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RTO TECHNICAL REPORT 24

Cognitive Task Analysis

(l'Analyse des tâches cognitives)

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Abstract
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Subject Terms Cognition; Reviews; Task analysis; Design; Human factors engineering; Performance evaluation; Decision making; Systems analysis; Man computer interface; Interfaces; Problem solving; Knowledge representation; Command and control; Reasoning; Requirements; Cognitive task analysis (CTA); Military training; User requirements; Organizations; Decision support systems; Job analysis; Teams (Personnel)	
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Cognitive Task Analysis

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Cognitive Task Analysis

(RTO TR-24)

Executive Summary

DEFINITION OF TERMS

Cognitive task analysis is the extension of traditional task analysis techniques to yield information about the knowledge, thought processes and goal structures that underlie observable task performance. In recent years, interest in the cognitive aspects of tasks has grown for several reasons. Modern automated systems have created jobs for humans that are conspicuously cognitive in character, emphasizing inference, diagnosis, judgment and decision-making. The term 'Cognitive Task Analysis' (CTA) began to emerge in reports in the early 1980's and it encapsulates attempts to apply current concepts in cognitive psychology to the analysis of complex tasks. Whereas in the 1950's and 60's the major emphasis was on control tasks (flying, steering, managing chemical plant), CTA has been primarily concerned with decision-making tasks such as air traffic control and military command and control (C2).

LITERATURE REVIEW

As part of its Programme of Work, RSG.27 on Cognitive Task Analysis has undertaken the task of reviewing existing cognitive task analysis techniques and computer tools. An analysis of the reviews themselves shows that a very large number of particular, rather limited methods are described over and over again. But little is said about how these can be effectively orchestrated into an approach that will yield a complete analysis of a task or job. Little is said about the conditions under which an approach or method is appropriate. The literature is also very weak when it comes to specifying the way in which the products of task analysis should be used in designing either training or systems with which humans will interact.

WORKSHOP

RSG.27 has organized a workshop with experts in the field of cognitive task analysis. The Workshop was held in Washington, D.C., USA, October 30-November 1, 1997. The goal of the workshop was to assess the state of the art by bringing together a diverse, yet representative sample of experts in the field.

The most important issues that were discussed during the workshop were:

1. The use of CTA in the design of new systems. The difficulty lies in the fact that when we try to predict future operator behavior, we can only rely on existing operator behavior.
2. The question when to use what technique. It was generally felt that a strict and fixed ordering of techniques for each project was unrealistic, as the order in which techniques are used may differ from project to project. Also, use of a single technique was generally felt to be too restrictive: multiple, coordinated approaches to CTA are required.
3. The role of CTA in system design. Most speakers agreed that CTA should not be a self-contained activity, the results of which are handed off to system designers. However, this being said, it is still very often the case that there is no integration between the activities of cognitive psychologists and system designers (e.g., software engineers).

MAJOR RECOMMENDATIONS

1. It is important for the CTA community to be able to empirically demonstrate the added value of a CTA. In this way, the analyst goes beyond mere observations and submits his or her ideas to empirical tests. Clear performance factors need to be chosen and to be engineered toward. Examples of performance factors are reaction time, training time, faults detected, firepower, coverage of weapon systems, etc.
2. It is critical for the success of CTA to be involved in the design process from the start to finish, and to establish clear links with methods that are used by other disciplines.
3. Due to the fact that customers are rarely willing to pay for an extra CTA, or the same CTA carried out by a different analyst, empirical tests of the reliability of CTA techniques are rare. More research effort should be devoted to this area.

MILITARY IMPLICATIONS

The digitization of military forces increases the importance of cognitive work relative to physical work. User-centered design is a key success factor in the introduction of computers into military forces. Cognitive task analysis techniques constitute a major part of the user-centered design process. Therefore, improving the effectiveness and efficiency of these techniques ultimately leads to higher user acceptance of digitized systems and increased combat power.

The military benefit of Cognitive Task Analysis lies in the following areas:
(1) better match between system functions and human cognitive capabilities
(2) optimization of system performance and workload
(3) improved operational Command and Control team performance
(4) better understanding of abilities needed for the job
(5) enhanced training system design

l'Analyse des tâches cognitives

(RTO TR-24)

Synthèse

DEFINITION DES TERMES UTILISES

L'analyse des tâches cognitives s'inscrit dans la continuité des techniques traditionnelles d'analyse des tâches destinées à fournir des informations concernant les connaissances, le fonctionnement de la pensée et la définition d'objectifs qui sous-tendent l'exécution observable des tâches. Au cours des dernières années, de plus en plus d'intérêt a été exprimé pour les aspects cognitifs des tâches et ce pour de nombreuses raisons. Les systèmes modernes automatisés ont créé des emplois qui sont manifestement cognitifs du point de vue de leur nature, de l'accentuation de l'inférence, du diagnostic, du jugement et de la prise de décisions. Le terme "Analyse des tâches cognitives" (CTA) est apparu pour la première fois dans certains rapports au début des années 1980. Il englobe les efforts qui ont été faits pour appliquer les concepts actuels de la psychologie cognitive à l'analyse de tâches complexes. Alors que dans les années 1950 et 1960 l'accent majeur avait été mis sur les tâches de contrôle (pilotage, guidage, gestion de produits chimiques), aujourd'hui, le CTA est principalement utilisé pour des tâches décisionnelles telles que le contrôle de la circulation aérienne et le C2 militaire.

ETAT DES DOCUMENTS DISPONIBLES

Dans le cadre de son programme de travail, le groupe de recherche scientifique RSG27 sur l'analyse des tâches cognitives a passé en revue les techniques existantes d'analyse des tâches cognitives et des outils informatiques associés. Cette analyse montre qu'il s'agit en fait de descriptions répétées d'un très grand nombre de méthodes spécifiques et quelque peu limitées. Peu d'éléments sont disponibles sur la manière de faire la synthèse de ces méthodes pour aboutir à une analyse complète d'une tâche ou d'un travail. De même, il n'y a que très peu d'indications sur les conditions et l'adéquation d'une approche ou d'une méthode donnée. Enfin, ce passage en revue a permis de constater que presque rien ne portait sur la définition d'un cheminement permettant d'utiliser les résultats d'analyse de tâches pour la conception soit de programmes d'entraînement, soit de systèmes impliquant des interactions homme-machine.

ATELIER

Le groupe RSG27 a organisé un atelier de spécialistes dans le domaine de l'analyse des tâches cognitives. Cet atelier s'est tenu à Washington, D.C., aux Etats-Unis, du 30 octobre au 1er novembre 1997. Il a eu pour objectif de faire le point de l'état actuel des connaissances en réunissant un groupe de spécialistes d'origines diverses mais représentatifs dans ce domaine.

Les questions les plus importantes qui ont été discutées lors de l'atelier furent les suivantes :

1. La mise en oeuvre du CTA pour la conception de nouveaux systèmes. La difficulté réside dans le fait que la seule base disponible pour la prévision du comportement des opérateurs futurs est le comportement des opérateurs actuels.
2. La question de savoir quand utiliser une technique donnée. De l'avis général, l'attribution stricte et immuable d'une technique donnée à un projet donné serait peu réaliste, car l'ordre dans lequel les différentes techniques sont mises en oeuvre change de projet en projet. Parallèlement, l'emploi d'une seule technique serait trop contraignant. Au contraire, des approches différentes du CTA multiples et coordonnées sont recommandées.
3. Le rôle du CTA dans la conception des systèmes. La majorité des intervenants étaient de l'avis que le CTA ne devrait pas être une activité autonome, dont les résultats seraient à distribuer aux concepteurs de systèmes. Cependant, il est souvent constaté qu'aucune intégration n'existe entre

les activités des psychologues cognitifs et les concepteurs de systèmes (par exemple les ingénieurs en logiciel).

RECOMMANDATIONS PRINCIPALES

1. Il est important pour la communauté CTA de pouvoir démontrer la valeur ajoutée du CTA. Ainsi, l'analyste va au-delà des simples observations et soumet ses idées à des essais empiriques. Il y a lieu de définir clairement des facteurs de performance et de les incorporer dans le processus de conception. Des exemples de facteurs de performance sont : les temps de réponse, les durées de formation, les défauts détectés, la puissance de feu, la couverture des systèmes d'armes, etc...
2. L'acceptation du CTA passe par son implication à tous les niveaux du processus de conception, ainsi que par la création de liens avec des méthodes mises en oeuvre dans d'autres disciplines.
3. Des essais empiriques de la fiabilité des techniques du CTA sont rares en raison du fait que les clients sont peu enclins à payer des CTA supplémentaires ou payer le même CTA réalisé par un analyste différent. Il y a lieu de redoubler les efforts de recherche consacrés à ce domaine.

CONSEQUENCES MILITAIRES

La numérisation des forces militaires met en évidence l'importance des travaux cognitifs sur le travail physique. La conception orientée utilisateur est un facteur clé dans l'informatisation des forces militaires. Les techniques d'analyse des tâches cognitives constituent une partie importante du processus de la conception orientée utilisateur. Par conséquent, toute amélioration de l'efficacité de ces techniques conduira à une meilleure acceptation par l'utilisateur des systèmes numérisés et à une plus grande puissance de combat.

Les avantages militaires de l'analyse des tâches cognitives peuvent être résumés comme suit :
(1) meilleure adéquation entre les fonctions système et les capacités cognitives humaines
(2) optimisation des performances système et de la charge de travail
(3) meilleure performance de l'équipe opérationnelle de commandement et contrôle
(4) meilleure compréhension des capacités demandées pour une tâche donnée
(5) meilleure conception des systèmes d'entraînement

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Contents

Preface

For almost a century, psychologists have been interested in matching tasks with human capabilities. The ultimate goal of this endeavour was, and still is, to make work safe, productive, and healthy. Matching tasks with human capabilities requires a deep understanding both of the task domain and the human practitioner. Over the past 100 years, various techniques have been at the psychologist's disposal, depending on the nature of work. Before World War II, psychologists mainly analysed manual work with the aim of improving the efficiency of every step in the work process. This changed in the 1950's when the number of white-collar workers started to exceed the number of blue-collar workers. New techniques were required for analysing mental rather than manual work. Cognitive task analysis is a broad area consisting of tools and techniques for describing the knowledge and strategies required for task performance. Cognitive task analysis has implications for the development of expert systems, training and instructional design, expert decision-making and policy-making. It has been applied in a wide range of settings, with different purposes, for instance: specifying user requirements in system design or specifying training requirements in training needs analysis.

Several historical developments have contributed to what we now call 'cognitive task analysis'. First of all, in the late 1950's, it became clear that computers were not just number-crunchers, but rather general-purpose symbol manipulation machines. Human mental work, in particular problem solving, could be considered a form of symbol manipulation. Hence, the argument went on; human mental work could be computationally modelled. The technique used to do such computational modelling was 'protocol analysis', followed by the implementation in the form of production rules. This school of thought, prevalent at Carnegie Mellon University, culminated in the seminal work by Newell and Simon on "Human Problem Solving" (1972), and continues today in the work of Anderson and colleagues (1983; 1993; Anderson & Lebière, 1998). Although the computational modelling approach is first and foremost interested in understanding the architecture of cognition for its own sake, practical spin-offs have been intelligent tutoring systems and expert systems.

A second development, in the 1960's, was the growing interest of psychologists in supervisory control tasks in the military and in civilian industry. Particularly in Great Britain, interest in training issues in process control led to a general approach to study tasks and task demands, called "Hierarchical Task Analysis" (HTA) (Annett & Duncan, 1967). On the basis of an HTA, individual techniques can be chosen to solve particular problems, such as a lack of knowledge by an operator.

A third development was a number of accidents in nuclear and chemical industries (e.g., the Three Mile Island nuclear power plant accident), which spurred research into how to design tools for operators that would prevent such accidents. This led to the "cognitive systems engineering" approach in the early 1980's (e.g., Hollnagel & Woods, 1983). In this approach, techniques for capturing user requirements are very important.

A fourth development was a growth in knowledge in the basis for expertise (Glaser, 1984), and, in parallel, the commercialisation of expert systems, starting in the early 1980's (Hayes-Roth, Waterman, & Lenat, 1983). It soon became commonplace to refer to the capturing of expert knowledge as the "knowledge elicitation bottleneck", as this seemed to be the most time-consuming activity, relative to implementing the knowledge in the expert system. Numerous books and articles appeared, describing literally dozens of techniques with which knowledge could be captured. An early attempt to combine the research on expert-novice differences with knowledge elicitation techniques, can be found in Schraagen (1986).

These multiples, parallel and independent origins all contributed to what has since the beginning of the 1980's been referred to as "cognitive task analysis". Cognitive task analysis is an activity that is not carried out for its own sake; rather, its primary aim is to dissect "mental work" into more manageable constructs that shed light on a particular problem. The choice of constructs is determined by the techniques chosen by the analyst, and these are largely determined by one's theoretical inclinations.

The increasing importance of cognitive task analysis for military system development was recognised by NATO's Panel 8 (Defence Applications of Human and Bio- Medical Sciences) Defence Research Group in 1994, when an Exploratory Group on Cognitive Task Analysis was established. The Group was chaired by Dr. J.M.C. Schraagen (TNO Human Factors Research Institute, The Netherlands), and met once in Soesterberg to draft the Terms of Reference and a Programme of Work for a subsequent Research Study Group (RSG). This RSG was formally established in the fall of 1995 as RSG.27 on Cognitive Task Analysis. The participating countries were: The Netherlands (lead nation), United Kingdom, France, and the United States of America. In 1997, Germany joined the RSG. RSG.27 met six times in three years, starting in January, 1996 (in chronological order:

Soesterberg, Montreuil-Juigné, London, Washington, Soesterberg, and Versailles). Its main activities consisted of (a) writing a state-of-the-art review on cognitive task analysis techniques, (b) organising a workshop with experts in the field in 1997 in Washington, DC, and (c) identifying new developments and issues for further research. The papers presented at the workshop were edited extensively by Schraagen, Chipman, and Shalin, and will be published by Lawrence Erlbaum Associates under the title "Cognitive Task Analysis".

The present Technical Report is the final deliverable of RSG.27 to NATO RTO. It consists of (a) a general introduction to the field of cognitive task analysis (also to be published as chapter 1 in Schraagen, Chipman, & Shalin, in press), (b) a state-of-the-art review of cognitive task analysis techniques, and (c) a report on the workshop with experts in the field.

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Chapter I

Introduction to Cognitive Task Analysis[1]

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SUMMARY

This introductory chapter will define cognitive task analysis and give the authors' view of the state of the art. Cognitive task analysis is defined as the extension of traditional task analysis techniques to yield information about the knowledge, thought processes and goal structures that underlie observable task performance. Cognitive task analyses are conducted for a wide variety of purposes, including the design of computer systems to support human work, the development of training, and the development of tests to certify competence. The introductory chapter will draw upon a recent review of the literature on cognitive task analysis, which was conducted by RSG.27. From that review, an image of the prototypic ideal case of a cognitive task analysis process emerges. The subsequent phases in the process are discussed. The introduction ends with a discussion of further research needed in the field of cognitive task analysis. Some important issues are the use of cognitive task analysis in the design of new systems, the development of systematic approaches that effectively integrate the many available techniques, the appropriate selection of approaches for a given problem and applied purpose, and the application of cognitive task analysis to team tasks.

INTRODUCTION

Modern work, with its increasing reliance on automation to support human action, is focusing attention on the cognitive aspects of work that are not accessible to direct observation. For example, it is obvious that the physical acts of button pushing that occur in the command center of a modern ship are of less intrinsic importance than the mental decision processes executed via those actions. The mental processes organize and give meaning to the observable physical actions. Attempts to analyze a task like air traffic control with traditional behavioral task analysis techniques made the shortcomings of those techniques strikingly clear (Means, 1993). Starting in the 1960s, the cognitive revolution in academic psychology has both increased our awareness of the extensive cognitive activity underlying even apparently simple tasks and provided research techniques and theories for characterizing covert cognition. Hence, the term *cognitive task analysis* is coming into use to describe a new branch of applied psychology. The relative newness of this

[1] This chapter is an abbreviated version of Chapter 1 in J.M.C. Schraagen, S.E. Chipman, and V.L. Shalin (Eds.), *Cognitive task analysis* (in press). Mahwah, NJ: Lawrence Erlbaum Associates. Published by permission of Lawrence Erlbaum Associates, Inc.

enterprise is evidenced by the fact that, as of this writing, a search of the entire PsychInfo database with the term yielded only 28 items, some irrelevant, and a search in the Science Citation Index yielded 30 items. The high current interest in cognitive task analysis is evidenced by recent literature review efforts undertaken by a British aerospace company (confidential) and by the French military (Doireau, Grau, & Poisson, 1996) as well as the NATO Study Group effort reported here.

Cognitive task analysis is the extension of traditional task analysis techniques to yield information about the knowledge, thought processes, and goal structures that underlie observable task performance. Some would confine the term exclusively to the methods that focus on the cognitive aspects of tasks, but this seems counterproductive. Overt observable behavior and the covert cognitive functions behind it form an integrated whole. Artificially separating and focusing on the cognitive alone is likely to produce information that is not very useful in understanding, aiding, or training job performance. The tension between traditional behavioral task analysis techniques and newer cognitive task analysis is largely a U.S. phenomenon. Elsewhere, behaviorism never took hold as it did in the U.S., where military regulations governing training development have forbidden talk of processes that go on inside the head almost until the present day. Annett, Duncan, Stammers, and Gray's (1971) hierarchical task analyses, for example, often segued smoothly from the domain of observable behavior to the internal world of perception and cognition. The changing nature of work, however, is universal throughout the developed world. Even those who did not eschew analysis of the cognitive aspects of work now need more powerful tools and techniques to address the large role of cognition in modern work.

Analyses of jobs and their component tasks may be undertaken for a wide variety of purposes, including the design of computer systems to support human work, the development of training, or the development of tests to certify job competence. An emerging frontier of modern task analysis is the analysis of entire working teams' activities. This is done for purposes such as the allocation of responsibilities to individual humans and cooperating computer systems, often with the goal of reducing the number of humans who must be employed to accomplish the team function. Given the purposes and constraints of particular projects, several (cognitive) task analysis approaches merit consideration. Savvy customers and practitioners of cognitive task analysis must know that one approach will not fit all circumstances. On the other hand, a thoroughgoing cognitive task analysis may repay the substantial investment required by proving applicable to purposes beyond the original intent. For example, Zachary, Ryder, and Hicinbothom (in press) analyzed the tasks of the AEGIS antiair warfare team in order to build an artificially intelligent training system, but these same analyses are being used to guide the design of advanced work stations and new teams with fewer members.

This report is the ultimate product of a NATO study group aiming to capture the state of the art of cognitive task analysis. The intent is to advance it toward a more routine engineering discipline—one that could be applied reliably by practitioners not necessarily educated at the doctoral level in cognitive psychology or cognitive science. To that end, two major activities were undertaken. One was a review of the state of the art of cognitive task analysis, focusing on recent articles and chapters claiming to review cognitive task analysis techniques. This effort produced a bibliographic resource appearing as a chapter in this report. We hope that this chapter gives sufficient information to help students and other readers decide which of these earlier contributions to the field they should read for their particular purposes. The second major activity of the NATO study group was an international workshop intended to provide an up-to-date snapshot of cognitive task analyses, emphasizing new developments. Invitations were extended to known important contributors to the field. The opportunity to participate was also advertised widely through electronic mailing lists, in order to capture new developments and ongoing projects that might not be known to the study group members organizing the workshop. This report is largely the product of that workshop, sharing its insights into the state of the art of this new field. This introduction provides an overview of these two activities. First, we sketch the prototype cognitive task analysis based on results from the NATO study group.

THE PROTOTYPIC COGNITIVE TASK ANALYSIS PROCESS AS SEEN IN PRIOR LITERATURE

Ironically, the cognitive analysis of tasks is itself a field of expertise like those it attempts to describe. Reviewing recent discussions of cognitive task analysis reveals that the explicitly stated state of the art is lacking specification of just those kinds of knowledge most characteristic of expertise. A large number of particular, limited methods are described repeatedly. However, little is said about how these can be effectively orchestrated into an approach that will yield a complete analysis of a task or job. Little is said about the conditions under which an approach or method is appropriate. Clearly, the relevant conditions that need to be considered include at least the type of task being analyzed, the purpose for which the analysis is being done (HCI; human-computer interaction design, training, testing, expert system development), and the resources available for the analysis, particularly the type of personnel available to do the analysis (cognitive scientists, cognitive psychologists, educational specialists, subject-matter experts). The literature is also weak in specifying the way in which the products of task analysis should be used in designing either training or systems with which humans will interact. The prior literature on cognitive task analysis is also limited by a focus on the tasks of individuals, almost exclusively existing tasks for which there are existing task experts.

Nevertheless, the literature review effort did, within these limits, provide the image of a prototypic ideal case of the cognitive task analysis process, as it might be when unhampered by resource limitations. What emerges as the ideal case, assuming that resource limitations are not a problem? Although the answer to this question may vary somewhat, depending the purpose for which the analysis is being done, we set aside that consideration for a while or assume that the purpose is training and associated proficiency measurement. Several of the articles we reviewed are strong in their presentation of an inclusive recommended approach to cognitive task analysis (e.g., Hall, Gott, & Pokorny, 1995; Hoffman, Shadbolt, Burton, & Klein, 1995; Means, 1993; DuBois & Shalin, 1995).

Preliminary Phase

One should begin a cognitive task analysis with a study of the job or jobs involved to determine what tasks merit the detailed attention of a cognitive task analysis. Standard approaches from personnel psychology are appropriate for this phase of the effort, using unstructured interviews and/or questionnaires to determine the importance, typicality, and frequency of tasks within job performance. Hall et. al., (1995) discussed this preliminary phase, as did DuBois and Shalin (1995) with somewhat more methodological detail. DuBois and Shalin also pointed out the importance of focusing on the tasks or problems within general tasks that discriminate more expert performance from routine performance, even though these may not be high-frequency events. Klein Associates' approach seems to embody the same view, with an emphasis on gathering data about past *critical incidents* in experts' experience.

Depending on the availability of written materials about the job or task, such as existing training materials, the first step for those responsible for the analysis probably should be to read those materials to gain a general familiarity with the job or task and a knowledge of the specialized vocabulary (this is referred to as *bootstrapping* by Hoffman et al., (1995), and *table-top analysis* by Flach (in press). The major alternative is to begin with informal, unstructured interviews with persons who have been identified as experts. In the ideal case, the task analysis becomes a team effort among one or more experts in cognitive task analysis and several subject-matter experts. Of course, it is important to obtain the time, effort, and cooperation of experts who are in fact expert. Hall et. al. (1995) discussed the issue of the scarcity of true experts and the selection of appropriate experts in moderate detail. Hoffman et. al.(1995) were also concerned with the gradations of expertise. Articulate experts with recent experience in both performing and teaching the skill are particularly useful. For example, the MYCIN (Buchanan & Shortliffe, 1984 expert was reknowned for his ability to teach medical diagnosis. It is also true that not just anyone is suitable for acting as a cognitive task analyst—not even just anyone who is educated in cognitive psychology and cognitive science. Analysts must have the social skills to establish rapport with the subject-matter experts (SMEs), sometimes across the barriers of different social cultural and economic backgrounds. If doing unstructured or even structured interviews, they must be verbally adept to adapt to the changing circumstances of the interview. They must be intelligent, quick learners because they have to learn a great deal about the task to analyze it effectively. Hoffman et al. (1995) and Crandall, Klein, Militello, and Wolf (1994) discussed some of these issues about the requirements for cognitive task analysts. Forsythe (1993) also appears to be a reference of interest on these points. There is also a good deal of literature from the expert systems community dealing with the practicalities of interviewing and with requirements that both the knowledge engineer and the expert must meet (e.g., Firlej & Hellens, 1991; McGraw & Harbison Briggs, 1989; Meyer & Booker, 1991; Waterman, 1986).

Identifying Knowledge Representations

A major goal for the initial unstructured interviews with the SMEs should be to identify the abstract nature of the knowledge involved in the task, that is, the type of knowledge representations that need to be used. This can order the rest of the task analytic effort. This point is not explicit in the literature, but the more impressive, convincing approaches are organized around a knowledge representation or set of knowledge representations appropriate for the job or task. For example, DuBois and Shalin (1995; in press) use a goal–method graph annotated with additional information about the basis for method selection and the explanation of the rationale or principles behind the method. Less explicitly, the PARI method (Hall et al., 1995) gathers essentially the same information supplemented by information about the experts' mental organization of device structure and function. Crandall et al (1994) advocated collecting mental models of the task and the team context of work, as well as of the equipment. For eliciting knowledge about how a device or system works, Williams and Kotnur (1993) described Miyake's (1986) *constructive interaction*. Benysh, Koubek, and Calvez (1993) proposed a knowledge representation that combines procedural information with conceptual information. Similarly, in ongoing work, Williams, Hultman, and Graesser (1998) have collaborated on ways to combine the representations of declarative and procedural knowledge. Semantic networks are probably over-represented in reviews of knowledge acquisition methods relative to their actual utility. Although measures of conceptual relatedness or organization are sensitive to growth in expertise, they may actually be derived from more complex knowledge organizations in the experts' minds, such as those mentioned earlier that integrate procedural and declarative knowledge. For example, it might be a mistake to attempt to directly train the conceptual organizations one deduces from studies of experts. However, semantic networking or clustering techniques have been successfully used to structure more effective computer interfaces (Patel, Drury, & Shalin, 1998; Roske-Hofstrand & Paap, 1986; Vora, Helander, & Shalin, 1994). As we gain experience with cognitive task analysis, it may become possible to define a taxonomy of tasks that, in effect, would classify tasks into types for which the same abstract knowledge representations and the same associated knowledge-elicitation methods are appropriate. However, we should always keep in mind the possibility that the particular task of concern may involve some type of knowledge not in the stereotype for its assigned position in the classification scheme.

Knowledge- Elicitation Techniques

Having identified the general framework for the knowledge that has to be obtained, the analysts can then proceed to employ the knowledge-elicitation techniques or methods discussed in the articles reviewed. Structured interviews can be used to obtain information—an approach that is well discussed in Hoffman et al. (1995), Randel, Pugh, and Reed (1996), and Crandall et al. (1994). The extreme of the structured interview is the computer-aided knowledge-elicitation approach, discussed in reviews by Williams and Kotnour (1993) and Cooke (1994) and exemplified by Shute's (in press) DNA cognitive task analysis software and Williams' (in press) CAT and CAT-Human–Computer Interaction tools. The latter structure and support a generalized version of a GOMS-style analysis, generating much the same sort of goal–method representation recommended by DuBois and Shalin. Of course these interviews and other methods must be focused on an appropriate representative set of problems or cases previously identified, as alluded to earlier. The PARI method (Hall et. al., 1995) features the participation of SMEs to develop appropriate problems. The importance of an appropriate sample of problems or tasks is perhaps most obvious for the simple case of the use of GOMS analysis to evaluate alternative keyboard/display designs. The basis for evaluation would be differences in the predicted execution times—for a representative sample of tasks. In training development, the issue is providing adequate coverage of essential knowledge and skills.

Structured interviews and their extensions into computer-aided methods used by SMEs assume that the experts have direct conscious access to their relevant knowledge and skill. However, research on expertise has shown that this cannot be assumed. Much goes on below the level of conscious awareness, especially in skills that are exercised under time pressure or have significant perceptual and/or motor aspects. (For this reason, although the true ideal case might seem to be having the cognitive analyst and SME combined in one person, as has been true for many of the successful intelligent tutoring projects, it is never safe to assume that experts can directly explicate task knowledge.) Often one may simply extract the expert's naive psychological theory of how the task is performed—a theory that will not stand up to empirical investigation. (Obviously even expert cognitive psychologists often propose theories of task performance that do not stand up to empirical investigation). For this reason, the use of process-tracing methods (cf. Cooke, 1994) is recommended. Observation of expert performance, which may be videorecorded and carefully and elaborately coded, belongs in this category. Observation tends to contribute primarily to an analysis of the overt, observable aspects of the task. However, if the task involves communication among team members, cognitive aspects of the task may be revealed. Observation of apprenticeship training is likely to reveal such information, and there is a variation of this in which the expert is asked to coach an analyst in task performance. Most conspicuous among the cognitive process tracing methods is the collection of verbal think aloud protocols while the SMEs perform a representative set of task problems. (The PARI method involves the use of SMEs to simulate problems—fault effects, test results etc.—for other experts attempting unfamiliar problems.) To increase the information yield for practical applications, protocols may be supplemented with probe questions or retrospective review of videotapes with probe questions (cf. Dubois & Shalin, in press; Zachary, Ryder, & Hicinbothom, in press). There is also a variant approach called interruption analysis that several reviews mention. The goal of these methods is to bring out relevant knowledge in the context of use. Of course Verbal protocol methods and other verbal methods are relatively ineffective in getting at nonverbal types of knowledge, although one may discover that a surprising amount of specialized perceptual vocabulary has been developed for purposes of training and teamwork. Experimental psychology has provided other process tracing methods, such as the collection of eye fixations, that may prove useful in getting at aspects of task performance not represented verbally.

If a semantic network of concepts seems to be an appropriate part of the representation of task knowledge, a large number of knowledge-elicitation techniques are available for this purpose. Olson and Biolsi (1991) provide the best discussion of these—the associated data analysis methods, and the relations among them—along with a useful diagram of those relationships. These methods generally can be used with only a small set of concepts, a serious limitation given the large number of concepts actually involved in any area of expertise. Cooke (1994) and Benyah, Koubek, and Calvez (1993) are the only authors who give much attention to the problem of selecting the set of concepts to be used with these methods.

Choosing target knowledge representations provides guidance to the overall cognitive task analysis effort. A wide variety of techniques from experimental psychology, including novel ones invented for the purpose, might be used to fill in the information needed in one's chosen knowledge representations. Hoffman et al. (1995) referred to this deliberate modification of the familiar task as the use of *contrived techniques*. Although contrived techniques can make the expert feel uncomfortable and may sometimes give misleading results, Hoffman et al. noted that they can be informative and tend to be more efficient in yielding information. Once they have been developed, it is usual to present the knowledge representations to the SMEs to review for reasonableness and for comments. Of course if the analysis becomes the basis of an expert system or expert cognitive model, one may also be able to evaluate its performance for its resemblance to the performance of human experts.

Using CTA Products

Once you have done a cognitive task analysis, how do you make use of the products in your application? This is a definite weak point in the literature. Using the output of PARI analyses to develop training systems has proved problematic for the U.S. Air Force. If one has a detailed goal–method analysis down to the production system level, an analysis of the type that Williams' CAT tool is designed to support, this can probably be converted into a running computational model that can function as the student model of an intelligent tutoring system. John R. Anderson (personal communication) has claimed that, once such a cognitive model has been developed, the actual development of a tutoring system is quite trivial, given the tools available in his lab. Of course the process described here would also have yielded a set of problems that could be used in the tutoring system. DuBois, Shalin, and their associates have developed a method for using task analysis results to generate test items. An elaboration of the same method applies to the identification of information requirements for interface design (Shalin & Geddes, 1994, 1998; Shalin, Geddes, Mikesell, & Ramamurthy, 1993). The ACTA CD-ROM (1997) developed by Klein Associates for training cognitive task analysis methods contains useful suggestions for the ways in which the information developed can be used to improve training (Mitillo & Hutton, 1998; Mitillo et al., 1997). From the work of Schvaneveldt (1990) and his associates, it appears that any of the techniques for analyzing concept organization can be readily used to provide crude assessments of the development of expertise by measuring the resemblance of learners' conceptual organization to that of experts. In Schraagen, Chipman, and Shalin (in press), the chapters by Boy (chap. 18); Johnson, Johnson, and Hamilton (chap. 13); Neerincx, van Doorne, & Ruijsendaal (chap. 20); Ormerod (chap. 12); Paris, Balbo, and Ozkan (chap. 16); and Potter, Roth, Woods, and Elm (chap. 21) attempt to bridge the gap between cognitive task analysis and system design using task models. Task models are formal ways of describing standard task elements. They serve to structure knowledge acquisition and bridge the gap between cognitive task analysts and software engineers. As in the case of training, applications of cognitive task analysis to human–system interaction began by analyzing the interactions of experienced users with existing systems, often to identify problematic features of existing interfaces. These methods could be extended rather readily to evaluate detailed designs for new interfaces or to compare multiple designs for a future interface, as was done with the GOMS engineering model approach developed by Card, Moran, and Newell (1983). The GOMS approach (analysis into Goals, Operators, Methods, and Selection criteria for methods) (John and Kieras, 1994 is conceptually similar to the tradition of hierarchical task analysis dominant in the United Kingdom.

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Chapter II

State-of-the-Art Review of Cognitive Task Analysis Techniques[1]

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SUMMARY

Cognitive task analysis is the extension of traditional task analysis techniques to yield information about the knowledge, thought processes and goal structures that underlie observable task performance. Interest in the cognitive aspects of behavior has grown since the mid 1980's because of the growing use of automated systems in task performance. In the armed forces, this is denoted with the term "digitization of the battlefield". Cognitive processes such as diagnosis, judgment, planning and decision making have come to the fore as a result of this development.

As part of its Programme of Work, NATO Research Study Group 27 on Cognitive Task Analysis has undertaken the task of reviewing existing cognitive task analysis techniques. The Group concludes that few integrated methods exist, that little attention is being paid to the conditions under which methods are appropriate, and that often it is unclear how the products of cognitive task analysis should be used.

1. INTRODUCTION

As part of its Programme of Work, RSG.27 on Cognitive Task Analysis has undertaken the task of reviewing existing cognitive task analysis techniques and computer tools.

RSG.27 has restricted itself to a "review of reviews", in order to keep the work manageable. Therefore, descriptions of individual methods and techniques were explicitly excluded from the review.

A literature search was conducted, starting with references from 1990 onwards. Twenty reviews were deemed useful for further reading. A common framework was adopted for summarizing the reviews. The categories comprising the framework were the following:

(i) full citation
(ii) indication of the year the review was covering the literature to
(iii) short description of the contents of the review
(iv) definition of CTA provided by the review
(v) depth of description of methods or techniques discussed
(vi) applications of interest to the author(s)

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[1] This chapter is an expanded version of Chapter 28 in J.M.C. Schraagen, S.E. Chipman, and V.L. Shalin (Eds.), *Cognitive task analysis* (in press). Mahwah, NJ: Lawrence Erlbaum Associates. Published by permission of Lawrence Erlbaum Associates, Inc.

(vii) apparent theoretical perspective of the author(s)

2. RESULTS

Table I presents the outcome of the literature review, with the exception of the description of the contents of the review. A full description of all reviews can be found after the recommendations.

Table I: references in chronological and alphabetical order

Reference	Coverage of literature up to ...	Definition of CTA	Depth of description	Applications of interest	Theoretical perspective
Grant & Mayes (1991)	1990	Analysis dealing with information flow and usage	Shallow	Human-computer interaction in complex systems	cognitive psychology /cognitive engineering
Reitman Olson & Biolsi (1991)	1989	No	Shallow for direct methods; detailed for indirect methods	General	experimental cognitive psychology
Wilson & Cole (1991)	1989	No	Shallow	Instructional design	instructional design
Alm (1992)	1991	No	Shallow	General	ecological psychology; systems thinking
Kirwan & Ainsworth (1992)	1992	Range of approaches used for looking at mental internal events or knowledge structure	Detailed, in-depth, practical	General, broad range of applications	applied ergonomics
Redding (1992)	1991	Determines mental processes and skills required to perform a task at high proficiency levels	Moderate detail, but insufficient for novice analysts	job training	cognitive psychology
Benysh, Koubek, & Calvez (1993)	1991	No	Shallow	Human–Computer Interaction design	applied psychology
Means (1993)	1988	Tasks in which the critical steps are cognitive operations rather than observable behaviors	Detailed for two cases (avionics troubleshooting and air traffic control)	Training	mainstream American cognitive science
Williams & Kotnur (1993)	1991	No	Detailed, particularly for machine-aided methods	Intelligent tutoring systems, but not limited to that area	Carnegie Mellon University-style cognitive modeling
Cooke (1994)	1994	No	Shallow	Expert systems	experimental cognitive psychology
Crandall, Klein, Militello & Wolf (1994)	1993	Methods for identifying cognitive task requirements for tasks that involve true expertise	Shallow, but accompanying CD-ROM is more detailed	Training development	naturalistic decision making

Reference	Coverage of literature up to ...	Definition of CTA	Depth of description	Applications of interest	Theoretical perspective
Essens, Fallesen, McCann, Cannon-Bowers & Dörfel (1994)	1993	CTA seeks to describe, in cognitive terms, how goals and tasks are accomplished	concise; more informative about elicitation techniques than about entire approaches	Design of decision aids, but not limited to this area	transitional between behavioral and modern cognitive perspectives
John & Kieras (1994)	1994	Analysis of knowledge of how to do a task in terms of the components of goals, operators, methods, and selection rules	Detailed, but insufficient for novice analysts who want to learn how to use GOMS	Human-Computer Interaction	Carnegie Mellon University-style cognitive modeling
Merkelbach & Schraagen (1994)	1993	Integrated use of task modeling, knowledge modeling and cognitive modeling	Detailed for HTA, KADS and GOMS; shallow for other techniques	General; connections between application areas and modeling perspectives are proposed	Carnegie Mellon University-style cognitive modeling; generic task method; practical task analytic behavioral approaches
Whitefield & Hill (1994)	1993	No	Shallow	Human–Computer Interaction design	computer systems engineering; software design
Dehoney (1995)	1992	Analysis of expert's mental model of the problem	Detailed on elicitation techniques	Instructional design	cognitive psychology
DuBois & Shalin (1995)	1993	No	Detailed on knowledge representation used and on combination of different methods	job knowledge testing; training needs analysis and design	personnel psychology and cognitive science
Hall, Gott, & Pokorny (1995)	1990	Analysis of underlying psychological processes and knowledge structures	Detailed for PARI methodology; moderate detail for four alternative approaches	Training of cognitively complex tasks (in particular, troubleshooting)	cognitive science and cognitive psychology
Hoffman, Shadbolt, Burton & Klein (1995)	1992	No	Shallow	Mainly expert systems	social, organizational, and experimental psychology
Gordon & Gill (1997)	1994	Theory or model of how experts perform their tasks	Shallow	General	cognitive psychology

Table I shows that the 20 reviews cover the literature up to 1994. Eleven reviews provide a definition of CTA, whereas 9 do not provide a definition at all. Nine reviews are shallow in their description of particular techniques: in these cases the reader should consult the primary sources that are being reviewed. However, eleven reviews provide detailed information on a limited number of techniques. The applications of interest to the authors appear to be mostly training and instructional design (8 cases), followed by human-computer interaction (4 cases) and expert systems (3 cases). The apparent theoretical perspective of the authors is predominantly a cognitive psychological one (7 cases), followed by a cognitive science perspective (e.g. Carnegie Mellon University-style production system modeling).

An analysis of the reviews themselves shows that a very large number of particular, rather limited methods are described over and over again. But little is said about how these can be effectively orchestrated into an approach that will yield a complete analysis of a task or job. Little is said about the conditions under which an approach or method is appropriate. Clearly, the relevant conditions which need to be considered include at least the type of task being analyzed, the purpose for which the analysis is being done (Human–Computer Interaction design, training, testing, expert system development), and the resources available for the analysis, particularly the type of personnel available to do the analysis (cognitive scientists, cognitive psychologists, educational specialists, subject-matter experts). The literature is also very weak when it comes to specifying the way in which the products of task analysis should be used in designing either training or systems with which humans will interact.

Based on the literature review, the following issues were identified by RSG.27 as timely and important to investigate:

1. Validity and reliability of CTA techniques and results
2. CTA for new tasks/systems
3. CTA for tasks that are difficult to verbalize (e.g., spatial tasks)
4. Requirements for analysts (required level of training and education)
5. Conditions under which particular techniques should be employed
6. Relation between the purpose of CTA and the results of the activity (do different types of applications require different results? E.g., training de novo, retraining, proficiency testing, Human–Computer Interaction, system (re)design)
7. CTA for team tasks
8. Relationship of CTA techniques to theories of cognition
9. Individual differences (culture, nationality) and their implication for solutions
10. Effects of environmental stressors on the conduct of CTA (does CTA need to incorporate the stressors in the environment in which the operator works?)
11. Selecting/defining expertise
12. Human Operator/Performance Modeling Systems
13. CTA for safety-critical systems; Human Reliability Analysis

RECOMMENDATIONS

1. RSG.27 recommends the organization of a workshop with experts in the field of Cognitive Task Analysis. The goal of the workshop would be to address the issues identified by RSG.27 and thus advance the field of Cognitive Task Analysis.

2. RSG.27 recommends that the workshop be centered around the following four themes:

1. What is the purpose of a Cognitive Task Analysis and what results are generated to achieve this purpose?
2. What integrated approaches are used by analysts and how should these be evaluated?
3. What are the scientific underpinnings of Cognitive Task Analysis?
4. What methods/topics/approaches are recommended for further research?

3. RSG.27 recommends that the results of the workshop be made available widely, preferably in an edited book format.

CHAPTER III

Reviews

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S. Grant & T. Mayes (1991). Cognitive task analysis? In G.R.S. Weir & J.L. Alty (Eds.), Human-computer interaction and complex systems (pp. 147-167). London: Academic Press

Literature covered up until 1990, most references are from the eighties.

The focus in this chapter is on cognitive task analysis for human-computer interaction in complex systems. The authors argue that since humans will continue to play a key role in controlling or supervising complex systems, these systems need to be designed taking into account the human's information needs. "A CTA will properly involve an analysis of the information flow and the required knowledge states throughout the entire system" (p. 149). The authors distinguish three approaches to CTA:

1. An analysis of a task in terms which relate to human cognition (decomposition formalisms)
2. Theories and models of human cognition which specify the terms in which the task has to be analyzed
3. Observations on salient features of human cognition in complex processes.

Examples of the first approach that are discussed are: GOMS, Cognitive Complexity Theory, Command Language Grammar, and Task-Action Grammars. The main shortcoming of these formalisms, according to the authors, is that they have been restricted to simpler systems and highly proceduralized behavior. The authors are also skeptical about representing knowledge in terms of an unrestricted production system, precisely because multiple solutions are equally possible. It is therefore unclear whether any particular production system bears any resemblance to actual cognitive behavior.
The models of cognition that are discussed as examples of the second approach are: The Model Human Processor, Programmable User Models, ACT*, Interacting Cognitive Subsystems. Again, these models are more suitable for analyzing short-term simple tasks than longer-term subtler cognitive abilities involving problem solving or decision making. Models such as ACT* (and SOAR) need a way of finding those production rules which best represent a particular human approach to a particular task. These models do not help to focus an approach to analysis, but rather leave this aspect of the analysis open (in general, it is possible to analyze a task in terms of production rules in many widely differing ways). The authors are clearly in favor of Interacting Cognitive Subsystems.
Among the important features of cognition in complex systems mentioned are the Rasmussen "Skills, Rules, and Knowledge" framework , Roth and Woods' "Mapping Cognitive Demands" framework and Moray's "Quasi-independent subsystems". Although the authors find the Rasmussen framework useful, it does not amount to a complete cognitive task analysis technique. Roth and Woods' attempt to map cognitive demands independently of representation and cognitive agent is difficult given the possibility of individual differences and uncertainty about how the domain

problem is to be described in the first place. The problem with Moray's analysis is that he offers no evidence about the extent to which actual models of operators match up with the methodical analyses.
The authors conclude from their review that none of the approaches discussed are fully adequate for a CTA in the context of complex systems: they either lack sufficient input from cognitive psychology, or they lack sufficient relevance to the realities of complex tasks, or both. The aim of CTA must be to integrate an investigation of tasks independently of human cognition and an investigation of cognitive processes involved in complex control tasks.
Overall, this is more a philosophical than a practical chapter, that is also somewhat outdated. The only practical advice offered is "investigate the information requirements of specific operators in specific situations" (pp. 165-166). The good point is that the authors are concerned with actual cognitive behavior as displayed by human operators. They offer some critical comments about cognitive modeling enterprises that seemingly ignore actual cognitive behavior. In a current version of their chapter, the authors would need to include EPIC (Meyer & Kieras) and ACT-R (Anderson), although many of their comments would remain the same.

Definition of cognitive task analysis: "an analysis dealing with information flow and usage" (p. 165)

Depth of description: The descriptions are quite brief and readers are referred to other sources for details. The overarching comments in this paper tend to be more valuable than the descriptions of the formalisms or models. The descriptions are not useful for practitioners who want to apply techniques.

Applications of interest to the authors: human-computer interaction in complex systems

Apparent perspective of the authors: cognitive psychology/cognitive engineering

J. Reitman Olson & K.J. Biolsi (1991) Techniques for representing expert knowledge. In: K. Anders Ericsson & J. Smith (Eds), Toward a general theory of expertise (pp. 240-285). Cambridge, England: Cambridge University Press.

This paper cites a great deal of methodological work that extends quite far back; it seems to provide coverage up to about 1988-89.
This paper reviews quite a number of knowledge elicitation techniques along with their associated analysis methods and resulting output representations of knowledge. The techniques are divided into direct (interview, think-aloud, observation, interruption analysis, commentary, drawing of groupings in a spatial array, card sorting) and indirect methods (direct judgments of similarity or relatedness, confusion probabilities, co- occurrence probabilities, repertory grid and recall orders). Useful diagrams bring out the relationships among the members of these two families of methods. The direct methods are not treated in any detail: they are described as a way to discover the vocabulary and concepts in an area of expertise and as the only way to uncover problem-solving strategies. There is no discussion, for example, of ways of designing or structuring interviews. Some comments are made about the domains in which think aloud methods are suitable (those naturally involving verbal concepts) and not suitable (perceptual, motor, highly automatized.) In contrast, the indirect methods are discussed in considerable detail both with respect to procedures and assumptions about the underlying knowledge representations and assumptions about the way in which subjects may be generating the data collected by the method from the underlying representation. A table summarizing experience with these methods (p. 274) reveals that most are suited when it is reasonable to assume a hierarchical representation of concepts. The text also comments that multidimensional scaling has proved more suitable to the analysis of perceptual similarities, whereas the other methods seem more appropriate for semantic concepts. Some concern is expressed about the psychological reality of the representations emerging from these methods and about the desirability of obtaining convergent evidence from multiple methods. A useful general comment is made about the importance of paying attention to the extent to which the data collection task appears to be easy and natural for the subjects. There are also a few useful comments about the orchestration of these different approaches into a total approach -- the use of interviews to identify important concepts, the use of indirect methods to explore relations among these concepts, and the possible integration of think aloud or similar methods into indirect data collection techniques in order to ease interpretation of the results. However, some points that are rather obvious from the discussion are not brought out strongly and explicitly. Although the paper begins by pointing out the richness of true expert knowledge, the implications of this are not brought out. In particular, the problem of the small number of concepts that can typically be studied with the indirect techniques is not discussed. Also, despite the emphasis on the importance of the nature of the representations and of the assumptions on this point, nothing is said about a direct focus on this issue.

Definition of cognitive task analysis: the term cognitive task analysis is not prominent in this paper and no definition of it is given.

Depth of description: As noted above, the description of so-called direct methods is shallow, while the description of indirect experimental methods is quite detailed and supplemented by useful comparisons among them and methodological critiques.

Tasks of interest: This review is quite general, with no focus on a particular type of expertise or application.

Apparent perspective of the authors: Although Reitman Olson has been involved in applied work, especially in Human–Computer Interaction, I would characterize this review as being written from the perspective of an experimental cognitive psychologist with a basic research orientation.

Wilson, B., & Cole, P. (1991). A review of cognitive teaching models. Educational Technology, Research and Development, 39(4), 47-64.

Dates covered: This review [of cognitive teaching models, not cognitive task analysis] spans the period from 1980 to 1989.

Abstract: This article reviews (from primarily an instructional-design perspective) nine teaching programs developed by cognitive psychologists over the last dozen years or so. Among these models, Collins' cognitive apprenticeship model has the most explicit prescriptions for instructional design. This cognitive apprenticeship model is analyzed, then components of the model are used as an organizing framework for understanding the remaining models. Differences in approach are noted between traditional ID prescriptions and the cognitive teachings models. Surprisingly, no design strategies were found to be common to all the model programs. Key differences among programs included: (a) problem solving versus skill orientations, (b) detailed versus broad cognitive task analysis, (c) learner versus system control, and (d) error-restricted versus error-driven instruction. The article concludes with an argument for the utility of continuing dialog between cognitive psychologists and instructional designers.

Definition of CTA: Only one small section in the paper actually addresses issues related to cognitive task analysis (pp. 59-60). Very generally, the main products of cta include: (a) the representation of the content/knowledge or skills taught by whatever methods, and (b) the instructional materials and interactions.

Depth of description: Again, this review was mostly on discussing a variety of "current" cognitive teaching models (e.g., anchored instruction, qualitative mental models). Each one of them had a different requirement with regard to the grain size of the instructional content, from low-level (e.g., Anderson's ITS, representing content as productions) to high-level (e.g., mental models).

Applications of interest to the authors: Their orientation is clearly instructional design thus their interest appears to be finding pedagogical prescriptions. But that doesn't happen. Rather, the strength of this paper is in terms of its clean summaries of some of the most influential approaches to teaching that arose during the 80s.

Apparent theoretical perspective of the author: Instructional Design.

I. Alm (1992). Cognitive tasks: A meta-analysis of methods(FOA report C 50098.5.5). Sundbyberg, Sweden: National Defense Research Establishment, Department of Human Studies.

This review covers the literature up until 1991.

This report does not fully deliver what it promises--namely a meta-analysis of methods (for cognitive task analysis). Only two methods are discussed in some detail: the Generic-Error Modeling System (GEMS) and Hierarchical Task Analysis. The major claim of the report is that these and other methods for cognitive task analysis generally ignore the context in which cognitive behavior takes place. This is similar to Simon's claim that the task environment to a large extent determines the representations used by problem solvers. For instance, according to Alm "it is not the same thing to drive alone on a road a sunny day and drive a car during a rush hour a rainy day" (p. 11). The task, driving a car, is the same on both occasions, but the change in context leads to quite different demands on the driver and consequently to quite different driving behavior.

The report distinguishes between two types of contexts: physical and social structures. In the first, a cognitive system interacts with a non-cognitive system; in the second, two or more cognitive systems interact. Furthermore, two different types of tasks are distinguished: iterative or repetitive tasks, and open-ended or dynamic tasks. Iterative tasks in either a physical or social structure require a different approach when being analyzed than open-ended tasks. Iterative tasks require that the analyst find out what instruction is valid for task performance, what the performer's mental representation of the task and/or the instruction is, and what biases cause the two to differ. Open-ended tasks performed in a physical or social structure require the observer to find out the system's function, the organization of the task, and the system's relation to the environment. Next, a context for a particular task performance is selected and studied during some period of time ('space-time structure'). This analysis should be checked with the performers. Finally, the mental representations of the task and the space-time structure should be examined.

The major conclusion of the report is that there does not exist any universal method which can analyse, describe, and explain all cognitive tasks performed in different contexts. Therefore, prior to analyzing a particular task's demands on the cognitive system, it is extremely important to differentiate between various kinds of purposes, situations, tasks, structures and organizations.

No explicit definition of cognitive task analysis is provided in the report. However, cognition is viewed as "an open self-regulating system characterized by feedback loops" (p. 27).

Depth of description: only GEMS and HTA are discussed in some detail, but still fairly superficially.

Applications of interest: the report does not focus on any particular application areas. Its conclusions are deemed relevant for all application areas.

Apparent theoretical perspective of author: ecological psychology (Bateson), systems thinking (Laszlo). Although the author does not refer to this theoretical area, she seems to be close to situated cognition.

Kirwan, B. & L.K. Ainsworth (Eds.) (1992), A guide to task analysis. London: Taylor & Francis. 417 pages.

This book covers the literature up until 1992. A British Task Analysis Working Group, consisting of members from industries, universities and consultancies produced the guide from 1989 to 1991.

Although it is sometimes claimed (e.g., by Gordon & Gill, 1997) that this book solely contains traditional behavioral task analysis methods, this is certainly not the case. Various methods that are usually claimed to be 'cognitive' in nature, are discussed, for instance: critical incident technique, GOMS, Hierarchical Task Analysis, structured interviews, verbal protocols, walk-through/talk-through analyses, withheld information. Admittedly, the authors very briefly list a technique they themselves describe as 'cognitive task analysis' on page 392 only (this is the TAKD technique). Since the only reference to cognitive task analysis in the book is to this short paragraph, the authors must view the other methods listed above as non-cognitive. This is strange because without doubt both GOMS and verbal protocols are purely cognitive in nature. The Guide is stronger, then, on the behavioral techniques, although the description of verbal protocols, for instance, is very useful and balanced.

The Guide contains descriptions of 25 techniques and illustrates the practical use of these techniques in 10 case studies. The case studies clearly show 'lessons learned' and are very powerful illustrations of what task analysis techniques can provide for an organization.

Definition of cognitive task analysis: "Cognitive task analysis covers a range of approaches used for looking at mental (hence cognitive) internal events or knowledge structure" (p. 392).

Depth of description: Excellent, in-depth descriptions of 25 techniques, with practical advice, resources required, links with other techniques, advantages and disadvantages. Key references to primary sources are provided.

Applications of interest to authors: allocation of function, person specification, staffing and job organization, task and interface design, skills and knowledge acquisition, performance assurance. The case studies are largely focused the above issues in industrial settings, e.g., nuclear power plants and process control.

Apparent theoretical perspective of the authors: Applied ergonomics.

Redding, R. E. (1992). A standard procedure for conducting cognitive task analysis. McLean, VA: Human Technology, Inc. (ERIC Document Reproduction Service No. ED 340 847).

Dates covered: This paper does not provide a review of published cognitive task analysis research, but provides guidelines for conducting a cognitive task analysis. A "Suggested References" section includes several citations for more detailed information about approaches to CTA within an ISD framework (dated from 1986 to 1991).

Abstract: The Instructional Systems Development (ISD) model has been widely used and found effective for analysis and training of psychomotor skills. It includes five phases: (Task) Analyze, Design, Develop, Implement, and Control. However, the ISD model has not been effective for jobs requiring complex cognitive skills (e.g., decision-making, problem-solving, attention-switching, and/or the effective organization and retrieval of large amounts of knowledge). As Redding points out, cognitive methods need to be incorporated into ISD task analysis, and this paper provides a standard procedure for conducting such an analysis.

The guidelines given in this document provide a method for accomplishing a cognitive task analysis and preparing the deliverables (i.e., research proposal, optional interim report, and final report). Redding outlines critical actions which are described, below. Additionally, he includes some sections regarding what should be reported in documentation (e.g., proposals and reports), data collection methods used for cognitive task analysis (i.e., protocol analysis, psychological scaling, performance modeling, and observation of job performance and interviewing), controlled experimental design, measures and experimental treatments, data analysis methods and validation of results. The 5 critical actions are: 1. Identify key job tasks and training issues. This includes determining the goals and foci of the task analysis, specific training problems, justifications for job task selections (e.g., tasks where frequent errors are made, high performance skills, tasks requiring large amounts of knowledge), what is already known about the nature of expertise in the job task (e.g., through manuals, operating procedures, expert interviews), and describing the population to be used in the analysis (i.e., defining "expert" on the task, determining sample size, determining the range of ability or experience levels in sample). 2. Develop visual representations of knowledge structures. One should present the organization of experts' (and/or less experienced persons') knowledge structures about the task in a visual model using a network of linked concepts, a tree diagram, or a schema depicting interrelationships between knowledge. 3. Describe cognitive processes underlying performance. This includes the skills, conceptual and procedural knowledge, and learning and performance strategies that result in effective task performance. For example, effective mental models for the task, types of skills required for competent performance, effective cognitive-optimizing strategies, visual representations, conceptual and procedural knowledge needed for the task as a whole and as they interrelate, important task components or subgoals, and strategies, heuristics, algorithms, or aids used for learning or during job performance (e.g., production rules, IF...THEN rules, GOMS, decision trees). 4. Identify differences between experts & novices. This includes differences in knowledge structures (optional), skills, conceptual and procedural knowledge, and learning and performance strategies. This also aids in determining effective job performance skills, knowledge and knowledge structures. 5. Determine implications of results for design phase. The results of a cognitive task analysis (i.e., curricular guts) should allow one to recommend a training structure (e.g., improve understanding of interrelationships, improve organization to support problem-solving, diagnose and remedy novice errors), a training sequence (i.e., according to skill, knowledge, and knowledge structure progressions), and the instructional setting, media, and strategies which facilitated learning.

Definition of CTA: "Cognitive task analysis determines the mental processes and skills required to perform a task at high proficiency levels and the changes that occur as the skills develop. Cognitive task analysis helps determine how a task is learned, how learning can be facilitated, and what cognitive processes underlie and support effective job performance. The information is then used in the design phase to determine the most effective manner of training employees to achieve high levels of proficiency in job performance." (p. 3)
Depth of description: Due to its guideline/outline format, this paper helps one consider the task from start to finish by mentioning every aspect of the analysis. The critical actions (given above) are described quite well. Questions to ask (e.g., for conducting the initial research into the domain) and methods to use (e.g., to learn about the expertise in the job task) are listed, but the suggested reading would be required for more specific details of how to go about these methods, if one is inexperienced in CTA. These readings are given on pages 5 and 6.
Applications of interest to the authors. These guidelines are quite general, but specify their use for job training and research proposals and deliverables. This paper is a great starting point for practitioners interested in organizing and conducting cognitive task analysis.

Apparent theoretical perspective of the author: cognitive psychology perspective, elaborating on the existing "Analyze" of the ISD model. His guidelines also include basic research methods to use in conducting a cognitive task analysis.

D.V. Benysh, R.J. Koubek & V. Calvez. (1993) A comparative review of knowledge structure measurement techniques for interface design. International Journal of Human-Computer Interaction, 5(3), 211-237.

Cites literature through 1990-1991.

The authors state that the purpose of their paper is to provide researchers in human computer interaction with a comparative review of available techniques and to summarize their potential application for aiding designers at various stages of interface design. They classify techniques into three classes: verbal reports, clustering techniques and scaling methods. (In fact, the latter two classes are not that cleanly separated in the actual review.) For each class, they discuss the manner of data gathering and concept elicitation, the method used to derive the knowledge structure and the analysis procedures used. The category of verbal reports includes interviewing, questionnaires, interruption analysis and protocol analysis. These are discussed very briefly but the authors do make an important point about the significant role of the analyst in determining how the knowledge structures will be represented. They point out that cognitive modeling schemes such as GOMS, Task Action Grammar, or production rules are sometimes used in the representation. In discussing clustering methods, the authors give much more attention to the problem of developing the list of concepts to be studied than do most reviewers, and they review several methods for this purpose. The methods of cluster elicitation discussed are card sorting, ordered recall, closed curve analysis (drawing curves around things that "go together"), and

spatial reconstruction. They point out that closed curve analysis has revealed overlapping clusters, whereas most methods of analysis assume discrete or hierarchical clusters. Scaling methods involve the same problem of creating concept lists. The methods of obtaining concept similarity that are discussed are similarity ratings, repertory grid, co-occurrence analysis (e.g. in card sorting), proximity in recall. Methods of analysis for these data include conversion to general weighted networks (e.g. by Pathfinder), multidimensional scaling, and hierarchical clustering. They briefly discuss the problem of comparing the resulting representations across individuals. Throughout the paper a few brief remarks are made about how this information could be useful in interface design (e.g. in grouping menu items). They comment that, with the exception of the verbal report methods, these methods primarily get at declarative knowledge.
Explicit definition of cognitive task analysis: there is none given; in fact, the term they use is "knowledge structure measurement techniques". They are motivated by the fact that knowledge structures have been shown to be predictors of operator performance.

Depth of description: For the most part, the descriptions are quite brief and readers are referred to other sources for details. The overarching comments in this paper tend to be more valuable than the descriptions of data collection or analysis techniques.

Applications of interest to the authors: as noted above, primarily Human–Computer Interaction design. However, they also show interest in the prediction of performance from the measurement of knowledge structures. Koubek has also done work in which he attempted to directly train knowledge structures. After this paper, he went on to propose a knowledge representation structure that combines both conceptual and procedural knowledge.

Apparent perspective of the authors: that of very applied psychologists who are involved in personnel selection, interface design and training.

B. Means (1993) Cognitive task analysis as a basis for instructional design. In: M. Rabinowitz (Ed) Cognitive science foundations of instruction (p. 97-118).

Key references are concentrated in 1988.

This paper effectively makes the case for the need to focus on cognitive aspects of many tasks to supplement the information provided by more traditional behavioral task analyses, using the example of air traffic control. It also points out the problems often posed by experts' lack of explicit conscious access to much of their task knowledge. It advocates a team approach to cognitive task analysis in which the instructional and/or cognitive experts work with collaborating subject matter experts who both design example tasks or scenarios to bring out necessary expertise and serve as subjects in solving problems, providing protocols, etc. Two case examples are described, one involving avionics trouble-shooting and the other air traffic control. These differ in greatly in task pacing and thus in the techniques that are feasible for studying task performance. The air traffic control case also provides interesting examples of the role of metacognitive knowledge or skills. The analytic approach draws heavily upon the tradition of expert–novice studies in cognitive science both as a theoretical foundation and as a source of experimental (or knowledge elicitation) techniques. Quite a number of such techniques were used in the cases described but they are not explicitly called out or separately described.

Definition of cognitive task analysis: No explicit definition is given but cognitive task analysis is described as appropriate for tasks in which the critical steps are cognitive operations such as hypothesis formation, judgements, or problem solving rather than observable behaviors. (p. 101).

Depth of description: The two cases are described in considerable detail, such that a cognitive psychologist or cognitive scientist might well be able to generalize the approach to other problems. Specific experimental or knowledge elicitation techniques and the analyses of the data they provide are not described in any detail.

Applications of interest to authors: Cognitive task analysis for the purpose of developing military, industrial, and similar training. The two cases concern electronics troubleshooting and civilian air traffic control; the more general class is tasks that involve high levels of expertise.

Apparent theoretical perspective of the author: mainstream American cognitive science, as evidenced by the emphasis on expert- novice studies.

Note: at least in part, this is describing the same cognitive task analysis approach as Hall, Gott & Pokorny (1995).

K. E. Williams & T.G. Kotnur (1993) Knowledge acquisition: A review of manual, machine-aided and machine-learning methods. (Technical report on Office of Naval Research contract N00014-91-J- 5-1500) Blacksburg, VA: Virginia Polytechnic Institute and State University, Management Systems Laboratories. 62 pages.

Literature cited extends to 1990-1991.

"This review and classification of knowledge acquisition methods was conducted as part of a design process in the development of an automated aid for creating detailed cognitive models of procedural tasks consistent with a production system architecture of cognition. The target application for the automated aid was the authoring of ideal student models for intelligent tutoring systems. The review was conducted to identify the various kinds of methods which have been developed for knowledge acquisition since ideal student model generation is a knowledge acquisition process. As a result of this review, approximately 40 different methods were identified and classified. The methods are classified along a continuum of the degree to which automation is employed in implementing the knowledge acquisition process. Three classes of methods were defined: manual methods, machine-aided methods and machine learning methods." (portion of authors' abstract).

A useful graph showing the classification and subclassifications of the methods reviewed, as well as naming those specific methods, appears on p. 6 of the report. The review is more comprehensive than most because of its inclusion of machine-aided and machine learning methods but does not claim to be exhaustive. In particular, the review tends to present one example of a machine-aided version of a method rather than discussing all versions that may be available. Some effort is made to provide worked out examples of the various fundamentally different methods for instructional purposes. More detail is provided for the machine-aided methods. In the description of methods for getting at conceptual organization, the report relies heavily on Olson & Reuter (1987). It credits Carbonell (1990) and, to a lesser extent Michalski (1991), for the taxonomy of machine learning methods. Among the cognitive task analysis methods, it includes Miyake's (1986) "constructive interaction" method for getting information about how a device or system works, which does not seem to be mentioned in most reviews. The paper ends with a conclusion and discussion focused on the system design purpose for which the review was done, but this section also contains a number of remarks about which methods are suited to obtaining various kinds of information.

Explicit definition of cognitive task analysis: There is none. Like Cooke (1994), the authors place cognitive task analysis far down in their taxonomy of methods, identifying it with a small set of methods, notably GOMS analysis and Mikyake's constructive interaction method.

Depth of description: Relatively detailed compared to other reviews, most detailed for machine-aided methods where examples of the dialogues between machine and expert are given.

Applications of interest to the authors: extraction of procedural knowledge for the purpose of building ideal student models for intelligent tutoring systems. However, the review is much broader than that; only the concluding section is really affected by that purpose.

Apparent theoretical perspective of the authors: Williams is a cognitive experimental psychologist by training who has worked primarily on military training applications such as simulators. He seems to have come at this review from the perspective of Carnegie Mellon University-style production system modeling of cognition.

N.J. Cooke (1994). Varieties of knowledge elicitation techniques. International Journal of Human-Computer Studies, 41, 801-849.

This review covers the literature up until 1994.

This article provides an extensive review of some 70 knowledge elicitation techniques. The list of references contains 231 books and articles on the subject. Relatively brief reference is made to cognitive task analysis approaches or methodologies (organized sets of methods or techniques). This notwithstanding, many of the techniques discussed in this article appear in the cognitive task analysis methods proposed in the literature. Moreover, quite a few of the techniques discussed are useful for practitioners conducting cognitive task analyses.

The author views knowledge acquisition as a modeling, not a mining activity. The major problem in this activity involves the abstracting of adequate models of expert knowledge from the data gathered during elicitation. The validity of the data gathered is limited because much knowledge is tacit and not subject to conscious introspection and subsequent verbalization. The validity of verbal reports has therefore been subject to controversy. Other problems in knowledge acquisition concern the unavailability of experts and the communication blocks that arise when experts try to convey their knowledge to non-experts (in an attempt to satisfy the elicitor, the expert communicates whatever knowledge is accessible).

No explicit definition of cognitive task analysis is provided. On p.813 cognitive task analysis is briefly mentioned: "(...) techniques that focus more intensely on cognitive processes (...)". PARI is the only example of cognitive task analysis mentioned.

The article organizes knowledge elicitation techniques according to the process of elicitation, rather than to elicitation stage or type of knowledge elicited. Three families of techniques are distinguished: (i) observations and interviews, (ii) process tracing, (iii) conceptual techniques.

(i) Observations and interviews The first family involves rather direct methods of watching experts and talking with them. These methods seem well-suited to the initial phases of knowledge elicitation, although the results are often unwieldy and difficult to interpret.
(ii) Process tracing The second family involves techniques that are generally performed concurrently with expert task performance. The data that are recorded are of a pre-specified type (verbal reports, eye movements) and are used to make inferences about the cognitive processes or knowledge underlying task performance. The validity of the data is highly dependent upon a number of factors that should be carefully considered before using the techniques, e.g. whether the task itself involves verbal communication or has high cognitive demands. The selection of cases presented to the expert to solve is highly critical: the cases should not be too routine (since the expert uses mainly tacit, unverbalizable, knowledge), nor too unfamiliar (since the expert cannot use his or her knowledge and the result will not be representative). Process tracing techniques result in large and often unmanageable data sets that are often difficult to interpret. On the positive side, the techniques are generally carried out easily.

(iii) Conceptual techniques The third family involves indirect techniques that produce representations of domain concepts and their structure or interrelations. These techniques are limited in the types of knowledge they yield, the focus being on concepts and their relations rather than on heuristics, rules and strategies. For this reason, a combination with process tracing techniques is recommended. In addition, the analyst requires some background knowledge in order to employ these techniques. Experts may often regard these techniques with suspicion, due to their artificiality. On the positive side, these techniques rely less on verbal reports, they are more suitable for dealing with data from multiple experts, and they center on data reduction.

The article concludes that more empirical comparisons between techniques are required. In the meantime, it advises to employ multiple techniques (with the caution that sequencing of techniques may influence the outcome of techniques), or to use iterative prototyping and evaluation for the purpose of refining the knowledge base.

Depth of description: Very concise, one-sentence to one-paragraph summaries with pros and cons of each technique. The extensive reference list should guide the reader to more elaborate descriptions.

Applications of interest to author: Mostly expert systems, although the techniques discussed can be applied very broadly.

Apparent theoretical perspective of author: the author has been mainly involved with the development of conceptual techniques (particularly, the Pathfinder scaling technique), coming from an experimental-psychological background.

B. Crandall, G. Klein, L.G. Militello & S.P. Wolf, Tools for Applied Cognitive Task Analysis. Contract Summary report on N66001-94-C- 7008. Fairborn, OH: Klein Associates, July, 1994. And associated draft CD-ROM training in ACTA, Applied Cognitive Task Analysis, 1997.

Literature reviewed extends to 1993, with one 1994 reference.

This is a summary report on a Phase I Small Business Initiative Research (SBIR) contract intended to draw upon the experience of Klein Associates in conducting cognitive task analysis in order to produce cognitive task analysis methods that could be used by training developers as well as other researchers. The work of the project included a review of the cognitive task analysis literature as well as a compilation of Klein Associates' in-house experience in conducting cognitive task analyses. Other professionals in the area were also interviewed. (The report contains an annotated bibliography of summaries similar to this, as well an appendix of reports of the interviews of other cognitive task analysis experts.) On this basis, a generic applied cognitive task analysis (ACTA) was developed. The methods reviewed included: unstructured interviews, FAST (functional analysis system technique), concept maps, conceptual graphs, cognitive interviews, critical decision method, constructed scenarios, repertory grid, modeling methods, and experimental methods. The authors report that concept maps are quite easy to do but can become excessively complex. Klein Associates uses concept maps in initial interviews, developing one for the task, one for the equipment and one for the teamwork. They report that more formalized conceptual graph analysis requires more time and specialized training to conduct. Although Klein Associates favors the use of the critical decision method, they find that conducting the necessary interviews requires at least a six month apprenticeship and that some experts also have difficulty participating in this method. They view cognitive modeling methods such as COGNET and GOMS as being extremely time-consuming and mostly applicable to tasks that involve interacting with a keyboard. They view the use of experimental psychology tasks (like scaling of similarity) as tedious and inappropriate for applied projects. Of the possible ways of representing extracted knowledge, the authors prefer the "decision requirements table" that they have developed and the "critical cue inventory". They have not found concept map representations or other methods that focus on extracting declarative knowledge to be very useful. Instead, the cognitive literature on the nature of expertise has proved more useful. Within the critical decision method, they like to seek this information: 1) expert–novice differences in dealing with a situation, as seen by the expert; 2) decision points; 3) goals vs. non-goals; 4) critical cues, patterns, and relationships; 5) response to hypotheticals including Marvin Cohen's crystal ball method; and 6) triggers. With respect to goals, they look at how goals get defined, adopted and modified, or not adopted as an important part of the process. Critical cues refer to the perceptual aspects of tasks. Triggers refer to violations of expectations, of either type. The report discusses difficulties some people have had in developing the necessary interview skills for the methods that Klein Associates and others typically use. In this project, they aimed to develop simplified methods that Educational Specialists can use to interview, observe, and help Subject-Matter Experts articulate the basis of their skills. They wanted to develop of method that would get at aspects of expertise, mental models and judgment and decision making. For this purpose, they developed corresponding knowledge elicitation methods: knowledge audit interviews, schematics of equipment, tasks and team/organization, and scenarios that probe key decisions and associated cues. They also developed corresponding knowledge analysis and representation methods: 1) inventory of expertise and compilation of specific examples; 2) aggregate schematics and task function clusters; and 3) the decision requirements table. They estimate that interviewing and analyzing 4-5 SMEs would require about a week's work by educational specialists and assert that some have reacted to this approach as potentially reducing the work typically involved in a course development effort. The Knowledge Audit, for example, is a structured interview with suggested probe questions tied to aspects of expertise and is to include the collection of examples and incidents -- "sea stories". These will later be used for instructional materials. The schematics are intended to be relatively simple. For example, the team schematic involves identifying the significant team members that the SME interacts with, the type of information exchanged with them, and the criticality of that information. These schematics are potentially useful as advance organizers for sections of instruction. To look at judgment and decision making, SME's are presented with challenging scenarios and asked about the embedded judgments and decision points. This is an easy method to learn and scenarios are frequently available already in military training contexts. For analysis, the decisions involved in the task are identified. SMEs are probed about the information, cues and other factors important in making the decision. They are asked which decisions are most difficult. This information can help to set training objectives, and the information about what experts do can serve as models for trainees.

Explicit definition of cognitive task analysis: Oddly, there does not seem to be one. In the end, they seem to view it as methods for identifying cognitive task requirements.

Depth of description: The report is not very well organized and it is not always easy to figure out how the recommended methods, let alone others that are briefly discussed, would be executed. However, a computer-based training for the ACTA process has now been developed. It appears to be aimed at persons revising existing courses to improve their cognitive content and it is quite good on how to use the products of the task analysis in developing improved instruction.

Applications of interest to the authors: the target application is training development and there is a tendency to emphasize decision making tasks. The authors say that cognitive task analysis is appropriate only for tasks that involve true expertise taking many years to develop.

Apparent perspective of the authors: Klein is the primary proponent of the naturalistic decision-making approach.

P.J.M.D. Essens, J.J. Fallesen, C.A. McCann, J. Cannon-Bowers, & G. Dorfel. (1994) COADE: A Framework for Cognitive Analysis, Design and Evaluation. Final Report of RSG-19 (Decision Aids in Command and Control), Panel 8 (Defense Applications of Human and Bio- Medical Sciences), NATO Defense Research Group. (206 pages)

Dates of references suggest coverage up to about 1993, with a heavy representation of 1990 and 1991.

This report is concerned with the broader topics of system design and evaluation within the application area of decision support for military command and control. Only a portion of the report is devoted to a review of cognitive task analysis techniques. Cognitive task analysis is covered in sections 5.1.3 (p. 43-45) and 6.3 (p. 113-129). The report assumes that cognitive task analysis will be done in the context of prior, more traditional behavioral task analyses. Relatively brief reference is made to cognitive task analysis approaches or methodologies (organized sets of methods and techniques) that have been proposed by other workers. More attention is giving to reviewing a large number (about 35) of specific knowledge elicitation techniques that are grouped according to whether they yield information about declarative knowledge (e.g. semantic nets), procedural knowledge, or strategic knowledge (defined as knowing when and how to apply the other kinds of knowledge, as well as metacognitive or monitoring capabilities.) Useful concise tables briefly describe these techniques, the type of knowledge representation they assume, their strength and weaknesses, whether they are direct, explicit approaches or indirect approaches to knowledge extraction, and provide references to publications discussing the techniques.

Explicit definition of cognitive task analysis (p. 113): Cognitive task analysis seeks to describe, in cognitive terms, how goals and tasks are accomplished. The value of cognitive task analysis is that it focuses on identification of the cognitive basis of behavior and its limitations or, positively stated, the opportunities for support. Cognitive task analysis is concerned with: a) the knowledge required for the task and the relationships among, and organization of important concepts; b) the mental operations for retrieval, storage, transformation, integration, and modeling of information; c) the meta-cognitive processes that control cognitive effort and attention; d) cognitive skill development and progression of knowledge structures from novice to expert.
Depth of description: Very concise. More informative about elicitation techniques than about entire approaches that are alternatives to the one developed in the report. A reasonably useful guide to further reading, with some sense of evaluative opinions.

Applications of interest to authors: As noted above, the design of decision aids for military command and control. However, the review of cognitive task analysis techniques is quite general, not much affected by that particular application interest.

Apparent theoretical perspective of authors: Seems to be transitional between behavioral perspectives and more modern cognitive perspectives. There are repeated references to "cognitive behavior" and goal structures are assigned to an external "behavioral model" of the task rather than to internal cognitive processes.

B.E. John & D.E. Kieras (1994). The GOMS family of analysis techniques: Tools for design and evaluation (Report CMU-CS-94-181). Pittsburgh, PA: Carnegie Mellon University, School of Computer Science.

The references in this technical report are concentrated around the late eighties and the early nineties, up until 1994.

This paper synthesizes the previous work on GOMS to provide an integrated view of GOMS models and how they can be used in design. The major variants of GOMS that have matured sufficiently to be used in real-world design and evaluation situations are described and related to the original GOMS proposal and to each other. A single example (text editing) is used to illustrate all of the techniques. Guidance is provided to practitioners who wish to use GOMS for their design and evaluation problems, and examples of actual applications of GOMS techniques are presented.

Insofar as this paper constitutes a review, it is a review solely of GOMS models. However, since the GOMS family is one of the most influential types of cognitive task analysis in the Human–Computer Interaction field, it is worthwhile to review this paper here. GOMS models are best viewed as engineering models of human-computer interaction, in contrast with research-oriented cognitive models. First, these models must be able to make predictions early in the design process when actual data cannot yet be obtained from users. Second, the models need to be used by computer system designers not trained in psychology or human factors (the authors claim that most GOMS techniques can be taught in single class sessions up to a full-day tutorial). This brings with it the need for explicit procedures for use and 'canned' psychological knowledge in the form of tables of parameter values. Third, engineering models must address a useful range of design issues. GOMS models cover the procedural aspects of a user interface well, together with lower-level perceptual-motor issues. Fourth, engineering models for Human–Computer Interaction must be approximate in nature: with 20% of the effort, 80% accuracy should be obtained. This is what GOMS models do.

The authors provide very useful background information on the concepts used by GOMS (e.g., the difference between goals and operators) and the conceptual framework underlying GOMS (being representative of stage models of human information processing). It is made clear that GOMS is a form of task analysis that describes the procedural, "how-to-do-it" knowledge involved in a task. GOMS does not deal with declarative knowledge (e.g., device knowledge) or analogical reasoning. GOMS is a form of task analysis that only deals with routine operating procedures, not with problem solving and exploration. However, since most tasks have some elements of routine cognitive skill, GOMS techniques may be used widely. An important aspect of using GOMS, which sets it apart from other task analysis techniques, is that the analyst must start with a list of top-level tasks or user goals. GOMS does not provide this list, other task analysis techniques (interviews, observations, intuition) should provide it (the authors do not consider the opinion that a list with top-level tasks is more important and more difficult to get than carrying out a GOMS analysis once you have defined the goals).

The paper attempts to classify the various GOMS techniques in terms of task type (user control versus system control; sequential versus parallel) and the type of design information required (e.g., does the system provide a method for every user goal; are the same methods used throughout for the same goals; what sequence of overt physical operators will a user perform; what will be the learning time and execution time). Using this classification scheme, analysts can choose a particular GOMS technique.

Definition of cognitive task analysis: No explicit definition is provided, but the general GOMS concept comes close to such a definition (p.4): "It is useful to analyze knowledge of how to do a task in terms of the components of goals, operators, methods, and selection rules".

Depth of description: Different versions of GOMS analysis are discussed in detail, illustrated with examples and the relative advantages and disadvantages mentioned. However, the level of detail is not sufficient for novice analysts who want to learn how to use GOMS.
Applications of interest to the authors: mostly Human-Computer Interaction type applications. Eleven cases in which GOMS techniques were applied are discussed in some detail. Perhaps surprisingly, these cases are not restricted to the typical word processing task in an office environment. GOMS techniques have been applied to CAD systems, on-line databases of telephone numbers, bank deposit systems, a command and control system for space operations, interfaces for complex televisions, an intelligent associate for nuclear power plant operators, and an industrial scheduling system. In almost all cases, future or proposed interfaces are evaluated before they are actually implemented. GOMS techniques are useful in those cases where too few domain experts are available to perform user tests. GOMS techniques may also supplement field tests by explaining the results of these tests.

Apparent theoretical perspective of the authors: Carnegie Mellon University-style cognitive modeling.

E.J.H.M. Merkelbach & J.M.C. Schraagen (1994). A framework for the analysis of cognitive tasks (Report TNO-TM 1994 B-13). Soesterberg, The Netherlands: TNO Human Factors Research Institute.

This review covers the literature up until 1993.

The report is based on a literature search which yielded 20 usable techniques or methodologies for cognitive task analysis. Based on the literature search, a framework is presented which integrates three views on cognitive task analysis: task modeling, knowledge modeling and cognitive modeling. The task modeling view concentrates on the decomposition of tasks into goals and subgoals. Hierarchical Task Analysis is discussed in some detail as an example of this view. The knowledge modeling view concentrates on the knowledge and strategies that are required in order to accomplish the task's goals. The KADS methodology for knowledge-based system development is discussed as an example of this view. The cognitive modeling view concentrates on the knowledge and strategies actually used in order to accomplish the task's goals. The GOMS method is discussed as an example of this view. Explicit definition of cognitive task analysis (p. 24): the authors make the strong claim that only when the three views mentioned above are used together, one can speak of 'cognitive task analysis'. Furthermore, it is stated that the task environment and the knowledge requirements should be analyzed first before the task performance itself is studied in practice.

Depth of description: Of the 20 techniques or methodologies which formed the input for the framework, only HTA, KADS, and GOMS are discussed in detail, with evaluative judgments. Other techniques are briefly mentioned, but not discussed in detail. All 20 analysis techniques are scored with respect to the emphasis they place upon the three modeling views.

Applications of interest to authors: The report proposes a speculative connection between application areas and the three modeling perspectives. Task modeling is viewed as important for describing the functional structure of a task domain for function allocation purposes. Knowledge modeling is viewed as important for developing knowledge-based systems. Cognitive modeling is viewed as important for generating interface specifications, for assessing and improving workload, for designing training materials, and for diagnosing performance and predicting performance time.

Apparent theoretical perspective of authors: Eclectic, with inspiration from Carnegie Mellon University-like cognitive modeling, European structured approaches to knowledge-based system development ('generic task method'), and practical task analytic behavioral approaches.

A. Whitefield & B. Hill (1994) Comparative analysis of task analysis products. Interacting with Computers, 6(3), 289-309.

References extend to 1992-93 but do not seem to include recent developments of the task analysis approaches reviewed.

By "products" this paper means the outcome product of task analysis processes. Four task analysis processes are reviewed from the perspective of applications to human-computer interaction; Hierarchical Task Analysis; Task Knowledge Structures; GOMS; Cognitive Task Analysis/Interacting Cognitive Subsystems.

The authors seem to be concerned primarily with tasks of low cognitive complexity such as word processing or other document manipulation tasks. To be more precise, they are concerned with "interactive work systems(IWS)" for such tasks. They have developed a schema for use in discussing task analysis "products" that they use to characterize the above processes, asserting that a task analysis product should contain descriptions of the following components: IWS behaviors, IWS behavior sequences, task goals, a decomposition, work domain objects [e.g. documents] and their attributes, abstract IWS structures, physical IWS structures, performance, cross-references between these components. The authors seem to be somewhat dissatisfied with all of the task analysis processes they review because all are focused on the human user and do not provide independent descriptions of the work objects or the physical characteristics of the IWS. They comment that this can make it difficult to ascertain whether alternative workstation designs could perform the same work. They believe that the GOMS approach can handle only serial operations, a view that is not up to date with current versions of the GOMS approach. They characterize Barnard's approach as being totally concerned with specifying internal cognitive processes of the user, as having aspirations to "psychological reality" in those descriptions and as giving a description only at that base level, without retaining any hierarchical description. This approach and GOMS are characterized as tending to a fixed vocabulary of low-level operations while the other approaches are more free-form and therefore perhaps more dependent upon the specialized expertise of the analyst.

This paper does not provide a definition of cognitive task analysis and does not appear to distinguish cognitive task analysis from task analysis in general.

Depth of description: This paper makes comments about the various methods but really does not describe them at a useful level of detail; the emphasis is on the author's own descriptive schema, which does not seem to be very well-adapted to the actual characteristics of the task analysis approaches described. It is useful primarily for a few comments generated from the authors' perspective, most of which I have noted above.

Applications of interest to the authors: Apparently Human–Computer Interaction design for systems like document processing systems.

Apparent theoretical perspective of authors: The authors appear to be writing from the perspective of computer systems engineers or software designers.

Dehoney, J. (1995). Cognitive task analysis: Implications for the theory and practice of instructional design. Proceedings of the 1995 Annual National Convention of the Association for Educational Communications and Technology (AECT) Anaheim, CA. (ERIC Document Reproduction Service No. ED 383 294).

Dates covered: This review spans the period from 1985 to 1992.

Abstract: Dehoney's CTA review is broken up into 3 sections: (1) Summary of the underlying theory of CTA, with a focus on problem-solving and expertise, (2) Review of CTA models and techniques (including weaknesses), and (3) Description of the implications of CTA techniques for instructional design. The state of current instructional design (ID) task analysis results in a linear description or hierarchical ordering of skills required to achieve the task, which are fine for top down, or bottom up, analysis. Cognitive psychologists have extended such analyses into methods for describing how people solve difficult problems, with the most important skills being "metacognitive strategies for selecting relevant information, prioritizing and revising goals, and working between multiple versions of the problem representation." The underlying theory of CTA in terms of problem-solving involves the problem representation of experts (or novice-expert comparisons). Learners internally represent objects, actions of objects, strategies to use with those objects, and any constraints of those objects, actions, and strategies. In experts, these representations are linked to the specific domain knowledge. The process of solving a problem is working through the problem space from the initial state (i.e., givens of the problem) to the goal state (i.e., problem solution). Performance by experts has been characterized with several consistent features (e.g., broader and better organized domain knowledge, better able to recognize patterns, focus on underlying principles instead of surface features), and it is the goal of CTA to extricate their representations and strategies. Several researchers describe various procedures for CTA focusing on different aspects of experts' problem solving-for instance, deriving an implicit rule base for problem solution (Ohlsson, 1990), or determining expert organization of domain knowledge into schemata, semantic webs, or mental representations (Means, 1993; Lesgold, Lajoie, Logan, & Eggan, 1990; Nelson, 1990). However, Gardner (1985) and Roth and Woods (1989) have proposed formal CTA models. Gardner (1985) states that the purpose of CTA is to identify performance components, knowledge structures, and metacognitive knowledge underlying a task. Roth and Woods (1989) define CTA as a two part process. The first part is to create a competence model (i.e., define competent performance on the task, or create a model of the problem-solving environment), which enables the analyst to identify problem areas. The second part is to derive a performance model of how the task is actually achieved in practice, whereby domain-specific knowledge is elicited through interviewing and other observational techniques. Dehoney describes these two models as compatible, with Gardner's viewed as part of a performance model for CTA and Roth and Woods' as a broad competency model. Dehoney grouped CTA strategies for conducting CTA into three general categories: (1) methods for using domain knowledge to structure the analysis (i.e., review existing materials on the task, interview practitioners, hold discussions with panels of experts), (2) development of focus problems (i.e., to gain an understanding of cognitive skills required for task, study/create/discuss representative or critical scenario problem-solving in the domain by experts), and (3) knowledge elicitation (i.e., at the performance level: observing and acquiring information about the task; at the knowledge structure level: interviews, discussions, protocol analysis, simulations; at the metacognitive skills level: protocol analysis, reconstruction, developing mental models). Results from these methods are then organized in a manner which is useful for task performance (e.g., tables with each knowledge type and examples listed). Although there are similarities in the ID and CTA procedures (e.g., hierarchical task descriptions), differences in terminology and emphasis make it difficult (but not insurmountable) for the instructional designer. Even though cognitive psychologists may not find any benefit from ID literature (e.g., the literature already shows some CTA-designed instruction which successfully remediates declarative and procedural knowledge: Sherlock), instructional designers would benefit from current CTA methods (e.g., by addressing metacognitive skills required in the task, by providing more specific dimensions to the current task analysis methods). Cognitive psychologists continue to identify, research, and instructionally manipulate complex mental models, and thus will continue to discover worthwhile instructional techniques for complex problem-solving domains. Instructional designers also need to capitalize on this importance of cognition.

Definition of CTA: Cognitive task analysis models and techniques are useful when the object of training is to move people to the level of expert performance on complex problem-solving tasks. Such techniques "focus on illuminating the 'covert heuristic' (Wilson and Cole, 1990) used by experts to solve problems, and result in a description of an expert's mental model of the problem." (p. 114)

Depth of description: The focus of Dehoney's paper is with cognitive task analysis of problem-solving. She provides rich descriptions and examples of elicitation techniques used in the literature (late 80s, early 90s). A brief summary of the roots of CTA is also provided.

Applications of interest to the authors: Dehoney points out that the major applications currently discussed in the literature are: air traffic controllers (Means, 1993), electronic specialists troubleshooting avionics equipment-testing workstations (Lajoie & Lesgold, 1992; Lesgold & Lajoie, 1991; Lesgold, Lajoie, Logan, & Eggan, 1990; Means, 1993), and nuclear power plant operators (Roth & Woods, 1992; Roth, Woods, & Pople, 1992). The focus of CTA is in terms of problem-solving and how experts go about solving problems, as compared to less experienced persons.

Apparent theoretical perspective of the author: Cognitive psychologist perspective with strong emphasis on problem-solving.

D. DuBois & V.L. Shalin (1995) Adapting cognitive methods to real- world objectives: An application to job knowledge testing. In: P.D. Nichols, S.F. Chipman & R.L. Brennan (Eds.) Cognitively Diagnostic Assessment (pp. 189-220). Hillsdale, NJ: Lawrence Erlbaum Associates.

Literature cited extends to 1993.

This chapter is not really a review of cognitive task analysis methods but the presentation of an approach to cognitive task analysis with the purpose of improving the quality of job knowledge tests by including questions that probe types of knowledge revealed by cognitive task analysis. It also presents a case example involving Marines' land navigation skill. The approach begins with a larger perspective than is usual, employing relatively standard personnel psychology methods for the analysis of jobs in order to identify the tasks that are worthy of detailed analysis. Current test development methods, they say, conceptualize knowledge as an accumulation of facts, concepts and skills and provide little information about how knowledge is organized and used in job performance. Existing test development methods are based on ratings of job importance, saliency, or frequency of use and do not serve well to differentiate novices from expert performers. In fact, they generate approximately the same results whether experts or novices are used as informants. The methods of knowledge elicitation discussed and used included protocol analysis, coaching of a collaborator by the expert, and analysis of naturally occurring team communication, as well as supplementary use of retrospective probe questioning and critical incident methods. This chapter gives much more attention to the resulting knowledge representation than most: the knowledge representation organizes most of the task analysis and test development activity. The chapter reviews the characteristics of knowledge that have been shown to differentiate expert and novice knowledge: ontology (cf. Chi, Feltovich & Glaser, 1981: differences in objects, relations and attributes), explanatory knowledge (understanding why procedures are constructed the way they are and what principles must be respected in modifying them), tacit knowledge (relevant conditions for task goals, knowing how to integrate bits of knowledge and information into performance), and recognition of goal attainment (which involves identifying both final states and - -sometimes -- whether proper process was used in getting there.) It is noted that representing novice knowledge may require the addition of "buggy" knowledge or misconceptions. The knowledge representation used was a plan(or method)-goal graph, similar to a GOMS analysis. The nodes of this graph were annotated with additional information: 1) concepts and principles explaining why the method works, 2) procedure selection knowledge, 3) pattern recognition knowledge of contexts required to select or execute task procedures, (4) procedure execution knowledge such as steps or subgoals, (5) goal attainment knowledge -- including priority, sequencing and standards. The nodes were also annotated with candidate test questions and descriptions of typical mistakes. In conducting the task analysis of land navigation skill, several different "experts" of varying skill were used, along with 2 novices and 2 "decayed experts" who had not actually practiced the skill recently. Videotaped think aloud protocols were supplemented with retrospective questioning (How did you know? Why did you select?) to fill in missing information. Analysis of team communication revealed the existence of vocabulary for many perceptual aspects of the task. The study was done in two different terrains and retrospective interviews were used to explore the effects of different terrains and conditions. The critical incident technique was used primarily to identify errors and buggy knowledge. The authors comment that they were aiming for a practical, cost effective method so that there were some methodological trade-off: relatively few protocols were collected in relation to the procedures involved (65 identified), the analysis were not taken to the level of detail required for computational modeling and no experimental analyses of expertise were done. (In other words, they did not use most of the techniques for knowledge acquisition described in most reviews.) For the purposes of test development, the method–goal graph information was converted to a matrix with domain specific methods as rows and the types of annotated knowledge described above (e.g. procedure selection) as columns. This matrix specified the types of test questions to be developed. In addition, expert ratings of diagnosticity, rather than importance or frequency of use, were used in selecting which questions to use. The authors also note that the method–goal graph representation is useful for practical purposes in demonstrating that one is testing job-relevant knowledge.

Explicit definition of cognitive task analysis: None is given. Implicitly, their definition seems to be the application of cognitive science methods to job or task analysis.
Depth of description: There is not much detail to the description of the methods used. There is considerable detail about the knowledge representation used to organize their activity and about how the different methods were combined and adapted in their case example.

Applications of interest to authors: as noted, the explicit purpose was to inform the design and development of improved job knowledge tests that would better correlate with measures of hands- on performance. However, the authors also recognize that their task analysis approach is equally applicable to training needs analysis and design. The knowledge representation is adapted from one (Geddes, 1989; Sewell & Geddes, 1990) developed for Human–Computer Interaction design.

Apparent perspective of the authors: A combination of personnel psychology (DuBois) and mainstream cognitive science (Shalin).

Hall, E. P., Gott, S. P. & Pokorny, R. A. (1995). A Procedural Guide to Cognitive Task Analysis: The PARI Methodology. AFMC, Brooks Air Force Base, Texas, USA. (Technical Report No. 1995-0108).

Dates covered: Even though this technical paper just recently came out, the four general CTA procedures reviewed therein span the 80s. The PARI methodology itself arose during this time and evaluations of the technique and resulting curricula/tutors took place in the mid- to late 80s.

Abstract: Developing effective instruction for complex problems-solving tasks requires analysis of the cognitive processes and structures that contribute to task performance. This report describes in great detail the exhaustive data collection procedures associated with a CTA technique known as the PARI methodology (for: precursor, action, result, and interpretation). The method was developed at Brooks AF Base (Basic Job Skills program, originally headed by Sherrie Gott, now led by Ellen Hall). The PARI method represents one component of an integrated technology for developing and delivering training of cognitively complex tasks. The specific data collection procedures they discuss in this paper can be considered an extension of existing task analysis techniques and are based on studies of over 200 AF technicians in aircraft maintenance specialties whose primary task is troubleshooting. The procedures derived from these studies impose a structure on the knowledge acquisition task which captures the cognitive as well as the behavioral components of troubleshooting skill. The structured interview approach yields data that allow qualitative comparisons of problem-solving performances within and across technical skill levels (novices, experts, shades of gray in between). Such analyses have informed instruction developed under the program by revealing the developmental course of skill acquisition and the components of expertise which are the training targets. That's a definite plus. More recent analyses have identified skill and knowledge overlaps across maintenance specialties and are informing training designed to facilitate knowledge transfer. A future goal of the program is to examine the generality of the PARI methodology and the extent to which it can be applied to problem-solving tasks in non-maintenance domains. The claim of the authors is that this PARI method represents a "general purpose" tool, but it's currently quite bound to eliciting and structuring troubleshooting knowledge & skills.

Definition of CTA: Cognitive task analysis is defined in contrast to behavioral task analysis, differing along an instruction dimension. That is, behavioral-rational task analysis specifies component steps of observable behaviors as targets of instruction, while CTA gets at the underlying psychological processes and knowledge structures that are required to produce the correct overt behaviors at the appropriate time (p. 12). The primary focus of behavioral task analysis (BTA) is procedural knowledge, while CTA additional elicits and structures declarative knowledge. [Note: I've personally asked various PARI persons to categorize "strategic knowledge" (i.e., whether it's more declarative or procedural in representation and application). But unfortunately, there's been no agreed-upon answer yet to my query.]

Depth of description: The focus of this paper was primarily on the PARI methodology. These sections were written in great depth. However, the "review" of the four alternative task analysis approaches were summarized in only moderate detail. The point of the summaries was to show how various parts of each system have been incorporated into the PARI approach. The four alternative methods include: (a) Instructional Systems Design, (b) GOMS, (c) Knowledge Engineering, and (d) Verbal Protocol Analysis.

Applications of interest to the authors. The primary focus of the PARI methodology has been to capture the cognitive aspects of certain military avionics jobs. Specifically, the goal has been to obtain rules underlying troubleshooting skills and develop the associated assessment items that reflect system, procedural, and strategic knowledge types.

Apparent theoretical perspective of the author: The theoretical basis of the PARI approach represents the integration of parts of the four alternative approaches summarized in the report (i.e., ISD, GOMS, protocol analysis, knowledge engineering). In other words, the authors write from a basic cognitive science approach along with cognitive psychology (i.e., individual differences approach with regard to novice–expert elicitations).

R.R. Hoffman, N.R. Shadbolt, A.M. Burton, & G. Klein (1995) Eliciting knowledge from experts: A methodological analysis. Organizational Behavior and Human Decision Processes, 62(2), 129- 158.

This paper has a very extensive reference list with heavy coverage of the late 1980's and some through 1992 and later. This paper is a very generalized review of approaches for capturing expert knowledge for purposes ranging from reduction of performance error through conventional training to the creation of artificial expert systems. The methods considered range from the use of texts, reports and courses (which they call indirect) to the analysis of experts performing naturalistic tasks, various types of interviews and various types of "contrived" techniques. It is relatively stronger on the less formal methods such as interviews than on the "contrived" techniques, which are mostly experimental methods from cognitive psychology. It discusses degrees and kinds of expertise and, briefly, ways of identifying experts to use in knowledge elicitation, as well as several different approaches for finding case examples to be used in studying experts' problem solving behavior. The value of structured (vs. totally unstructured) interviews is discussed and references on this subject are given, along with a detailed example of generic probe questions. The "contrived techniques" discussed include some unusual ones like decision analysis and the use of group decision-making situations as well as the more usual rating and sorting tasks, repertory grid, and explicit construction of conceptual graphs. The use of experimentally constrained problem solving conditions, in which time or information is abnormally constrained, is also mentioned. There is little detail on these techniques, although there is some mention of and references to computerized knowledge acquisition tools that implement such techniques. The latter portion of the paper discusses experience with knowledge elicitation approaches and some comparative evidence. It is admitted that contrived tasks seem to be more efficient providers of information than interviews. Some possible problems are discussed: apparently inaccessible expert knowledge, interactions between the method of elicitation and the knowledge or strategies that are evoked in the expert, and biases that are introduced by the structure of the interview or contrived task. Towards the end of the paper there is a suggestion of an overall approach: study of documentary sources or courses to familiarize the analyst with the concepts and vocabulary of the domain, followed by unstructured interviews, expert review of the resulting "first pass knowledge base", followed by structured interviews, think aloud problem solving and contrived tasks for refinement. Throughout, some useful comments on the social niceties of working with experts are made. At the end, the possibility of a taxonomy of tasks that could be associated with recommended knowledge elicitation techniques is raised.

Definition of cognitive task analysis: the term is not prominent in this paper and no definition is given.

Depth of description: Although the paper is quite wordy and discursive, most techniques are not described in useful detail, with the exception of generally applicable probe questions for a semi-structured interview.

Applications of interest to the authors: as noted above, these are wide-ranging but mention of the development of expert systems may be over-represented.

Apparent perspective of the authors: they show more interest in techniques that are typical of social or organizational psychologists as compared to experimental psychology techniques, although in the end they recommend a mixture of methods.

S.E. Gordon & R.T. Gill (1997). Cognitive task analysis. In C.E. Zsambok & G. Klein (Eds.), Naturalistic Decision Making (pp. 131-140). Mahwah, NJ: Lawrence Erlbaum Associates.

This paper covers the literature up until 1994, with a heavy emphasis on the late 80s and early 90s.

This short chapter's origins lie in a panel discussion that was held in 1994 during the second Naturalistic Decision Making Conference held in Dayton, Ohio. Unfortunately, the panel members are not mentioned in the chapter. They were: Hoffman, Kaempf, Gott, Gordon, Ryder, and McNeese.

The chapter contrasts cognitive task analysis (CTA) with traditional behavioral task analysis methods. Because many jobs are beginning to involve complex cognitive processing, CTA methods are better suited to modern-day jobs than behavioral task analysis methods. Tasks that are cognitively complex are well-suited for CTA (Gordon [1992] claims to have developed a software tool that helps an analyst estimate the cognitive complexity of a task). In practice, many tasks contain both cognitively complex and more behavioral subtasks at the same time, such that a variety of task analysis methods is most useful. It is also recommended to use a variety of CTA methods, because each method may get at different types of knowledge or is biased in different ways.

The chapter discusses five CTA methods in some detail: Concept Mapping and Expert Design Storyboarding; COGNET; Conceptual Graph Analysis; PARI; Critical Incidents, Tough Cases, and Constrained/Contrived Cases. Overall methodologies are not discussed. The discussion of these methods is fairly shallow and non-evaluative. The authors note that these methods differ along a number of dimensions, such as how, and by whom, scenarios or test cases are generated, the type of cases analyzed, and the types of representational formalisms used.

The chapter concludes with issues for the future. One is the issue of when to use what method. The authors propose that system designers evaluate the type of information required for a particular project first, and then select a CTA method that yields that type of information (the authors do not specify what they mean by 'type of information', so this advice is not really helpful). A second issue concerns the validity and reliability of various CTA methods. Validity concerns the question whether the domain expertise is adequately captured. Since the authors view CTA as a modeling enterprise, the model of expert performance can be used to generate predictions and these can be tested empirically. A second way to validate the model is to look at the success of the artifact it has supported (e.g., the training program designed with the aid of the model). Unfortunately, the artifact itself may be a confounding factor (e.g., the training program could have led to improved results without the CTA being conducted in advance). Reliability of CTA methods concerns the issue whether different analysts using the same method end up with the same results or not. The authors note that there is a scarcity of publications, seminars and courses on how to conduct a CTA. This may lead to low reliability of methods. Relatively simple methods that can be taught to training and system analysts should be identified. Finally, an issue for the future is the translation of the results of CTA into a final system, training program or interface. There is still a gap here that may have more ramifications than the choice of any particular CTA method.

Definition of cognitive task analysis: CTA is fairly narrowly defined as "a theory or model of how experts in a field perform their tasks" (p.132). CTA attempts to "identify how (primarily) experts perform a cognitive task" (p.133). More specifically, CTA methods "capture the richness of the knowledge base and cognitive processing embodied in expert performance of a task" (p.132).

Depth of description: concise, half-page descriptions of five methods. The methods are compared along some dimensions, but this is not very enlightening.

Applications of interest to authors: very broad, no specific application mentioned in any detail (CTA is said to be useful for developing system interfaces, intelligent support or decision aids, and training programs). The focus is more on methods than on applications. No attempt is made to link methods to applications.

Apparent theoretical perspective of the authors: general academic cognitive psychological perspective, with a focus on semantic networks as representational formalisms for domain knowledge.

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CHAPTER IV

Report on the NATO-ONR Workshop on Cognitive Task Analysis

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SUMMARY

NATO Research Study Group 27 on Cognitive Task Analysis has organized a workshop with experts in the field of cognitive task analysis. The Workshop was held in Washington, D.C., USA, October 30-November 1, 1997. The goal of the workshop was to assess the state of the art by bringing together a diverse, yet representative sample of experts in the field. The outcome of the workshop will be an edited book and a report to NATO.

This chapter briefly describes the organizational and financial structure of the workshop. A summary of all presentations is provided. The chapter ends with a list of important issues that arose from the discussions in the workshop.

1 INTRODUCTION

NATO Research Study Group 27 on Cognitive Task Analysis has organized a workshop with experts in the field of cognitive task analysis. The organization of such a workshop was recommended by RSG.27 in its first deliverable (Schraagen, Chipman, Shute, Annett, Strub, Sheppard, Ruisseau & Graff, 1997). The goal of the workshop was to assess the state of the art by bringing together a diverse, yet representative sample of experts in the field. The outcome of the workshop will be an edited book and a report to NATO.

2 ORGANIZATION OF THE WORKSHOP

In its meeting of March, 1997, RSG.27 selected potential speakers for the workshop. In June, a first mailing went out to potential speakers, inviting them to submit an abstract before August 1. In parallel, a notice was posted on the Cognitive Science Society Bulletin Board, in order to attract more potential speakers. In the beginning of August, 50 abstracts were received. Of these, 23 were selected for presentation. The 23 participants were asked to submit a draft chapter by October 1. Most of the participants fulfilled this requirement.

3 FINANCIAL STRUCTURE OF THE WORKSHOP

Although the workshop was organized as part of the activities of RSG.27, NATO itself did not provide substantial support for the workshop (as is common for these activities). Fortunately, the American representative in RSG.27, Dr. Chipman of the Office of Naval Research, was able to provide sufficient funding to allow the workshop to proceed. Travel costs (including accommodation and meals) for all speakers were reimbursed by ONR. Members of RSG.27 had to provide their own funding. As ONR, being a government agency, could not legally pay for individual speakers, the entire funding was carried over to Wright State University in the form of a grant. Dr. Shalin of Wright State University was in charge of the grant and all organizational matters, including the choice of venue for the workshop (the Hay-Adams Hotel). The executive organizing committee consisted of the Chairman of RSG.27, Dr. Schraagen, and the US representative in the RSG, Dr. Chipman. The executive committee determined the final list of speakers, assisted by Dr. Shalin.

4 LIST OF SPEAKERS

The following 23 speakers presented their paper during the workshop (country of citizenship in brackets):

Barnard (UK)
Boy (FR)
Seamster (USA)
Vicente (CAN)

Hoffman (USA)
Hamilton (UK)
Williams (USA)
DuBois (USA)
Schaafstal (NETH)
Gray (USA)
Flach (USA)
Hunt (USA)
Annett (UK)
Klein (USA)
Cooke (USA)
Zachary (USA)
Neerincx (NETH)
Paris (AUS)
Roth (USA)
Ormerod (UK)
Johnson (UK)
Woods (USA)
Kieras (USA)

In total, 13 speakers were from the USA, 5 from the UK, 2 from The Netherlands, 1 from France, 1 from Canada, and 1 from Australia.

In addition, two guest speakers gave presentations. The first was Rear Admiral Huchting, Program Executive Officer for Surface Combatants. The second was Dr. Lesgold of the Learning Research and Development Center, University of Pittsburgh.

5 SUMMARY OF PRESENTATIONS

All presentations were grouped into 6 sessions:
Session I: General frameworks (Barnard, Boy, Seamster & Vicente)
Session II: Tools and Techniques (Hoffman, Hamilton, Williams, DuBois)
Session III: Facets of expertise with implications for CTA (Schaafstal, Gray, Flach, Hunt)
Session IV: Team CTA (Annett, Klein, Cooke, Zachary)
Session V: CTA for design I (Neerincx, Paris, Roth, Ormerod, Johnson)
Session VI: CTA for design II (Woods, Kieras)

Papers were either 30 or 40 minutes in length, with a 5 minute question and answer session after each paper. At the end of each session, a 50 minute general discussion session was planned. A discussant was assigned to each session, with the role of initiating and leading discussions. The discussant for Session I was Schmalhofer (GER), for Session II: Shalin (USA), for Session III: Hoffman (USA), for Session IV: Schraagen (NETH), and for Session V: Vicente (CAN).

Session I: General frameworks

Barnard (MRC Applied Psychology Unit) presented the Interacting Cognitive Subsystems (ICS) framework, from which a form of CTA of broad scope and applicability has been derived. For any task, four components are described:
(1) The configuration of mental processes called into play
(2) Their procedural knowledge or processing capability
(3) The task relevant contents of memory records they can call upon
(4) A description of the way in which the overall mental mechanism is controlled and coordinated.
Applications have been mainly in the Human–Computer Interaction area. The focus is on predictive modeling of either existing or future systems.

Boy (EURISCO) distinguished between the normative, prescribed, task and the descriptive, 'effective', task. The cognitive function is a mapping between the prescribed task and the effective task. The cognitive function has a role, a context, and resources (user, task, artifact, environment). Transferring cognitive functions from humans to machines is called automation. Cognitive function analysis (CFA) has been applied mainly in the domain of advanced cockpit automation. CFA is supported by a cooperative use of active design documents (ADDs). ADDs are shareable prototypes of the real artifacts being designed that can be used by real users to assess their usability. Users work from the prescribed task directly with a simulated task. In this way, CTA is part of the system development, not an activity that is done up-front first and the results of which are then handed over to designers. CFA is a form of event-oriented task analysis, in contrast to goal-oriented task analysis. It is suitable for complex, open system environments where problem formulation is more important than problem solving.

Seamster (Cognitive & Human Factors), Redding, and Kaempf have developed a skill-based CTA framework for practitioners in aviation. The framework highlights the skill or performance side of cognition and proposes a set of complete methods to analyze cognitively complex tasks. The main skill types in the framework, together with relevant methods for analyzing these skill types, are:
(1) strategies: metacognitive skills such as coordination and monitoring. Relevant methods: Team Communication Method and Verbal Report Method.
(2) decision making skills: decision making rules of thumb. Relevant methods: Critical Decision Method and Error Analysis Method.
(3) representational skills: 'mental models' that allow mental simulation and the prediction of outcomes. Relevant methods: Diagramming Method and Rating/Sorting Methods.
(4) procedural skills: building blocks of skilled performance. Relevant methods: Simplified PARI Method and Verbal Report Method.
(5) automated skills: foundation of skilled performance. Relevant methods: Consistent Component Method and Job Performance Method.

Vicente (University of Toronto) presented as his main aim to support operators in turbulent environments. Most disturbances in these environments were unanticipated by designers. For open systems, with disturbances that need to be taken into account, a constraint-based approach to task analysis is more appropriate than an instruction-based approach. A constraint-based approach just lists constraints, does not tell you the right way to do your task. This leads to the distinction between task analysis and work analysis: in task analysis, the focus is on efficiency of task performance, while in work analysis, the focus is on flexibility and broad scope of applicability. An analysis of the work domain (system) should precede a task analysis, at least in open systems. Tools that may be used in a work domain analysis are the decision ladder and the use of abstraction hierarchies. This leads to a functional description of systems.

Session II: Tools and techniques

Hoffman (Adelphi University) presented research on the validity and reliability of one CTA method: the Critical Decision Method (CDM). The CDM is a case-specific multi-trial retrospection, structured by probe questions, designed to elicit information about the important cues, choice points, options, and action plans. It has been applied in areas as diverse as neonatal intensive care, fire fighting, and anti-air warfare. Validity and reliability of the CDM have generally been high. For instance, in clinical nursing skill, cues derived from the CDM data were both more specific and more pertinent than the cues culled from the literature. Retest reliability and inter-coder agreement have been in the 80-90% range. The CDM research was used to illustrate how a number of CTA methods can be combined.

Hamilton (Human Engineering Ltd) presented a software tool for CTA purposes, called ATLAS. ATLAS has a GOMS-like hierarchical goal structure. For specific goals, only the knowledge that is relevant for achieving that goal is specified. Based on a transaction analysis, the following elements result: goal, initiation, input, knowledge elements, transactions, translation, and outcomes. ATLAS can be used for performance time predictions, workload analysis, and reliability analysis. It has been applied to more than 15 projects.

Williams (Teknowledge Corporation) described a tool for lay people that yields total task execution time for a serial list of activities. Parallel activities are excluded. The focus of the tool is on production rules, not declarative memory. The tool is therefore primarily applicable to routine Human–Computer Interaction performance. It guides the user through a series of detailed questions at the key-stroke level. At the same time, questions concerning the number and content of chunks have to be answered.

DuBois (Psychological Systems and Research, Inc.) focused on test design for areas such as land navigation, crew coordination, and computer maintenance. Four phases in each CTA activity were distinguished:
(1) planning
(2) knowledge elicitation (mostly protocol analysis)
(3) knowledge representation
(4) products (error lists, task & method lists, detailed test specs)
The focus was on the domain content of the knowledge representation. Special emphasis was given to multiple, conflicting constraints and goals, choice in response, multiple levels of abstraction.

Session III: Facets of expertise with implications for CTA

Schaafstal (TNO Human Factors Research Institute) presented the results of a successful project on training for troubleshooting, carried out for the Royal Netherlands Navy. In the project, the results of a cognitive task analysis of experienced maintenance technicians were used to develop a new training course in troubleshooting. The main features of the new course, as compared with the regular courses, are: more emphasis on functional system understanding and more emphasis on a systematic approach to troubleshooting. Initially, the new course was a one-day add-on to an existing course. An empirical evaluation showed a large improvement in troubleshooting performance and system understanding, compared with the regular course. As these results could have been due to the lengthening of the course rather than the novel contents, a completely new course was developed, which in fact resulted in a 4-week instead of a 6-week course. Even this reduced course resulted in better performance and system understanding than the regular course. The Dutch Navy has accepted the new way of designing courses, based on the cognitive task analysis, as the basis for all courses in troubleshooting.

Gray (George Mason University) discussed some lessons learned from project Nemo, an attempt to model the expertise of the submarine Approach Officer. The most important lesson was that 'needless naturalism' should be avoided, that is, that high-fidelity simulations carry with it the risk of loss of experimental control, and hence lead to problems in interpreting the data. Instead, 'manageably complex systems' should be used for research purposes. These systems are based upon complex real-world environments and extract the essence of those environments in such a way as to enable key features of this complexity to be studied.

Flach (Wright State University) emphasized the importance of studying the work domain of experts, as the constraints put upon the experts by the environment they operate in, determine, to a large extent, their behavior. This general principle then leads to a variety of methods for cognitive task analysis: table top analysis (read books before talking to experts), knowledge elicitation (across a wide sample of perspectives and experts: include operators, designers, managers, scientists), naturalistic observation (watch real phenomena; try to perform the task yourself), laboratory studies (necessarily reductionistic; use stimuli that are meaningful with respect to the phenomenon you are interested in), synthetic task environments (high-fidelity simulation).

Hunt (University of Washington) presented results of an empirical study on public safety dispatching. Based on on-site observations of dispatchers (and not a formal CTA), Hunt and his co-workers were struck by the differences in skills of dispatchers. They formed the hypothesis that the basis for these skill differences lay in the ability to handle different kinds of events at the same time. The question arose whether this was an abstract task or a highly context-specific one. An abstract decision-making task was developed which supposedly captured the essence of the dispatching task. The real dispatching task was also simulated, and correlations in performance were determined for both tasks. It turned out that well-trained students, performing as well as dispatchers on a dispatching simulation task, showed a correlation of .70 between the abstract decision making task and the dispatching simulation. The correlation was .50 with real dispatchers. The importance of this work is that observations were submitted to an empirical test. What was not captured in the simulations was the ability to do really uncommon problem solving, e.g., talking someone out of committing suicide or combining two different views of the same incident.

Session IV: Team CTA

Annett (University of Warwick) described a study in which Hierarchical Task Analysis was applied to the team level, in this case a naval command team. The purpose of the study was to improve team training. As a first step, a scientifically-based objective measurement of team performance was carried out. This measurement was guided by a model of teamwork that distinguishes between team *product* and team *process*. As the recording of communication in a command team was too expensive, questionnaires were used instead for measuring team process variables. As team product variables were taken the times at which the teams carried out certain critical behaviors. The results showed no relationship between process and product. Instead, technical competence of individual team members accounted for most of the variance in team performance.

Klein (Klein Associates) identified a small set of cognitive processes for teams that guide the analysis of team CTA. The 5 key processes are: control of attention (information management), shared situation awareness, shared mental models, application of strategies and heuristics to make decisions, metacognition. A further distinction can be made between *planning teams* and *action teams*. The job of a planning team is to produce a plan (e.g., command and control teams). The job of an action team is to accomplish a task (e.g., carrying out a plan created by higher echelons). Results of two team CTA projects (one for the U.S. Marine Corps command posts and the other for an emergency response organization of a nuclear power plant) showed that team members are often confused about each others' roles. This results in information overload (in accordance with the maxim "when in doubt, send it out"), a sign of ineffective information management. The output of the team CTA needs to describe the 5 key processes. The techniques that are often used are observations, interviews and simulations.

Cooke (New Mexico State University) focused on team cognition as an emerging feature of the interplay of the cognition of individual team members. One important aspect of team cognition is shared knowledge. Three types of sharing can be distinguished: common, complementary and conflicting. An important question in this respect is what knowledge should be shared by teammates for effective task performance and how is this knowledge most effectively shared. Cooke then focussed on an agenda for Cognitive Team-Task Analysis. First, knowledge of individuals should be measured and compared to a referent (using similarity metrics) to assess accuracy. Second, each individual's knowledge should be compared to other team members' knowledge (also using similarity metrics). Third, the question: Are patterns of common, complementary or conflicting knowledge predictive of performance?, may be answered.

Zachary (CHI Systems, Inc.) introduced ORGNET, a novel language for describing cognitive processes at the team level. ORGNET is abstracted upwards from an individual-level cognitive modeling language called COGNET. COGNET should be supplemented by a set of principles for allocating cognitive functions among a team of people based on existing literature. One principle, for instance, is to minimize required communication among team members. The question is whether these principles are general enough to be applied to all kinds of teams (e.g., for some well-performing teams, it has been found that they are characterized by intense communication).

Session V: CTA for design

Neerincx (TNO Human Factors Research Institute) presented an integrated method for Cognitive Task Analysis, including cognitive task load analysis and a design method for user interfaces providing cognitive support in high task load situations. The method was applied to the user interface development of a future Ship Control Centre. The outcome of the CTA is used for software development for platform control systems. The CTA consists of a task break-down, event descriptions, task allocation to persons, scenario narratives and action sequence charts. In this way, it is possible to predict, for each scenario, and for each person, the percentage knowledge-based actions, the number of task-set switches, and the percentage of time occupied. Together, these results indicate moments of high peak load. These results will be used in the design phase to improve the proposed user interface, in order to reduce peak load.

Paris (CSIRO Mathematical and Information Sciences) described two case studies in which task models were used to bridge the gap between software engineering and Human-Computer Interaction. The first case study concerned the design of a decision-support software system for the Australian Navy. The problem from an analysis point of view was the absence of a common model among the users. The task model used (MAD) enabled communication among the software designers, the end-users, the interface designers and the technical writers. Structured interviews were used to provide the knowledge and representation. The new system has reduced training time from 6 months to a few weeks and performance has improved. The second case study, Isolde, involves the development of an authoring tool for on-line documentation. This tool is developed for technical writers who have to write on-line help after the software has been developed. Their task was studied first. It turned out that technical writers do not understand the software first, as is prescribed, but develop a mental model based on a partial understanding and start writing immediately. In this second case study, the task models are used to represent the functionality of the software from which documentation is automatically generated. Task models are also used to represent the cognitive task of technical writing.

Roth (Roth Cognitive Engineering) emphasized that CTA is more than the application of any single technique. CTA is a modeling effort, aimed at modeling both the domain and the expertise and error. First, the analyst needs to understand the way the world works and what makes the world hard (e.g., keeping track of events is difficult because the world is constantly changing). Current methods and tools for this effort are: functional means–ends analysis, structured interview methods, functional task modeling, ethnographic–observational investigations. Second, the analyst needs to understand the way people operate in their world (to model their expertise, knowledge, strategies, error). Current techniques are: semantic mapping, critical incident technique, critical decision method, ethnographic–observational investigations, and structured interview methods. After that, the envisioned world needs to be explored: how will envisioned technological change shape cognition and collaboration and how will practitioners adapt artifacts to meet their own goals? To answer this question, the analyst can again focus on the domain and the practitioner. Typical techniques for the former are scenario generation and for the latter storyboard walkthroughs, participatory design, wizard-of-Oz technique and high-fidelity simulations.

Ormerod (Lancaster University) discussed the role of CTA in the design process. He noted that the design community has been slow in adopting task analytic methods. This is partly due to the device dependence of most methods, and the failure to make explicit the stopping conditions for task analysis. Moreover, most methods are difficult to learn by non-specialists. The sub-goal template methodology (SGT) was proposed to remedy these problems. SGT starts with a Hierarchical Task Analysis, but adds sub-goal templates or standard task elements. Four classes of elements are distinguished: action, communication, monitoring and decision making elements. Each of these can be decomposed further. Next, sequencing elements are added to specify the way information should be arranged for presentation to the user. The SGT method has been applied primarily to interface design tasks. A computer-based tool has been developed to support its use. As yet, no evaluation studies of the SGT method and tool have been carried out.

Johnson (University of London) developed Task Knowledge Structures (TKS) for the purpose of user interface design. Starting with an existing task model, an abstraction process yields an envisioned task model, which in turn results in the design of new interfaces. The abstraction process is guided by principles of similarity, causality, conformance and transformation. For instance, the principle of similarity states that objects that are the same or similar will be conceptually grouped together, and actions on the same or similar objects will be carried out together. Empirical tests of these principles showed that interfaces developed according to these principles led to fewer errors and faster performance. In the case of unprincipled design, users will impose their own task structure but this will take longer to achieve. The use of these design principles puts task analysis in front of the design process, in a prescriptive instead of evaluative role.

Woods (The Ohio State University) sketched the envisioned world problem: there are many different views of the future world (problem of plurality) and these views are under-specified. The challenge for CTA is to deal with this problem in the design of new systems, since the introduction of new technology will transform the nature of practice. This, in turn, means that the nature of the cognitive activities will change, hence, CTA should anticipate this change. Effective CTA must face a challenge of prediction. As an example, the proposed Free flight system was discussed and the issue was to predict accidents that had not yet occurred. It turned out that scenario design (or the future incident method) was a valuable tool: different kinds of participants in the current system view full incident reports about a possible future world. It was important to incorporate different perspectives (controllers, pilots, dispatchers), in order to deal with the problems of plurality and under-specification.

Kieras (University of Michigan) emphasized the importance of task strategies over the architecture or the representation of task-specific inputs. Particularly in complex militarily relevant tasks, performance depends very heavily on the task strategy. The problem is: what strategies are people going to use in novel systems? Often, the strategy is not obvious, even to "experts". This makes system design with predictive models of human performance very difficult. Kieras described the "bracketing" heuristic to address this issue. Starting with a plausible cognitive architecture (e.g., EPIC), one can define a "fastest-possible" and a "slowest-reasonable" strategy. The former strategy matches human performance when humans place a high priority on speed and use parallel processing; the latter strategy is best characterized as deliberate and unhurried. Actual human performance should lie between these two extreme strategies, and this is confirmed by experimental data. Devising the two bracketing strategies requires a task analysis that specifies what people should do, not what they actually do. Existing CTA methods are satisfactory for this purpose.

Guest speakers

Huchting (Program Executive Office Surface Combatants/Aegis Program) described the recent changes the Navy is faced with. The environments are much more demanding these days. Failure in decision making is not allowed any more. The difference with civilian environments is that "late is wrong". The use of commercial products will increase: after the year 2000, the US Navy will buy Commercial Off the Shelf products only, no standard Navy computer equipment any more. The challenge cognitive psychologists face is to get in front of the manufacturer, and help them design systems so that they are usable. The sailors on board are faced with the challenge to use all the new technology. Embedded training is very important in this respect, more so than display design. In the Vincennes incident, it turned out that humans were not well trained. The Aegis system has an automatic data recording system and later analysis of the system showed that the system knew that the Iranian Airbus was rising (and hence had no hostile intentions). Apparently, the human operators did not get this information out of the system, or, if they did, they remembered things differently than they really did, because the operators said the Airbus was descending towards them.

Lesgold (University of Pittsburgh) gave an overall perspective on the papers presented during the workshop. He started by briefly summarizing the purposes of CTA: design of interfaces, design of work procedures and design of training. He noted that there are good techniques for designing interfaces, at least those for routine tasks. For non-routine tasks, schemes for opening up the analysis are evolving. The challenges for CTA lie in the areas of team work, task selection (do people really do what we think they do?), and high rates of turnover in personnel (how to fit in a new team member into an existing team?). CTA should focus more on cases where systems and knowledge do not fit very well, because once you really understand the task, it is a good candidate for automation and there is no need for CTA any more. Even though the scale of automation keeps increasing, there remains a need for operator flexibility and adaptation. Instead of focusing on the task as performed, or the work as observed, analysts should focus more on the negotiation of the problem character or the problem solution requirements. Finally, cognitive task analysts should take a look at object-oriented design and see what they can learn from the software engineers.

6 GENERAL ISSUES

Design of new systems

One issue that dominated the workshop was the issue of the use of CTA in the design of new systems. Many speakers addressed this issue and different tentative solutions were proposed. The difficulty lies in the fact that when we try to predict future operator behavior, we can only rely on existing operator behavior. As analysts, we therefore either have to make informed guesses about the strategies that operators are going to use, or we have to elicit current expert opinion with regard to future expert behavior. Using a wide range of scenarios of possible future worlds and incorporating a wide range of perspectives of current experts are prerequisites for successfully addressing the "envisioned world problem". Of course, the analyst may always be charged with taking too few scenarios into account; the list of possible future events can be extended infinitely. The only way an analyst can respond to this charge, is to use principles in the selection of scenarios, thereby giving some indication of the amount of coverage of future events.

Open versus closed domains
Another dominant theme was the different emphasis put by different speakers on either the cognitive architecture or the analysis of the work domain. The emphasis on cognitive modeling and cognitive architectures is appropriate for relatively closed and static domains, but is inappropriate, according to some speakers, in relatively open and dynamic domains. In open domains, the analysis should start with a functional description of the system constraints, before going into an analysis of (routine) tasks. It was pointed out by a number of speakers that multiple conflicting goals will remain in the future a major source of cognitive difficulty. Number of rules, reaction times, and system interaction will become less important as automation proceeds. Due to automation, more has to be done at the level of minutes instead of seconds. This would imply a shift in emphasis from 'task analysis' to 'work analysis', and a less dominant role for cognitive architectures that try to predict user behavior at the level of seconds or below.

Selection of appropriate techniques
The question when to use what technique was touched upon in various presentations and in the general discussion sessions. It was generally felt that a strict and fixed ordering of techniques for each project was unrealistic, as the order in which techniques are used may differ from project to project. Also, use of a single technique was generally felt to be too restrictive: multiple, coordinated approaches to CTA are required. This is not to say that no guidelines at all can be given for practitioners. A difficult matter remains according to what dimensions techniques should be classified. Some suggested a coupling of technique to type of knowledge to be elicited, some suggested that different techniques are needed for open-ended tasks than for closed tasks, and some suggested that different techniques are needed for understanding either the domain or the practitioners.

Role of CTA in system design
Most speakers agreed that CTA should not be a self-contained activity, the results of which are handed off to system designers. However, this being said, it is still very often the case that there is no integration between the activities of cognitive psychologists and system designers (e.g., software engineers). It is probably still unclear what designers need in the first place, and the CTA community needs to explicitly reflect on this. Some authors addressed this issue and developed methods that would be of more use to software designers. An approach that has not been taken so often, is to look at current software engineering methods and to try to incorporate cognitive task analysis notions into those methods. An example of successful integration of CTA techniques in the design process are the "active design documents". At any rate, it is critical for the success of CTA to be involved in the design process from the start to finish, and to establish clear links with methods that are used by other disciplines.

Value of CTA
It is important for the CTA community to be able to empirically demonstrate the added value of a CTA. In this way, the analyst goes beyond mere observations and submits his or her ideas to empirical tests. Clear performance factors need to be chosen and to be engineered toward. Examples of performance factors are reaction time, training time, faults detected, firepower, coverage of weapon systems, etc. Projects in which the effectiveness of CTA was measured included the redesign of training courses for troubleshooting, which resulted in a 100% performance improvement and a reduction in training time by 10% to 50%, and the design of a decision support system, which reduced training time from 6 months to a few weeks and improved performance.

Assessment of reliability and validity of CTA techniques
Due to the fact that customers are rarely willing to pay for an extra CTA, or the same CTA carried out by a different analyst, empirical tests of the reliability of CTA techniques are rare. A notable example concerns the Critical Decision Method that has been found to be sufficiently reliable and valid.

Team CTA
An important new theme that emerged from the workshop concerns the application of CTA techniques to team tasks. It is perhaps odd that CTA has always limited itself to individuals, since cognition in real-life settings is always distributed across humans and machines. It appeared that techniques that were originally designed for individual level tasks could be upscaled to team level tasks (HTA, scaling techniques, critical decision method, COGNET). This notwithstanding, the result from a large number of studies indicate that "a team of experts is not an expert team", in other words, that there are specific team skills that determine team effectiveness over and above individual proficiency. Important research questions concern the nature of shared mental models (what exactly needs to be shared?), and of

team situation awareness (is it more than the sum of individual SA's?). A number of broader issues was raised regarding teams: the role of personality (team roles), distributed decision making, social skills, leadership skills, morale, cohesion, and turnover in teams. These issues do not seem to have the highest priority on the research agenda of cognitive psychologists.

Some issues that were not discussed

- CTA for tasks that are difficult to verbalize (e.g., spatial tasks
- Individual differences (culture, nationality) and their implication for solutions
- Effects of environmental stressors on the conduct of CTA
- Selecting/defining expertise

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14. Abstract

Cognitive task analysis is defined as the extension of traditional task analysis techniques to yield information about the knowledge, thought processes and goal structures that underlie observable task performance. Cognitive task analyses are conducted for a wide variety of purposes, including the design of computer systems to support human work, the development of training, and the development of tests to certify competence. As part of its Programme of Work, NATO Research Study Group 27 on Cognitive Task Analysis has undertaken the task of reviewing existing cognitive task analysis techniques. The Group concludes that few integrated methods exist, that little attention is being paid to the conditions under which methods are appropriate, and that often it is unclear how the products of cognitive task analysis should be used.

RSG.27 has also organized a workshop with experts in the field of cognitive task analysis. The most important issues that were discussed during the workshop were: (1) the use of CTA in the design of new systems, (2) the question when to use what technique, and (3) the role of CTA in system design.

RSG.27 emphasizes: (1) that is important for the CTA community to be able to empirically demonstrate the added value of a CTA; (2) it is critical for the success of CTA to be involved in the design process from the start to finish, and to establish clear links with methods that are used by other disciplines, and (3) recommends that more research effort be directed to the issue of the reliability of CTA techniques.

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