognition that coordination had been identified as a significant weak point in the performance of the emergency services (Hidden, 1989). Dowell (1995) had identified 'coordination issues', and our task was to focus on the 'mechanism' of coordination as part of a case study of the train collision which took place in the Severn Tunnel in 1992. We use the term 'coordination mechanism' (CM) to refer to the structure which supports a class of behaviour.

Modus Operandi

Our basis for the development of such a structure as the CM is the idea of cognitive engineering which underlies the conception of HCI as an engineering discipline (CE) (Dowell & Long, 1989 and 1998). This idea consists in the research and practice of solutions to design problems of a cognitive nature, where the motive for the design is to achieve *effective* work, via the behaviour of an *interactive worksystem* (IWS) (hereafter 'worksystem') defined with reference to the *domain* of work (hereafter 'domain'), itself defined by the design requirements.

Figure 1: HCIe(e=engineering) framework



The worksystem bounds the behaviour of agents/cognitive devices, and is supported by *structures* (Fig.1). Cognitive engineering operates with explicit knowledge and aims for an adequate level of guarantee. There is, further, a clear distinction to be made between scientific knowledge and engineering knowledge, the latter bringing with it no assumptions of a scientific nature. CE may employ models from any source, including science, but it is constrained by the design practices of the discipline. Such models are, therefore, 'conjectures' in the same sense as meant by Popper (1959): that, in science, the rationality of competing 'conjectures' is determined by scientific practices - not their origin. Similarly, models for engineering, whatever their source, are 'conjectures' assumed for a design purpose - their status is determined by the engineering practices. In this spirit, what follows has to be considered largely 'conjectural' (even though the models we employ have been applied in HCI and CSCW design practice).

As well as describing the early stages of the research, this brief exposition of the work should contribute to bringing closer some of the distinct strands of HCI and CSCW. In the first place, the cognitive engineering approach of the research is indifferent to the source of potential design models; and, secondly, elaboration of the idea of a CM might bridge the gap between HCI's tendency to focus on individual cognition and the socially based cognition of CSCW.

Approaches to Cooperative Design

"Conceptualization is, in principle, a coordination of viewpoints....Conceptual thinking is a cooperative effort." Schmidt (1991) goes on to say that there is no inherent difficulty, for us, in coordinating. However, in certain instances we need to do it more effectively. We come, then, each enabled for coordination. The challenge is to see in what this coordinative competence consists; and to refine it for the purposes of design. Schmidt provides analyses and categorisations, in general terms, of how and why people cooperate; and Rasmussen (1991) offers a framework for distributed decision making. Neither, however, targets what supports interaction between individuals who are doing effective cooperative work.

COORDINATION

Groundwork

Since it is legitimate to take up models etc., all the while checking and adapting them for the purpose of solving a design problem, it was considered valuable (cf. Schmidt's quote above) to think in terms of distributed cognition (DC), as exemplified by the work of Hutchins (1989 and 1995). He writes (1989), "The distribution of labour can only be negotiated if the distribution of knowledge and ability is at least partially redundant". That is to say, any coordination presupposes a common or shared view: that *relevant* knowledge is held publicly and transparently. This contrasts with the Distributed Artificial Intelligence (DAI) view of Shaw & Fox (1993) who note that of the 'agents' in AI collaborative work, "each...only possesses local view" (sic), and that it is *on account of this fact* that they must coordinate with other agents "to achieve globally coherent and efficient solutions".

Coordination is central for both Hutchins and Shaw & Fox. However, Shaw & Fox attempt to individuate a 'coordination mechanism'. They write: "The design of coordination can be viewed from three different perspectives: the *information content*, the *exercise of control*, and the coordination mechanism" (our italics).

The Coordination Mechanism

Can we, therefore adopt Shaw & Fox's characterisation of the CM as a starting point for our own conceptualisation, while acknowledging the cogency of distributed cognition? It is difficult to relate, in any rigorous way, the intuitive concept of cognitive coordination with one from DAI, which is, in a sense, an anthropocentric gloss on a technical expression of solutions to AI design problems. However, the very simple nature of the enquiry, in cognitive terms, may provide useful pointers. What they mean by 'information content' is relatively uncontroversial. 'Exercise of control' is less clear, but they go on to write, "the initiative to coordinate ... may be self directed, externally directed, mutually directed or a combination of them". The agents' coordination, then, might be described as having different sources of motivation or goal-orientation with respect to each other, individually or mutually, or with respect to the system.

To develop this 'primitive' notion of a CM in the direction of DC, and since we are concerned with coordination of the widest variety, we take our cue from Clark (1996), who asserts that "language use and joint activity are inseparable". However attentuated it might be, there is an element of communication in any cognitive coordination. We could look then to linguistics for inspiration; and a convenient template for such a structure might be the *speech act* (Austin, 1962), with its *illocutionary* and *propositional* components[1]. Our CM, then, consists in what we shall call an *attitude* (where 'attitude' is evaluative or goal-oriented) and a *content* component, corresponding to the illocutionary and the propositional. The CM has a much broader application than the structure of the speech act as utterance (cf. Rogalski & Samurçay, 1993), and coordination behaviour often takes place without language, yet arguably supported by such a structure, even conforming with the Gricean account of 'non-natural' meaning: "'[S] meant something by x' is

[1] E.g., "The bull is charging" as well as expressing a simple *proposition* may have the *illocutionary* force of warning.

(roughly) equivalent to '[S] intended the utterance of x to produce some effect in an audience by means of the recognition of this intention'"(where S = speaker) (Grice, 1957). If we substitute 'execution' for 'utterance', and 'spectator' for 'audience' we can capture the 'attitude' and the 'content' of the CM, linguistic or not.

We have, thus, started with an idea of coordination which is intuitively attractive (DC) and widely accepted in CSCW, returned to an austere alternative in the form of Shaw & Fox's coordination mechanism, and attempted to wed them by adapting the use of the well-worked-out speech act schema to the function of inter-agent coordination Though borrowing from Speech Act theory, the cognitive aspect of coordination need not presuppose a linguistic element and so corresponds broadly with Clark's (1996) notion of 'joint activity'. Conversational Analysis supporters should not be sceptical because it is based on Speech Act Theory (see Schegloff, 1988), since the CM is employed in an engineering context. Schegloff's concern is conversation, generally, and, as such, is not domain-related, in the strict sense stipulated by our cognitive engineering.

COGNITIVE ENGINEERING & THE CM

Our approach to cognitive engineering, after the conjectural and analytic investigative stages, requires a kind of conceptual testing which we call 'proto-operationalisation' (Stork, Lambie & Long, 1998). This is essentially the repeated application and revision of the conjectural concept to the observations of a case study (with a view to re-design): in this instance, the Severn Tunnel Accident (Seymour, 1993).

"If the worksystem is well adapted to its domain, it will reflect the goals, regularities and complexities in the domain." (Dowell & Long, 1998).This expresses the rationale for uncovering links between the complex of tasks and the structures of the worksystem. One of the components of the CM (attitude) is determined by perceived task goals of the domain (see footnote 1: Do you try to identify the breed of bull, wonder at its strength, or run for your life?); the other (content) refers to the states of the actual domain (The bull is running from a to b, and you are situated at b). In the Severn Tunnel Accident report, a misunderstanding over the location of the trains involved in the accident was a crucial factor leading to ineffective emergency management; and we wanted to see how this might exemplify the mapping of the requirements of the domain to the purposeful behaviour of the worksystem.

We took this misunderstanding as a potential CM and characterised it as follows: the 'content' of the potential CM is the objective location of the trains. The 'attitude' component could be multi-faceted, and, in this case, relevant features might include the manner of location designation and the mode of delivery. In the Severn Tunnel accident the location was expressed, over the phone, in the British Rail standard of miles and chains, but the speaker added, more colloquially, "fifty yards from the Bristol end" (which was, in fact, the wrong end); and the whole expression was said to have been delivered "in a definite and concise manner". As a consequence, the person at the other end of the telephone line acted on the colloquial description. In this case, the perceived task goal was, "Carry on and relay the interpreted message". In the projected design, desirable task goals are for the speaker to describe the location univocally, or for the listener to question any mixed mode of location description, irrespective of the perceived or actual role or authority of the speaker.

CONCLUSION

The CM, thus, provides place holders for the specification of agents' coordination - coordination which has been identified as faulty or absent resulting in ineffective cooperative work, with respect to the domain. In this way, and in accordance with Dowell & Long (1989), the CM is a structural interface which supports an element of *behaviour* in a *worksystem*, delimited and defined by a *domain* of work; and the CM, a *structure* supporting that behaviour, refers both to the required task goals (attitude) and to the actual states (content) of that domain.

Finally, with respect to the CM's part in facilitating the narrowing of the gap between HCI (as an engineering discipline) and CSCW, Clark (1996) writes, "cognitive scientists have tended to study speakers and listeners as individuals... social scientists, on the other hand, have tended to study language use primarily as a joint activity", but "the study of language use must be both a cognitive and a social science". As cognitive engineers, we hope to enable a similar integration with respect to design, with the help of the CM.

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Cognitive Model of Debugging Expertise

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ABSTRACT

We present in this paper our model of debugging expertise of complex computer systems. This model is based on a psychological cognitive approach of debugging which we consider a central activity in programmer-computer interaction. This model takes into account three aspects: stimulus structures processed by the programmer; knowledge structures which allow him to process the problem's data as well as the domain knowledge; and finally, the dynamics of the solving process stemming from the interaction between the different stimuli (contained in the context) and the knowledge structures.

Keywords

Debugging, problem-solving, expertise, knowledge structures, solving dynamics, hypothesis construction-testing process, cognitive processing cost, conceptual domains, semantic networks.

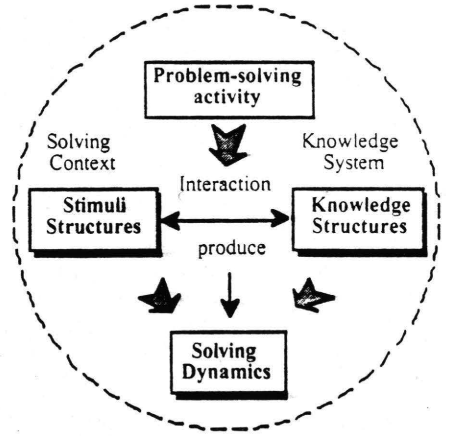
INTRODUCTION

The cognitive aspects of debugging, an activity which is - often - made by experts, are more and more gaining importance. These aspects include problem-solving processes and knowledge organisation of the expert programmer. Cognitive research on debugging elucidated some of these aspects. Nevertheless, this research, across the models proposed in the literature, did not adopt an inclusive approach which would take into account the complexity of the cognitive system architecture, and its different components. The originality of our work resides in the model which we propose and which is based on this approach.

PROBLEM

What are the basic cognitive aspects that we might take into account to model the debugging activity ? To answer this question, we suppose that, as a problem-solving activity, debugging takes place in a "problem-solving space". As shown in Figure 1, this space is composed of three components: a solving context, that contains the different stimuli processed by the solver; a knowledge system that contains the solver's knowledge schemata; and a solving dynamics which is the interaction between the two first components.

Figure 1: The problem-solving space.



BRIEF THEORETICAL REVIEW

Vessey (1985, 1989) presented a functional model based on the strategic and the tactical aspects of debugging activity. Katz and Anderson (1988) considered it as a troubleshooting activity. Thus, they proposed a model of the error diagnostic activity, which focused on the kind of programmers reasoning (backward, forward) and on the change of solving strategies. Moreover, Gugerty and Olson (1986) compared the mental representations of textual structures respectively of expert and novice programmers. Their model emphasized the functional representation of experts and the syntactic representation of novices. Not far from this perspective, Pennington (1985, 1987) developed a model of the comprehension sub-activity of programs, which emphasized the different kinds of knowledge and the role of abstraction in comprehension. Finally, Gilmore (1991) presented a model of debugging as a conception activity which is influenced by two factors: bug's type and programmer's knowledge of the problem.

METHOD

We performed an extended case study of the debugging activity of an expert programmer (25 years of programming experience). We used a protocol tracing technique to collect data, and a verbal protocol analysis technique to analyse them. To generalize the findings of this study, we conceived and broadcast a questionnaire in an expert programmers population. This questionnaire allowed us also to highlight other aspects of the debugging activity, which could not be elucidated by the extended case study. Otherwise, we performed a computer-mediated experiment with the aim to go into the program-texts comprehension question thoroughly, and precisely to emphasize the " abstraction mode " concept. The extended case study, the questionnaire, and the experiment play together complementary roles and collaborate to the model's construction.

MODEL

Based on the " problem-solving space ", the model we propose (Figure 2) is constructed along three axis:

1. Cognitive system and spontaneous / sought after stimuli;
2. Knowledge structures and Conceptual activation;
3. Solving Dynamics (programmer's global actions and cognitive sub-activities).

Cognitive system and spontaneous / sought after stimuli

One of the expertise related aspects resides in the capacity to process and manage an important quantity of informations stemming from contextual clues. The expert is able to manage different stimuli according to their pertinence to the current solving aim. He can stock temporarily, in working memory, some spontaneous contextual informations which are less pertinent than others; he can then process in line the most pertinent sought after stimuli. To represent how working memory functions (as we suppose), we adapted the model of Ericsson and Kintsch (1995) to debugging context. Moreover, we found that the programmer have to process three kinds of information: static-functional, dynamic, and structural-dynamic. The first kind of information is provided by " source-code " stimuli; the second is provided by a set of stimuli including " values ", " traces " and " debugger messages "; the third is provided by " dump texts ". The case study as well as the questionnaire showed that the expert programmer processes more functional than dynamic informations.

Knowledge structures and Conceptual activation

We identified two kinds of knowledge structures:

- *solution-oriented knowledge structures:*
  - CPB: Cognitive Pattern of Bug. It plays a role of abstraction by selecting the pertinent elements from the context to define the bug, and a role of mental representation of it.
  - CPACB: Cognitive Pattern of ACB (Appearance Conditions of the Bug; *cf.* Masmoudi, 1995). An " ACB " can be an object, a property or a situation for which the bug occurs. A " noACB " is an object, a property or a situation for which the bug do not occur. The generalization of ACBs corresponds to a new categorization, within the context, of objects, properties and situations, only according to the bug's production criteria.
  - Hypothesis: we consider it as a knowledge schema. It is a dual structure composed of two principal attributes: " state " and " process ". The expert programmer supposes that there is an erroneous state (S1) instead of a correct expected state (S2): he makes a " state hypothesis ". He then formulates a " process hypothesis " according to which there is an erroneous process (P1) instead of a correct expected process (P2). The hypothesis construction and testing process consists of an iteration between the two kinds of hypothesis.
- *domain-oriented knowledge structures:*
  - We note the role of Conceptual Domains: concepts are activated relatively to a set of conceptual domains, such as system-to-be-debugged domain, programming domain, or programming language domain. Thus, a conceptual domain is a large set of concepts inter-connected with functional links.
  - We emphasize the role of Semantic Networks as a domain knowledge representation, and the role of conceptual activation processes.

Four fundamental steps of conceptual activation are elucidated. First, a conceptual domain is activated based on informations in CPB structure. Then the specialization and refinement of this conceptual domain lead to a " focal element " whose origin is the difference between the expected value and the real wrong value. The activation of other concepts which belong to other conceptual domains remains generally related to the processing of the focal element's value. Finally, activation continues based on the iteration between " state hypotheses " and " process hypotheses ".

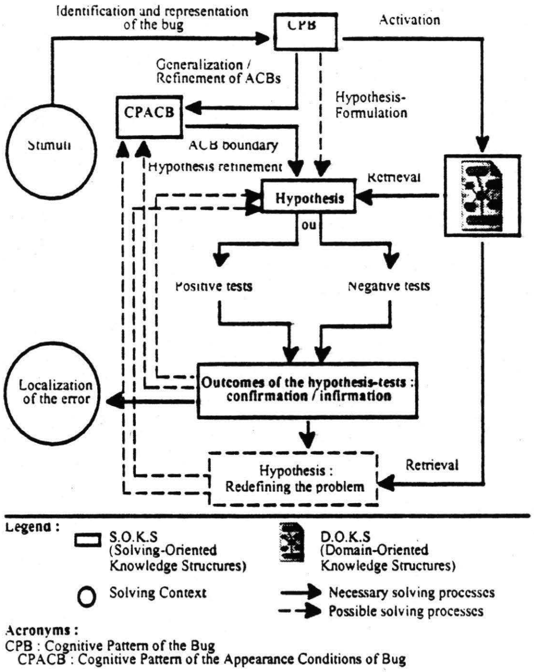
Solving Dynamics

Fundamental steps

1. Detect a bug and construct a mental representation of it through the cognitive schema " Cognitive Pattern of Bug " (CPB).
2. Construct a mental representation of the Appearance Conditions of the Bug through the cognitive schema CPACB.
3. Generalize or refine the ACBs.

4. Formulate an hypothesis: begin with a " state hypothesis ".
5. Test the first " state hypothesis " or gather informations which confirm it automatically.
6. Formulate a " process hypothesis ".
7. Test the first " process hypothesis " or gather informations which confirm it automatically.
8. Iterate between steps 3 and 7 until the error is located.

Figure 2: Model of debugging cognitive activity made by the expert.



Intermediate operations

Among the most interesting findings of our study, we note the importance of two cognitive sub-activities: gathering dynamic and static informations, and managing the material as well as the cognitive information's cost. We identified different operations included in these sub-activities.

(1) Gathering informations:

- Follow up the different states of an object during an execution process.
- Identify the components of an object.
- Pay attention to time-related informations (*e.g.* When did an event occur ?).
- Compare an object's behaviours in two different situations.
- Compare the behaviours, right and wrong, of two objects which are parts of a same category.
- Pay attention to the chronological account of the execution events of the program.
- Adopt a VOTAT (*Varying One Term At a Time*) hypothesis-testing strategy
-

(2) Managing information's cost:

- Verify an hypothesis whose cost is more reduced than another even if it is unlikely.
- When testing hypothesis, try to avoid the " Heisenberg " effect (changing a phenomenon when observing it).
- Gather legible informations at just the right time.
- Try to synchronize between the information's production and the external observed behaviour of the system.
- Compare typical and atypical functions which are parts of a same category, this reduces the search-space of the error.

CONCLUSION

We presented in this paper our model of debugging expertise of complex computer systems. Construction of this model is based on a set of complementary methods, including an extended case study and a questionnaire which are global approaches, and a computer-mediated experience whose aim is to focus on the programs comprehension activity. This model takes advantage of a cognitive psychological approach. It is based on our representation of the " problem-solving space " which distinguishes between stimulus structures, knowledge structures (solving-oriented and domain oriented structures) and solving dynamics. Some future interdisciplinary works will begin to implement this model.

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Explicit, Informal Cooperative Work: Integrating Human Factors and Software Engineering

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ABSTRACT

An approach to supporting cooperative work between human factors (HF) and software engineering (SE) specialists, during the software design process, is presented. The approach is characterised as explicit by virtue of its specified design method (MUSE), and informal due to the lack of defined relationships between HF and SE design products. Contrasting approaches are outlined, and outcomes from using the approach are described. A theoretical understanding is offered in the form of the coordination mechanism.

Keywords

Human factors, software engineering, method, integration, specification, user interface, design.

INTRODUCTION

This poster concerns cooperative work between human factors (HF) and software engineering (SE) specialists to design interactive software. Different approaches to cooperative work, supporting HF contributions to software development, have been proposed. These approaches vary as to their explicitness and formality. Explicitness relates to whether the design process is specified by a method. Such methods offer detailed proceduralisation of the design process. Implicit approaches rely on the experience of the practitioner to determine the design process and the form of any specifications produced. Formality relates to the relationships between the HF and SE products. Formal approaches offer defined relationships between the two sets of products, whereas informal approaches leave it to the design teams to determine the compatibility of their designs. The approach reported here is explicit (a method), but informal (no defined HF and SE product relations). Explicit, but informal cooperation, between HF and SE specialists is supported by the MUSE method (Lim and Long, 1994) - a structured HF method for usability engineering. MUSE employs a structured diagram notation to represent HF design products, which are cross-checked informally against SE products. Cooperation, in the form of MUSE cross-checks, is divided into *mandatory* (ensuring HF and SE specifications will not diverge), and *discretionary* (enhancing SE design uptake). Cross-checking may require design iteration or intermediate design products, and is planned before method application. Discretionary cross-checks are specified during configuration of MUSE to the SE method, or occur as required during the design process.

CONTRASTING APPROACHES TO COOPERATION

Explicit, Formal Approaches

Explicit, formal, approaches, typically promoted by software engineers, specify the design method and define formal relationships between HF and SE products. Barthet (1988) has proposed and applied an explicit, formal approach to co-operative work, integrating HF and SE concerns in system development. The cooperative work is explicit, because the design method (DIANE) is specified. The work is also formal, because the HF and SE product relations are defined by means of a common general architecture and common notations (those of MERISE).

Implicit, Informal Approaches

Implicit, informal approaches, typically promoted by HF specialists acting as consultants, have no specified method or defined HF and SE product relations. The cooperative work is, thus, implicit (no method) and informal (no defined HF and SE product relations). Nielsen (1993) presents a representative approach ("discount usability engineering"), based on user and task observation, scenarios, thinking aloud, and heuristic evaluation. Although HF activities are situated within a lifecycle model, detailed design procedures are not provided. Also, the relations between HF and SE design streams are unspecified. Without a specified design method, HF-SE cooperation is implicit. As no HF design products are defined, the relationship with those of the SE stream is informal.

Informal, Explicit Approaches

The informal, explicit approach is typically promoted by HF specialists, integrating HF and SE by structured HF design methods, whose products are used to cross-check with SE products. This approach to HF-SE cooperation is characterised by methods such as GUIDE (Redmond-Pyle and Moore (1995)), STUDIO (Browne (1994)), and MUSE (Lim and Long (1994)). Whilst implicit approaches often employ specific HF techniques to inform selected aspects of design, HF structured methods are characterised by explicit detailed procedures for the design of the user interface. These methods generally offer advice concerning their use in conjunction with SE methods; SSADM in the case of STUDIO, JSD in the case of MUSE, and object-oriented methods in the case of GUIDE. However, the methods do not define formal relationships between their design products and those of these SE methods; the result is that cross-checking is reliant on the judgement of the design teams rather than verification of the existence of defined relationships.

INFORMAL, EXPLICIT COOPERATION

To use MUSE with an SE method, SE and HF design stages must be integrated. Integration is achieved by compatibility checks (termed links) between the SE and HF design products at key points in the design process. Once the links have been specified, MUSE is said to be configured for the SE method.

Specific HF support that might be required by the SE method are task design, allocation of function between user and computer, dialogue design, and fit between the SE specification and the task of the user. Specific requirements vary depending on the SE method; the nature of the process i.e. the phases and stages of the method, the model that the method employs i.e. object-oriented or function-oriented, and intended scope i.e. the technical specification of software systems.

Overview of MUSE

The first phase of the MUSE method is called the Information Elicitation and Analysis Phase, and involves collecting and analysing information, to inform later design. Information relates both to the system in use and to other systems that are related. The information is summarised in a device independent task model of the existing systems, and a similar model of the target system is constructed, based on the end-user Statement of Requirements. The objective is to identify features of systems problematic for users or that may be reused in the target system.

The second phase of MUSE, the Design Synthesis Phase, begins by establishing the HF requirements of the design, in terms of performance criteria, likely user problems, and task support required. The semantics of the task domain, as it relates to the worksystem, are also analysed and recorded. A conceptual design of the target system is produced based on the device-independent task models constructed in Phase 1, but using the information collected about the task domain and the HF requirements. Finally, the agreed conceptual design is divided, separating those subtasks performed using the system under development from those using other devices.

The final phase of MUSE is termed the Design Specification Phase, and develops the conceptual design in more detail to a device-specific implementable specification that includes error-recovery procedures. A number of products are generated, each detailing a different aspect of the user interface design. The user interface is then assessed and refined iteratively before implementation begins.

COOPERATION BETWEEN HF AND SE DESIGN STREAMS

Links between stages of the HF and SE design streams may be divided into mandatory in order for MUSE to function, and discretionary. Discretionary links may be specified in advance (known as planned links), or may occur on an ad-hoc basis during the design process (known as opportunistic links).

Mandatory Cross-checks

The mandatory links in MUSE are those that exist between the Composite Task Model (CTM) and Statement of User Needs (SUN) stages and some stage of the SE method, and the links between the Display Design (DD) stage of MUSE and some stage of the SE method. Only the obligatory and planned cross-checks are detailed in advance.

Link Between CTM and SUN and SE Method

This link is to ensure that the HF and SE design streams share the same design concerns with respect to the target system. These concerns are design scope, design basis, and design rationale. The information that is shared from MUSE is the SUN, Domain of Design Discourse model (DoDD) and the CTM. The SE method shares high-level specifications such as the requirements definition document or a list of the functions or processes, and the objects and actions. As a result of this cross-check, refinements to the SE specifications may occur in terms of the functions required to support the user's task and any relevant performance characteristics. Alternatively, revisions to the CTM may be required.

Link between DD stage and SE method

This link is to ensure uptake of the MUSE detailed user interface specification by SE. The information shared consists of the products of the Interaction Task Model, Interface Model and Display Design stages of MUSE, and represents a complete specification of the appearance and behaviour of the user interface. By this stage, the required high-level functionality should have already been specified to some degree by the SE stream. It remains to ensure that the requisite windows, dialogues and dynamic behaviour of the interface are implemented as required. The particular SE products depend on the method in use, but this cross-check would normally inform low-level design.

Discretionary cross-checks

Additional cross-checks may be specified between MUSE and the SE method; discretionary cross-checks are normally indicated whenever either stream would expect to make major design decisions. Within MUSE, allocation of function decisions are made at the System and User Task Model (SUTaM) stage; a discretionary cross-check is often specified at this point.

Links Between SUTaM stage and SE Method

Where the functions list alone may be insufficient to ensure convergence, the System Task Model, plus relevant aspects of the DoDD, SUN and CTM may be cross-checked with the SE stream. The SE method would contribute products such as the software requirements specification, or detailed functional specifications describing the anticipated input and output event streams, and any input sub-system specifications. The concern is to prevent divergence between the HF and SE specifications that would result in design iterations after their integration.

Opportunistic cross-checks

Opportunistic cross-checks are not specified in advance, but occur as required. These cross-checks occur frequently and informally during team work, and are often no more than a verbal request for clarification; although an implicit form of co-operation, they appear to be facilitated by explicit co-operation.

Scheduling of Design Stages

The requirement to share information between the HF and SE streams highlights the need for careful scheduling of the work so that the two streams arrive at the links at the same time, avoiding delays to the progress of either stream.

EXPLICIT, INFORMAL COOPERATION IN PRACTICE

The explicit, informal approach to design co-operation was tested by three companies on commercial-scale applications as part of an EC funded research project (European Systems and Software Initiative project 10290: Benefits of Integrating Usability and Software Engineering Methods). All three companies considered that use of the method was overall of benefit, and that the design products supported collaborative resolution of design issues between the HF and SE design teams by reducing ambiguity and providing a vehicle for discussion; collaborative team working was supported even where team membership changed over time, or the team was geographically distributed (Bell et al. (1995)). Some minor reservations were expressed about certain default notations; this issue would normally be addressed during method configuration, but for the purposes of the project the default notations were employed.

CONCLUSIONS AND FURTHER WORK

The work described above indicates that explicit, informal approaches to HF-SE cooperative work show promise as a way of promoting the address of human factors concerns during the software design process, and provide good support for team work during design.

However, how might such explicit, informal HF and SE cooperative work be understood theoretically, and so advanced practically? Stork et al. (1998) and Lambie et al. (1998) have proposed the coordination mechanism as a structure individuating a class of cooperative behaviours. They ascribe two aspects to the coordination mechanism. The first is information content, that is, propositional or locutionary, referring to the states of the domain of work, here the designed software product. The second aspect is attitude, that is, perspective or illocutionary, referring to the task goals of the design worksystem, here the design method. Their concept of coordination mechanism might be used to understand and render more effective HF and SE cooperative work as follows. Cooperative work requires the alignment of the aspects of the coordination mechanism – attitude as the design method with information content as the designed software product. The alignment might be either along the dimension of explicitness or formality. Our ongoing research seeks to make HF and SE cooperation more effective through enhanced alignment of the design method with the designed software product by improving method configuration.

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A Framework for Code Reuse in OOP: Individual, Social and Technological Dimensions

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ABSTRACT

The goal of this work was to study how developers re-use objects that have been already created in Java. One of the claims of the Java programming language and, in general, Object Oriented Programming (OOP) languages, is that components are highly reusable. However, what are the programmers' thoughts and experiences about code reuse? To investigate this central question, we interviewed professional programmers about their code reuse experiences, and the advantages and disadvantages that they found. Then, we organised the collected information in the light of the literature, and built a framework which could help us study code reuse. Finally, we tested some of the predictions derived from this framework in a case study.

Keywords

Object Oriented Programming (OOP), code reuse, framework, dimensions, individual, cognitive and social factors, communication technology, trust.

INTRODUCTION

In the last few years, there has been an enormous increase in the number of people writing and sharing code. Therefore, it is increasingly necessary that programmers, other than the original developers, need to re-use a program in many different situations. Our work intended is to enhance code reuse in the context of a project for Java-based objects on the Internet, the Educational Object Economy project (EOE). One of the claims of the Java programming language and, in general, Object Oriented Programming (OOP) languages, is that components are highly reusable. However: Why isn't there more code exchange in real life? Why is there so much duplication in educational objects? What are the programmers' thoughts and experiences about code reuse? These were the central questions which motivated this work.

To investigate these questions we started a discussion in several newsgroups of interest to programmers and did numerous interviews of professional programmers. We asked them about their code reuse experiences, and the advantages and disadvantages that they found.

As a result of this survey, we have collected much data from the programmers. In general, all of them agreed about the advantages of code reuse. They also indicated, however, numerous disadvantages and very diverse problematic situations that arise when code is reused.

FRAMEWORK

In order to understand these problems and be able to propose some solutions we needed to define and clarify some terms and situations. Therefore, our next step was to organise this information using what we know from the literature in this area. That allowed us to build a framework which could help us study code reuse. With this method we found four major problems, identified below. Our goal was not to investigate each of these dimension, but instead to link everyday programmer experiences with what we already know, and organise this knowledge so to facilitate further research:

1. Individual Dimensions: programmers Mental Representation of the code.
2. Cognitive dimensions: characteristics of the code.
3. Social Dimensions: the Re-user/Developer interaction.
4. Communication Technology Dimensions: the communication technology used between the Re-user and Developer (telephone, face-to-face, etc.).

In this paper we will first briefly define each of these dimensions and list their principal components. Then, we will describe a pilot study that exemplifies how this framework could be tested, and how it could help to get information about the interaction between the proposed dimensions.

INDIVIDUAL DIMENSIONS: THE PROGRAMMER'S MENTAL REPRESENTATION

Among programmers, there are a large number of individual differences. One of the differences most referenced by programmers[1] was their different points of view about the problem (i.e. - how they mentally represented it).

Research in Psychology of Programming has shown that, although programmers have some stereotypical knowledge, many variables influence the mental model developed from the program (Pennington, 1987). Based on this literature, we propose two main sources of problems for code re-use:

a) *Closeness between the Developer's program domain representation and problem domain representation*: it is not easy to deal with entities in the program domain that do not have corresponding entities in the problem domain (Brooks, 1977)
b) *Different programmers could develop mental models of the code at different levels of abstraction:* (Soloway & Ehrlich, 1984). Some levels of abstraction would make code re-use difficult.

COGNITIVE DIMENSIONS: ANALYSIS OF CODE CHARACTERISTICS.

The importance of this variable was pointed out by the programmers in different ways[2]. Unfortunately there was no common vocabulary in which each of them could specify and get agreement in the Developer's community. We tried to address this lack, with an approach based on the Cognitive Dimensions framework developed by Green, et al. (1996), adding some components from our data:

a) *Size and diffuseness*: our collected data showed that programmers have more problems with large or very diffuse pieces of code.
b) ***Level of Trust*** in a piece of code. There are some code objects which are more *error prone*.
c) ***Hidden dependencies in the program and the need for the programmer to make premature commitments*** (when they do not have enough information).
d) *Superficial Layout*: this aspect includes several variables like Role Expressiveness, Secondary Notation and Visibility of the code.
e) *Viscosity and Hard mental operations:* if effecting a small change requires much work from the Re-user, then the re-use will be more difficult.

SOCIAL DIMENSIONS

In our interviews with programmers, we were often told that it is not automatic for two programmers to understand each other when one is explaining his code to the other[3]. Because of the above problems with the code, this communication is very important in order that the code reuse be successful. Toward this goal, it is necessary that several of the social situation characteristics have an optimal level. To define these dimensions, we looked to the model of Bellamy, et. al. (1997). This model identifies the variables involved in a successful learning conversation, which we applied to code reuse:

a) *Conversational props*: problems very easily arise because a programmer is using a concept in a non-conventional way.
b) *Learning attitude and Trust level* of the partner.
c) *Rhythm of the conversation*: a successful communication requires periods of reflection and interaction.
d) *Expertise.*
e) *Accessibility of the programmers.*

COMMUNICATION TECHNOLOGY DIMENSIONS:

New technologies allow access to much larger amounts of information in less and less time. In spite of the continuous advance of technology, for some programmers it seems to be very important that they have direct contact (face-to-face) with the Developers. We still do not know much about how these technical advantages will enhance or make it more difficult to communicate[4]. One of the few studies in this area is the recent work by Michailidis & Rada (1997), which has shown the influence of different modes of communications (e-mail, face to face, conventional mail and phone) in co-ordinating activities, including decision making, communications and the sharing of common objects. Of special importance for us was the interaction between technological and social dimensions, because technology could delimit the social aspects.

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[1] As an example, one programmer commented: "I have attempted to use public domain classes to achieve what we wanted.(...) Unfortunately it didn't work well because the code makes a lot of assumptions that turned out to cause major problems".

[2] One example was the following comment: "The cons (of code reuse) are that it could have a bad interface, could mess up badly if not written well, and it could be written for a different compiler".

[3] As another example, one programmer commented "The problem for me is to talk with the programmer who wrote the code because very often we do not understand each other."

[4] With regard to these problems, a programmer told us: "For me, the only way I can understand another person's code, is if I have him next door, so I can go and ask him face-to-face what I do not understand."

PILOT CASE STUDY

To test the usefulness of our framework, we manipulated some of the communication technologies (face-to-face vs. telephone) and cognitive dimensions (level of trust). We measured their effect on the social interaction between the Developers and the Re-users (by recording verbal protocols), and on the subjects' mental representations. This study has to be seen as a pilot, because it focused on one sample from the multiple possible combinations of variables that can be manipulated.

Following our framework, communications needs could be very different from one technical and personal situation to another. Our hypothesis is that: IF the level of trust in the code is low and the technology allows a closer communication, OR IF the level of trust in the code is high (independently of the technology), THEN code reuse will be successful.

We defined success in code reuse as when Re-users develop a good mental model (close to that of the developer), and finish the task in a reasonable amount of time. We also measured the verbal protocols, paying attention to those interactions when the Re-users consulted the Developer with a problem.

There were six subjects in this study, three Re-users and three Developers. The Developers wrote a simple piece of Java code that shows a button which produces a sound when clicked. They were also available to answer the Re-user's questions during the code reuse situation, via different communications methods described above. The Re-users had to understand and reuse the Developers code. Their task was to make a modification in the code, such as making the button display a word when selected. To do this, they had to study and reuse the code that was given to them. After the Re-users had modified the code, they completed a Sorting Task in which they had to sort lines from the program code that was previously given to them. Developers also completed this Sorting Task.

The six subjects were divided into three groups, each of them with a Developer and a Re-user: one group where the participants were able to interact face-to-face with each other and the Re-user had a high level of trust in the code (HTFF); in a second group the participants were able to interact face-to-face with each other and the Re-user had a low level of trust in the code (LTFF); in the last group, they communicated only by phone and the trust level was high (HTPH). The trust level was manipulated by the instructions.

RESULTS:

TASK DATA:

All the participants successfully completed the tasks. There were no significant differences in the total time to complete the modification task. Probably because our task was too simple.

VERBAL PROTOCOLS:

There were important differences between the HTFF and the other two groups. While under the HTFF conditions there were a total of 22 successful interactions between the Re-users and the Developer, under the other conditions there was only one interaction in each of them.

SORTING TASK:

Our goal with this task was to get the programmers' mental structure of the code. With data about relationships between lines of code, we built a matrix of similarities for every line of code with all the other lines. These matrices, one for each subject, were introduced into a Cluster analysis.

The result of this analysis showed that under the HTFF conditions the Re-user had a very similar mental structure of the program to that of the Developer. This structure seemed to be based on the role of each portion of the code. On the other hand, the Re-user from the LTFF group had a very simple mental representation of the program, totally different from the Developer's representation. Finally in the HTPH group both the Re-user and Developer had similar mental representations of the program, which were mostly based on control statements.

CONCLUSIONS

These data should be interpreted as tentative, which could help us understand code reuse situations and the interactions of variables that need to be taken into account. We found a significant influence of the communication technology between Re-users and Developers. But face-to-face interactions do not guarantee successful communication; it seems that a high level of trust is also needed. More research is needed to support this interpretation. Another important finding was that of the influence of the social dimension in mental representations. More relevant to our original goal was that we found interactions between the technology and the communication variables. This means that our approach to the code reuse situation is useful in studying the interactions among all these relevant variables.

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Using Intranet Technology to Support Engineering Design: The Human Factors Database

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ABSTRACT

This paper describes an application based on Intranet technology to deliver Human Factors expertise to engineering designers. The Human Factors Database (HFDB) provides information in terms of standards, research reports, key topics, and ongoing projects. The HFDB also provides users with access to Human Factors specialists to provide advice on particular design problems. The HFDB was developed as a result of an identified requirement within British Aerospace plc (BAe). Version 1 has recently been evaluated by a representative group of engineering designers in the company.

Keywords

Human Factors, Engineering Design, Intranet, Web Browser, GUI, HCI, Evaluation.

INTRODUCTION

The engineering design process involves the use of a diverse range of information. Some of this information is gained through experience, however much is acquired through publications, reports, manuals, published standards, and personal communication. The time taken to gain access to relevant design documentation can be significant for a complex project, particularly where that information is in a professional domain outside the normal working experience of the engineer. Having easy access to a wide range of Human Factors information directly related to the product improves efficiency in accessing information at all stages of the design process. Generally a "depth first" approach to the design process is supported when a range of appropriate information is easily available (Whitefield and Warren, 1989). Alternative design solutions based on Human Factors requirements are thus considered at higher level before more detailed design work is undertaken. This is considered to result in a more effective design solution.

A requirement was identified within the company for a more efficient way of accessing Human Factors engineering design information for use throughout the design process. The initial solution for this requirement was based on a stand-alone system using web browser technology which could be implemented on a wide range of computer platforms.

During the development process, the company implemented an Intranet which allowed the HFDB to take advantage of a number of supporting technologies which allow increased functionality.

Intranet technology provides immediate benefits with very little requirement for additional infrastructure investment. The Intranet provides real-time, cost effective information flows in a platform-independent environment

The use of Intranet technology represents a major technological shift within the company. The technology provides one solution to the problem of information management. Information can now be accessed on demand facilitating the flow of information from providers to users, helping to avoid information overload.

Introduction of the new technology does require changes to working practices and users will have to learn how to use web browser technology. By developing the HFDB to run within a web browser using a Graphic User Interface (GUI) based on sound Human Computer Interaction (HCI) principles, the application is intended to be both intuitive and easy to use in the engineering design workplace.

The development of the HFDB has been guided by regular meetings of a steering group comprising representatives of users from BAe.

Following a description of the functionality of the HFDB a brief report is given on the recent evaluation carried out by a representative group of engineering designers.

HFDB DESCRIPTION

The HFDB runs within internet browser versions equal to or greater than Netscape Navigator ™ 3.01 or Internet Explorer 3.02. These browsers are available on many different platforms within the company. The HFDB is located on an Intranet server for access by the whole of the company. Currently access has been restricted to the staff of the Sowerby Research Centre at BAe and a group of engineering designers working within the company. These engineering designers recently took part in an evaluation study of version 1 of the HFDB. This was intended to drive the development of version 2 of the HFDB which will be released to the whole company.

The HFDB consists of six main sections of data:

- Defence Standard 00-25 - Ministry of Defence Human Factors Standard for designers of equipment;
- Key Issues - provided by specialists in the Human Factors Department in the Sowerby Research Centre;
- Projects - description of current Human Factors projects within the company;
- Reports - abstracts of Human Factors reports written by specialists in the company;
- Specialists - photographs of Human Factors specialists in the company with descriptions of areas of expertise and contact details;
- World-Wide Web (WWW) Links - a hierarchical index of web sites with Human Factors information.

In addition to the data sections, there is a range of functionality available to users on a top menu bar including:

- Index button - allowing the index to be switched off when using alternative navigation modes;
- Search button - providing sophisticated search navigation using a server based search engine;
- Map button - for navigation using a map representing the data contents of the HFDB;
- Help button - providing help on the functionality and use of the HFDB;
- News button - providing information about recent additions and configuration control;
- Feedback button - allowing users to give feedback on use of the HFDB and containing the evaluation section;
- Glossary button - providing an indexed glossary of all technical terms used in the HFDB.

The HFDB interface comprises three windows. The Main window contains data derived from any of the six main sections or the function buttons; the top window contains a Menu Bar with buttons to access HFDB functionality; and the side window contains an Index Bar running down the left side of the interface.

The Index Bar is arranged to provide a hierarchical record of the route taken to locate the data currently displayed in the Main window. Each level of the route record hierarchy is a hyperlink. At any time users can click on any part of the record of their route to return to a previous location. The hierarchical record ensures that users cannot be lost in hyperspace.

Any information contained in the Main window can be copied and pasted into documents held within concurrently running word processor applications.

For clarification of Human Factors issues or for questions about applying the results of research findings displayed in reports, users can contact specialists and authors of reports directly via EMail using hyperlinks.

EVALUATION OF THE HFDB

The HFDB has been tailored to the requirements of engineering designers in BAe through a steering group which has been meeting since the start of the project. The design of the interface and the types of information in the HFDB were guided by feedback from the steering group during the development process. The evaluation phase took place once the HFDB contained enough data to support a range of tasks. These tasks were based on the search for Human Factors data relevant to carrying out particular design activities.

The evaluation exercise consisted of twenty four data retrieval tasks and a usability evaluation based on the HFDB interface and functionality. The usability evaluation included sections for change requests and any additional information or functionality identified by users.

The twenty four tasks could be solved by referring to the HFDB and could be answered in any order. The tasks were representative of the type of information requirement commonly required when carrying out product design work. The evaluation tasks and usability evaluation were contained within the HFDB. The tasks could be completed electronically and answers sent back to the evaluator by clicking a "send" button. Users also had the option to print the page and write their answers, sending the results back in the internal post - no one took this option.

Users had a range of expertise in using browsers, so all were given a sheet of instructions on how to use the HFDB within a browser. Users were informed that they could address the problems using the HFDB by whatever means they wished; using the search facility to search the database for keywords, or browsing using the Index as a guide. Both methods could be used if they wished.

When carrying out the tasks, users were asked to provide an indication of how easy it was to find the information and the strategy adopted to find it. Finally, they were also asked to keep a note of the approximate time required to complete each task.

Results of the Evaluation

Generally the users completed all tasks within a reasonable time period. The tasks were set such that users would have to visit most areas of the HFDB to complete all tasks. No significant problems were encountered by users in completing most tasks.

Most tasks were completed in a period under two minutes. Those tasks which were rated as difficult related to problems reading figures which had been scanned into the HFDB. Not all users encountered these difficulties.

The most interesting part of the evaluation exercise for the HFDB development project was the usability evaluation, where direct feedback was obtained on the HFDB interface and functionality.

Generally users found the HFDB easy to use and found the navigation philosophy intuitive. The hierarchical record of sections visited in the Index Bar was reported as very useful in determining current location within the HFDB. The Index Bar was also found to be very useful in browsing through information in the HFDB.

Users were particularly positive about the facility to copy and paste information from the HFDB into reports. The Glossary section was also seen as being very useful.

The Specialists section was also well received. Photographs of subject area specialists together with lists of expertise and contact details were seen as a great aid in identifying appropriate staff within the company to contact for problem solving.

There were problems for some users when accessing the search engine. This was due to technical problems with the BAe Intranet server rather than the design of the search facility. System response times were slow on some occasions when a large diagram was accessed; users did however find the delay acceptable.

The open comments section was very complimentary to the overall design of the HFDB and its potential for use on BAe projects. Overall the evaluation was very positive. Minor changes to the HFDB will be made based on the results of the evaluation.

DISCUSSION

The HFDB is now being developed further with additional information and a revised search engine. It seems likely that the project will provide a useful intranet tool for use by anyone in the company who requires Human Factors information or expertise in carrying out their work. Issues related to configuration control and maintenance are currently being discussed.

There has been much interest in the application for disseminating information within the company for a range of different subject areas. The HFDB should provide a suitable framework for constructing similar applications in these different subject areas.

Version two of the HFDB will be released in about six months time. An evaluation section for constructive feedback will remain as one feature of the HFDB to ensure that it continues to satisfy user requirements. Capturing heuristics and rules of thumb used by engineering designers may also be possible using this facility. These could then be incorporated into the Key Issues section of the HFDB.

The changes in working practices required to use the HFDB are slight. The improvement in efficiency and effectiveness of design solutions by providing easy access to Human Factors information is expected to be significant. The HFDB is a very practical example of technological change providing a solution to information management. It seems likely that there will be many more examples of the new technology improving the effectiveness of engineering practice within BAe.

REFERENCES

Whitefield, A. and Warren, C. P. (1989) A blackboard framework for modelling designer's behaviour. *Design Studies, 10,* 3.