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# Task analysis and human-computer interaction: approaches, techniques, and levels of analysis

Abe Crystal
*University of North Carolina at Chapel Hill*

Beth Ellington
*University of North Carolina at Chapel Hill*

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**Abe Crystal**
School of Information and Library Science
University of North Carolina at Chapel Hill
acrystal@email.unc.edu

**Beth Ellington**
School of Information and Library Science
University of North Carolina at Chapel Hill
elliv@email.unc.edu

## ABSTRACT

In this paper we critically review task analysis models and techniques. These approaches to task analysis are discussed in order to develop a richer picture of human activity, while analyzing their limitations, general weaknesses, and possibilities for improvement. We consider their ability to determine the appropriate set of atomic actions in a task, their effect on workers' motivational needs, their support of users' cognitive and sociocultural processes, and their effectiveness in supporting interface design. We note that the major approaches have focused on very different levels of analysis, and call for greater integration of these different levels in task analysis theory.

### Keywords

Task analysis, cognitive modeling, activity theory.

## INTRODUCTION

Practitioners and researchers routinely advocate building user-centered systems which enable people to reach their goals, take account of natural human limitations, and generally are intuitive, efficient and pleasurable to use (Preece, Rogers and Sharp, 2002). Central to the design of such systems is a clear understanding of what users actually want to do: What are their tasks? What is the nature of those tasks? Many techniques have been proposed to help answer these questions. Task analysis techniques are particularly important because they enable rigorous, structured characterizations of user activity. They provide a framework for the investigation of existing practices to facilitate the design of complex systems.

Task analysis is especially valuable in the context of human-computer interaction (HCI). User interfaces must be specified at an extremely low level (e.g. in terms of particular interaction styles and widgets), while still mapping effectively to users' high-level tasks. Computer interfaces are often highly inflexible (when compared to interacting with a physical environment or another person). This inflexibility magnifies the impact of interface design problems, making the close integration of task structure and interface support especially crucial.

This paper discusses how task analysis has evolved from studies of physical activity to encompass the cognitive and sociocultural challenges faced by today's knowledge workers. We analyze the strengths and weaknesses of the primary approaches, and discuss possibilities for future developments of task analysis techniques and technologies.

## HISTORICAL ROOTS OF TASK ANALYSIS

The study of tasks has its foundation in the field of Scientific Management (Taylor, 1911). Taylor's work began with his classic stopwatch time-study procedure, timing workers' performance, and developing standards for the time needed to complete various tasks. The procedure did not include the human factors and limitations involved in the performance of the task, so Taylor expanded his studies to include personnel selection, work methods, labor standards, and motivation.

Taylor argued that managers should establish rigorous systems of work organization based on empirical evidence. With data in hand, the workplace could be designed to optimize workflow. Taylor focused on unskilled workers, who he treated as cogs in a larger machine. This approach made "Taylorism" much less relevant as the nature of work changed to incorporate more complex tasks, contingent upon individual initiative, analysis and decision-making. However, Taylor was successful in improving manufacturing productivity and provided the inspiration for future attempts to incorporate human factors and into work methods.

The psychological component of job design was first examined in the Hawthorne Studies, conducted by the Harvard Business School faculty from 1927 to 1932 at the Western Electric Hawthorne Plant. These studies were initiated to examine the effect of lighting on workers' performance, but eventually concluded that performance was influenced more strongly by the attention given to workers during the studies than by environmental effects such as lighting. The studies concluded that there is a dynamic social system in the workplace, and that individual differences, beliefs, and values play a large role in what workers contribute to or expect from their jobs. The Hawthorne Studies were the foundation for the field of industrial psychology (Heizer and Render, 1999).

Herzberg's (1966) job satisfaction theory exemplifies the contributions of industrial psychology. Building upon Maslow's (1943) hierarchy of needs, Herzberg identified "motivation" and "hygiene" as two factors that determine worker job satisfaction or dissatisfaction. Hygiene factors—such as pay, status, job security, working conditions, company policy and supervision—are considered preventive (if they are absent the worker will be unmotivated). Motivators are job satisfiers; they correspond to Maslow's esteem needs and self-actualization needs. Herzberg's theory also introduced "job enrichment," by which workers are helped to fulfill higher-level needs (such as esteem and self-actualization) through the introduction of new, more difficult tasks, or more specialized tasks, or giving additional authority to workers. Thus Herzberg's theory links the methods of task analysis with the job satisfaction and psychological states of workers.

As the importance of task design to job performance and satisfaction became increasingly apparent, applied psychologists (working in the emerging subdisciplines of human factors and ergonomics) turned their attention to developing formal models of human performance. Linear process flow charts (Chapanis, 1959) enabled the analysis of relatively complex tasks incorporating control, planning and problem-solving. From these studies of the psychological component of work it was deemed important to evaluate how a task is accomplished. Industrial engineers began incorporating methods analyses into work and time studies to improve performance, safety and quality by analyzing the movement of individuals or material, the interaction between human and machine, and body movement (Heizer and Render, 1999).

Hackman and Oldham (1975) developed a framework for task design, the Job Characteristics Theory. This theory identified three psychological states critical to motivational work output: meaningfulness of work, responsibility for work outcome, and knowledge of results. They found that when these states were achieved workers exhibited high internal motivation, resulting in high quality work performance, high job satisfaction, low absenteeism, and low turnover.

The Sociotechnical Systems Approach emerged at the Tavistock Institute of Human Relations, where researchers began studying—using ethnographic and participatory action methods—the social and technical subsystems of an organization and how these subsystems interact (Trist and Murray, 1990). The Tavistock researchers reconsidered the traditional emphasis on exclusively technical requirements of systems design, and encouraged worker participation in organizational design. Technology was considered and integrated, rather than imposed. Although some argue that the sociotechnical approach failed to fully integrate technology with user needs to improve the tasks being performed (Preece et al., 1994), it is clear that in some cases organizational performance was generally enhanced.

As applied psychologists and system designers dealt with ever-more complex tasks and supporting systems to increase efficiency and productivity, they began to search for more rigorous, systematic, and cost-effective analytical techniques. These techniques influenced the emerging interdisciplinary practice of HCI. As computing power expanded, HCI came to encompass vast new areas of human behavior, and task analysis took on greater scope and complexity. Task analysis now includes a range of techniques aimed at obtaining descriptions of what people do, representing those descriptions, predicting difficulties, and evaluating systems against functional requirements (Jordan, 1998). These techniques focus on quite different levels of analysis and contribute different insights.

## HIERARCHICAL TASK ANALYSIS

Hierarchical Task Analysis (HTA) was introduced by Annett and Duncan (1967) to evaluate an organization's training needs. The underlying technique, hierarchical decomposition (Annett, Duncan, Stammers and Gray, 1971), analyzes and represents the behavioral aspects of complex tasks such as planning, diagnosis and decision making (Annett and Stanton, 2001). HTA breaks tasks into subtasks and operations or actions. These task components are then graphically represented using a structure chart. HTA entails identifying tasks, categorizing them, identifying the subtasks, and checking the overall accuracy of the model.

HTA is useful for interface designers because it provides a model for task execution, enabling designers to envision the goals, tasks, subtasks, operations, and plans essential to users' activities. HTA is useful for decomposing complex tasks, but has a narrow view of the task, and normally is used in conjunction with other methods of task analysis to increase its effectiveness. HTA serves as both an analytical framework and a practical tool for designers.

The strengths and weaknesses of HTA flow from its strong system-centric stance. While user-centered design advocates often see task analysis as requiring deep understanding of individual behavior, HTA theory views tasks in a more abstract sense, as a set of interlinked goals, resources and constraints. The focus is on the system and its properties (Shepherd, 2001).

The system-centricity of HTA is logical given its close ties to systems engineering and ergonomics. These fields typically analyze systems with the same hierarchical approach that HTA applies to tasks—systems consist of subsystems, which then interact through various inputs and outputs. System behavior is regulated by control mechanisms, which incorporate feedback—as is operator behavior in a typical task. It is recognized that the system (or the task) exists in a wider context, which may influence its behavior, but little attempt is made to model this context explicitly.

HTA seeks to establish testable design hypotheses, each representing a performance lever—either a potential problem, or a potential method for improvement. The hypotheses guide the formulation of design options, criteria and constraints (e.g. MacLean, Young, Belotti and Moran, 1991). Since there are a potentially unlimited number of issues to be examined and hypotheses to be generated, practical analysis must have some basis for choosing its focus. The analyst proceeds in a disciplined manner by first assessing goals for potential issues, and then proceeding to detailed consideration of subgoals. Subgoals should be examined closely only if justified by a cost-benefit analysis (Annett et al., 1971). Specific studies can then be conducted to gather data about critical operations.

Once a set of goals and issues is assembled, the analyst can begin drawing up plans to specify how the goals should be achieved. Contrary to some criticisms of HTA (e. g. Preece et al. 2002), these plans can describe quite complex activities, including contingencies, decision points, concurrent operations and cycling (Shepherd, 2001). Seemingly intractable task situations can be "unraveled" into a composite hierarchy of simpler plans (Shepherd, 2001). For example, MUSE (Lim and Long, 1994) incorporates a Composite Task Model (CTM) for describing complex domains; this model has been applied to domains such as air traffic control (Marti, 2000). DUTCH (van der Veer and van Welie, 2000) integrates multiple representations using a "task world ontology."

HCI has rapidly evolved continuing to embrace new approaches and perspectives in order to cope with the complexity of modern work and the pervasiveness of computing. Considering this evolution, what are the prospects for HTA as tool for analyzing complex work situations and as an adjunct to HCI? Stanton and Annett (2000) suggest that HTA can progress by embracing contextual analysis (e.g. Beyer and Holtzblatt, 1999). However, it is doubtful whether HTA provides a sufficient framework for such analysis, given its system-centric, prescriptive nature.

HTA recognizes the responsibility of the operator (user) to plan the use of available resources to attain a given goal, but it treats the operator's cognitive processes as a black box: "how behavior is actually organized is a question for cognitive psychology" (Shepherd 2001:16). But—as has long been apparent in HCI—it is crucial to understand the structure of human cognition in order to appropriately support cognitively intensive tasks. Moreover, compartmentalizing cognition in this way is limiting. Cognition is intimately connected to sociocultural processes (Hollan, et al., 2000), but HTA provides no systematic way for dealing with the rich social and physical context in which activities are embedded. Similarly, HTA fails to support the components needed to analyze system flows and dynamics. These limitations necessitate the use of additional theoretical structures to develop a more complete understanding of human activity.

## COGNITIVE TECHNIQUES

### Cognitive modeling

What do we find if we peer inside the "black box" of cognition? By developing models of how the brain and body respond in certain situations, psychologists have created valuable insights for HCI theorists and designers, enabling them to create what Norman (1988) calls "natural mappings" between cognition and interface.

Card, Moran, and Newell (1983) proposed a Model Human Processor (MHP), consisting of three interacting systems: perceptual, motor and cognitive. The MHP assumes that the brain is capable of performing various information-processing operations, such as comparing, matching and calculating.

While this model does not directly apply to task analysis or system design, Card et al. developed an engineering model of human performance—GOMS. GOMS enables the MHP's characterizations of human performance to be applied to task analysis. According to Card et al., the purpose of a task analysis is to map out the constraints imposed on behavior by the nature and features of the task environment, and to determine what users knows about the task, and when they know it.

GOMS models tasks in terms of a set of Goals, a set of Operators, a set of Methods for achieving the goals, and a set of Selection rules for choosing among competing methods for goals. A "set of goals" is defined as a symbolic structure that defines a state of affairs to be achieved and determines a set of possible methods for achieving it. Operators are defined as elementary perceptual, motor or cognitive acts whose execution is necessary to change any aspect of the user's mental state or to affect the task environment. A method is defined as a description of a procedure for accomplishing a goal, and is one of the ways that users store their task knowledge. Methods are learned procedures that the user already has and are not created during a task performance. The selection rules in a GOMS task analysis determine how a user selects a particular method, and can be used to predict which method the user will select on the basis of knowledge of the task environment. Furthermore, a GOMS analysis can be used to predict the quality of an existing system or prototype (Preece et al., 1994).

Ideally, these predictions are based on "parameters that are robust and reliable across tasks and can be used without further empirical validation" (John and Kieras, 1996a:3). Thus analysts can assess system performance without extensive user testing, lowering both the time and cost required to develop a system. This is especially valuable when user testing is restricted (for example, if there is a small pool of skilled users who are rarely available for testing).

GOMS analysis produces a description of a task, often in the form of a hierarchical plan similar to those produced by HTA. However, while HTA generally describes high-level activity, GOMS typically works at the keystroke level. This low-level focus arises from the requirement that the lowest-level operators in a task have rigorous estimates of execution time.

Like HTA, GOMS has been refined and expanded in order to better cope with more complex tasks and domains, and to deal with additional issues such as parallelism and error estimation. NGOMSL (Kieras, 1996) is a natural-language version of GOMS based on improvements in the understanding of human information processing—specifically, cognitive complexity theory (Bovair et al., 1990). It provides additional information to the analyst beyond what is available from a traditional GOMS model, including quantitative estimates of learning and execution times. The downside is that its "higher degree of formality and precision" make it harder to learn and use (John and Kieras, 1996b). Cognitive-Perceptual-Motor GOMS (CPM-GOMS) enables the description of tasks in which operators are performed in parallel.

Building upon these more advanced GOMS models, Kieras and Meyer (1997) developed Executive Process-Interactive Control (EPIC), a cognitive architecture for modeling multiple-task and multimodal situations. EPIC incorporates three conceptual innovations. First, it recognizes that cognition is fundamentally embodied and depends on human perceptual and motor capacities. Second, it provides computational models of attention and performance. Third, it accounts for the role of executive processes in coordinating and regulating multiple-task performance. In addition, EPIC provides the foundation for a computational model of user error, which could be used to predict potential causes of error in a system.

Unlike GOMS, EPIC is still a research system and is unsuitable for practical use. Applying EPIC to a particular task situation is extremely complex, involving programming the cognitive processor in its own language. It appears that as cognitive models have become increasingly powerful in their ability to characterize human performance, they have also become increasingly impractical.

TAG, another task analysis technique inspired by GOMS, illustrates this tradeoff. TAG is a technique for evaluating system learnability using consistency and compatibility as predictors of how easy a new task is to perform (Payne and Green, 1989). TAG utilizes a set of constraints for writing grammars to capture the task knowledge required to use a particular computer interface, but does not include the role of the computer interface in enhancing the learnability of a system. Like GOMS and EPIC, TAG can require extensive work by the expert designers.

Thus an important research challenge for advocates of cognitive modeling is to make state-of-the-art models accessible to task analysts. The complexity of GOMS was sufficient to deter many analysts, who embraced "discount" techniques such as cognitive walkthroughs instead. Contemporary architectures are even more difficult to learn and use, and may require considerable refinement for practical use.

### Cognitive task analysis

Close analysis of cognitive activity has led to another class of techniques, known as Cognitive Task Analysis (CTA). Development of CTA has been motivated by the observation that as "tasks have become more intricate, knowledge-intensive, and subject to increasingly integrated forms of technological support, traditional forms of task decomposition appear to have an overly restricted scope" (Barnard and May, 2000:147). In contrast to GOMS-style cognitive models, CTA targets more abstract, high-level cognitive functions (Militello and Hutton, 2000).

Compared to HTA or GOMS, CTA presents quite different challenges to the analyst. It requires deep engagement with a particular knowledge domain, working closely with subject-matter experts to elicit their knowledge about various tasks (Chipman, Schraagen and Shalin, 2000). Here, many techniques—such as structured interviews, naturalistic observation, ethnography and contextual inquiry—could be of value. Ultimately the analyst must seek to define a coherent knowledge representation for the domain being studied. This representation might be, for example, a semantic network or a goal/method graph.

CTA represents an attempt to capture task expertise. Since expertise is often tacit or idiosyncratic in nature, it can be much more difficult to analyze than the explicit actions typically considered by HTA. In fact, CTA requires "making explicit the implicit knowledge and cognitive-processing requirements of jobs" (Dubois and Shalin, 2000:42). This challenge has spawned a diversity of CTA methods, ranging from ecological approaches (Flach, 2001) to constraint-based analysis (Vicente, 1999).

Compared to HTA or cognitive modeling, CTA has increased understanding of many important cognitive aspects of modern task environments. However, it is unclear how effective CTA techniques are in representing these aspects in a systematic and useful way (Shepherd, 2001). Another significant problem with many CTA techniques is that studying high-level cognitive functions in a real task situation is very difficult. Studies may take months or years and rely on the dedicated efforts of senior researchers. Consequently, some practitioners are developing simpler approaches that can form a "practitioner's toolkit" (Militello and Hutton, 2001). Others have pursued more automated techniques that promise to simplify manual task analysis.

## ACTIVITY THEORY

Activity theory derives from the Russian ergonomic tradition, which takes a more holistic view of work (Bedny and Meister, 1997). In contrast to information-processing psychology it models people as agents, rather than as collections of cognitive attributes. In contrast to traditional task analysis it takes an "activity," rather than a task, as the highest level of analysis.

Activities, as opposed to tasks, are inherently context-sensitive. The key principle of activity theory is to establish a "minimal meaningful context" for individual actions (Kuutti, 1996). This context is the activity, defined as "a form of doing directed to an object." Activities are not seen in isolation. They are under continuous development, so their history accumulates and serves to inform their evolution. This is possible because of the presence of artifacts. Artifacts carry culture in the form of "historical residue," delivering the lessons of the past to the future, mediating between different elements of an activity, and enabling the coordination of complex actions.

Activities (representing motives) are composed of actions (representing goals) and operations (representing conditions). Operations, the most primitive level, represent "well-defined habitual routines," analogous to operators in GOMS. Activity theory typically works at a much higher level of abstraction than cognitive modeling, while accounting for learning effects, in that actions can be converted into operations through practice, thereby linking the internal and external aspects of an activity. Activity theory anticipates and can help to model contemporary ecological approaches to cognitive psychology, such as distributed cognition (Hollan et al., 2000). It seeks to extend the scope of technology to support much more complex processes and problems. On this view, analysts should seek to make new activities possible and uncover powerful emergent behaviors. The goal should be to shift from "automating work to supporting it" (Kuutti, 1996).

Activity theory in its current form is only the beginning of a coherent foundation for task analysis and HCI. Key concepts—such as activity, action and operator—are situation-dependent. The lack of consistent definitions makes it difficult to compare and generalize empirical results. Activity theory has yet to provide a disciplined set of methods to guide design, as information-processing theory has. Until such methods are available, activity theory may serve to provoke creative design thinking in particular cases, but will be difficult to apply systematically.

## CONCLUSION

The development of task analysis can be seen as mirroring the progress of research trends in HCI. HCI research has evolved over the past fifty years from focusing on technical (ergonomic) aspects, to conceptual (information-processing) models, to work-process (contextual) models (Kuutti and Bannon, 1991; Grudin, 1990). On this view, HTA is an attempt to model the ergonomic facet, cognitive modeling the information-processing facet, and activity theory the contextual facet (see Figure 1).

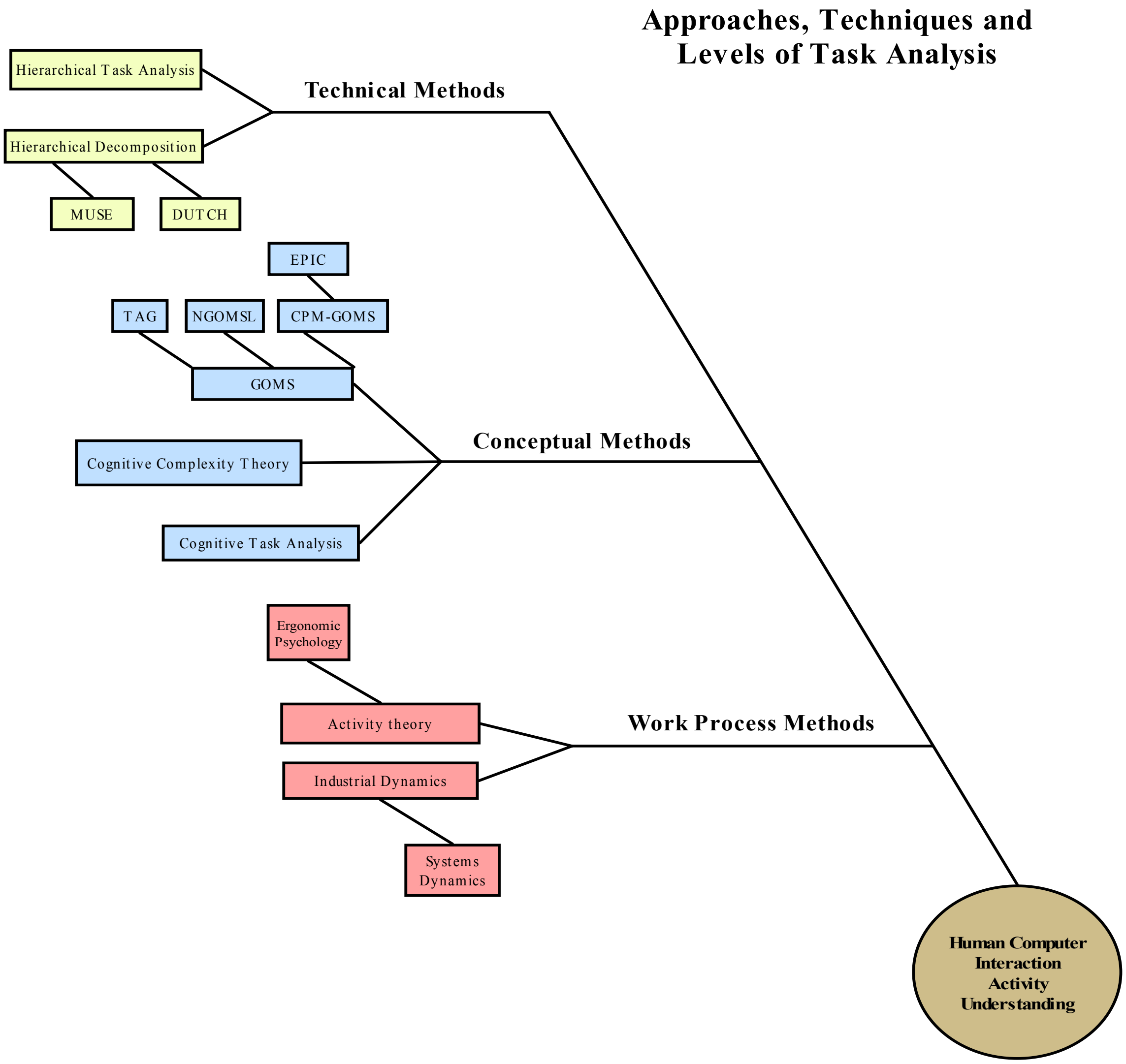


**Figure 1. Approaches, techniques and levels of task analysis.**

As they have evolved, task analysis techniques have become increasingly complex and fragmented. As a result the sophisticated forms of task analysis developed by researchers are often ignored in practice. For task analysis to realize its potential, researchers must improve its *usability* and degree of *integration*.

### Usability

Task analyses are too difficult to perform, and when they are performed they are too difficult to understand and use. As Chipman, et al. (2001) note, "The usability of the products of cognitive task analysis is another major issue for the future… Currently, too little is being said about the use of cognitive task analysis products in discussions of cognitive task analysis." It remains unclear how to marry increasingly sophisticated models of human cognition and action with simpler, practitioner-friendly techniques. Still, it should be possible to develop new lightweight or "discount" task analysis techniques that are both easy to use and informative. Usability engineers already rely on simple techniques such as cognitive walkthroughs and heuristic evaluation, but these approaches sacrifice the richness of true task analysis. Alternatively, task analysis software could be developed to support designers and systems analysts by providing a clear framework and automating routine aspects of analysis.

### Integration

Inevitably, there is a tradeoff (see Table 1) between efficiency (encompassing complexity and usability) and effectiveness (encompassing quality, depth, and breadth of output). The challenge is to develop techniques that optimize this tradeoff. Empirical evidence is crucial here, but this research is still nascent, as many techniques have been proposed with little empirical evaluation.

| | Technique | Efficiency | Effectiveness | Evidence |
|---|---|---|---|---|
| Technical | **HTA** | ▪ Decomposes complex tasks into subtasks<br>▪ Complex activities demand extensive hierarchy construction/charting | ▪ Improves problem diagnosis and useful for concurrent operations<br>▪ Does not account for system dynamics | MacLean et al., 1991<br>Annet and Stanton, 2000<br>Hollan et al., 2000<br>Shepherd 2001 |
| | **GOMS** | ▪ Requires detailed analysis of keystroke level interaction | ▪ Improves productivity<br>▪ Not applicable to broader problems<br>▪ Ignores contextual factors | Card et al., 1983<br>Preece et al., 1994<br>John and Kieras, 1996 |
| Conceptual | **CTA** | ▪ Defines a coherent knowledge representation for the domain being studied<br>▪ Requires deep engagement with a particular knowledge domain | ▪ Increases the understanding of cognitive aspects of the task<br>▪ Captures task expertise<br>▪ Fails to fully incorporate learning, contextual and historical factors | Barnard and May, 2000<br>Chipman et al., 2000<br>Dubois and Shalin, 2000 |
| Work-Process | **Activity Theory** | ▪ Analyzes the activity, not the task, implying a potentially great increase in scope and complexity<br>▪ Requires near-ethnographic knowledge of culture | ▪ Accounts for learning effects<br>▪ Extends scope of technology<br>▪ Requires a high level of abstraction<br>▪ No disciplined set of methods<br>▪ Difficult to apply systematically | Kuutti, 1996<br>Hollan et al., 2000 |

**Table 1. Efficiency, effectiveness and empirical evidence in task analysis research.**

So a major challenge for future research is to investigate the use of task analysis techniques in context, assessing the efficiency and effectiveness of these techniques for particular tasks, situations, design problems and organizational structures. Findings from such research would enable refinement and elaboration of a taxonomy of task analysis techniques which could guide practitioners. Such a taxonomy would facilitate "best practices" in task analysis usage and help accelerate the spread of task analysis techniques in practice. In addition, it would lay the groundwork for innovative new forms of task analysis that integrate multiple levels of analysis.

These new forms might combine technical models with conceptual and work-process models, or high-level HTA plans with low-level GOMS or EPIC analyses. Future research might address possibilities for integrating HTA and CTA to optimize cognitive activity in complex task flows. Or, cognitive modeling might be better integrated with CTA by combining the underlying theoretical constructs of each approach (human cognitive architecture and task knowledge structures), as a prelude to developing design tools that draw upon both approaches (Chipman, et al., 2001). Another area for possible investigation involves understanding the dynamic aspects of tasks and their place in larger systems (e.g. Systems Dynamics, cf. Forrester, 1990).

Efforts in these areas can continue progress in "extending the capability of task analysis techniques to capture as rich a picture of human activity as may be desired" (Annett and Stanton, 2000), yielding new possibilities for interaction designers and systems analysts.

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