THE FORGOTTEN HISTORY OF COGNITIVE TASK ANALYSIS

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Many reports of recent research on topics in cognitive systems engineering describe their methods by distinguishing cognitive task analysis from "traditional" or "behavioral" task analysis. A hallmark of modern cognitive task analysis (CTA) methods is that they place primary focus on understanding the cognitive demands of a task and the knowledge and strategies that underlie performance. While cognitive task analysis may have seemed to be a revolutionary approach introduced in recent years, a review of the history of task analysis reveals many things that have been lost in modern treatments of the history of human factors. This presentation will review some highlights of this forgotten history, including the ideas and methods of the Psychotechnicians, the earliest industrial psychologists, the Taylorists, and others who contributed to modern CTA. Task analysis never lacked cognitive categories. Even microscale "time and motion" studies involved the analysis of the work of domain experts. Basic ideas of human-machine systems and of complexity also appear in some of the earliest literatures — industrial psychology of the first decades of the 20th century.

INTRODUCTION

It is generally agreed that Cognitive Task Analysis (CTA) methods represent a relatively new approach to the study of human cognition in real-world settings. This new approach emerged in the early 1980s in response to demands of the workplace. The introduction of smart machines created unanticipated complexities for human operators and led to high-visibility incidents such as the Three-Mile Island incident. Corporate managers and military leaders called for researchers to develop methods that would lead to better design of training and technology. These improved designs would reduce the likelihood of error and allow workers to better leverage the strengths of increasingly powerful technologies.

In response to these challenges, researchers developed interview techniques (e.g., Klein, Calderwood, and Macgregor, 1989; Gordon & Gill, 1992; Hall, Gott, and Pokorney, 1994) and adapted ethnographic observation strategies with the goal of explaining the mental processes involved in performing a task (Klein & Militello, 2001). The last 20+ years has seen refinement and extension of these CTA methods (Schraagen, Chipman, and Shalin, 2001) in pursuit of tools to aid in the design of safer and more effective technologies to meet the complex challenges of the modern workplace.

While this story of the very recent evolution of CTA methods is generally accepted, a close look at history suggests that many components of CTA methods were introduced decades ago. While the development and adaptation of CTA methods may have seemed revolutionary in the 1980s and 1990s, the seeds for these methods can be found throughout the history of applied psychology (dating back even to the Psychotechnics movement in the late 1880s!), industrial engineering, and human factors.

This paper takes a historical look at the precursors to CTA leading up to modern perspectives. While the authors of some of the modern perspectives discussed here may not describe their methods as CTA, they are included as an important part of the discussion because of shared goals, points of view, and approaches to the study of humans at work.

HISTORY OF CTA

A high-level view of historical events that can be seen as precursors to modern CTA is presented in Figure 1.

1857-1890s: Introspection, Psychotechnics, Ergonomics

Some of the earliest applied psychologists pioneered self-report methods that serve as the foundation of many modern CTA methods. Wundt and his colleagues investigated the use of retrospection as a data collection technique. In some studies, participants were asked to solve a puzzle and then give a retrospective report (Ruger, 1910). This core data collection strategy is present in many CTA techniques used today in which interview methods are designed to aid participants in accurately retrospecting about real or simulated incidents.

One technique used in the early 1900s bears a striking resemblance to the cued retrospective interviews currently used to study modern surgical teams, search and rescue teams, and firefighters. Külpe and his students called

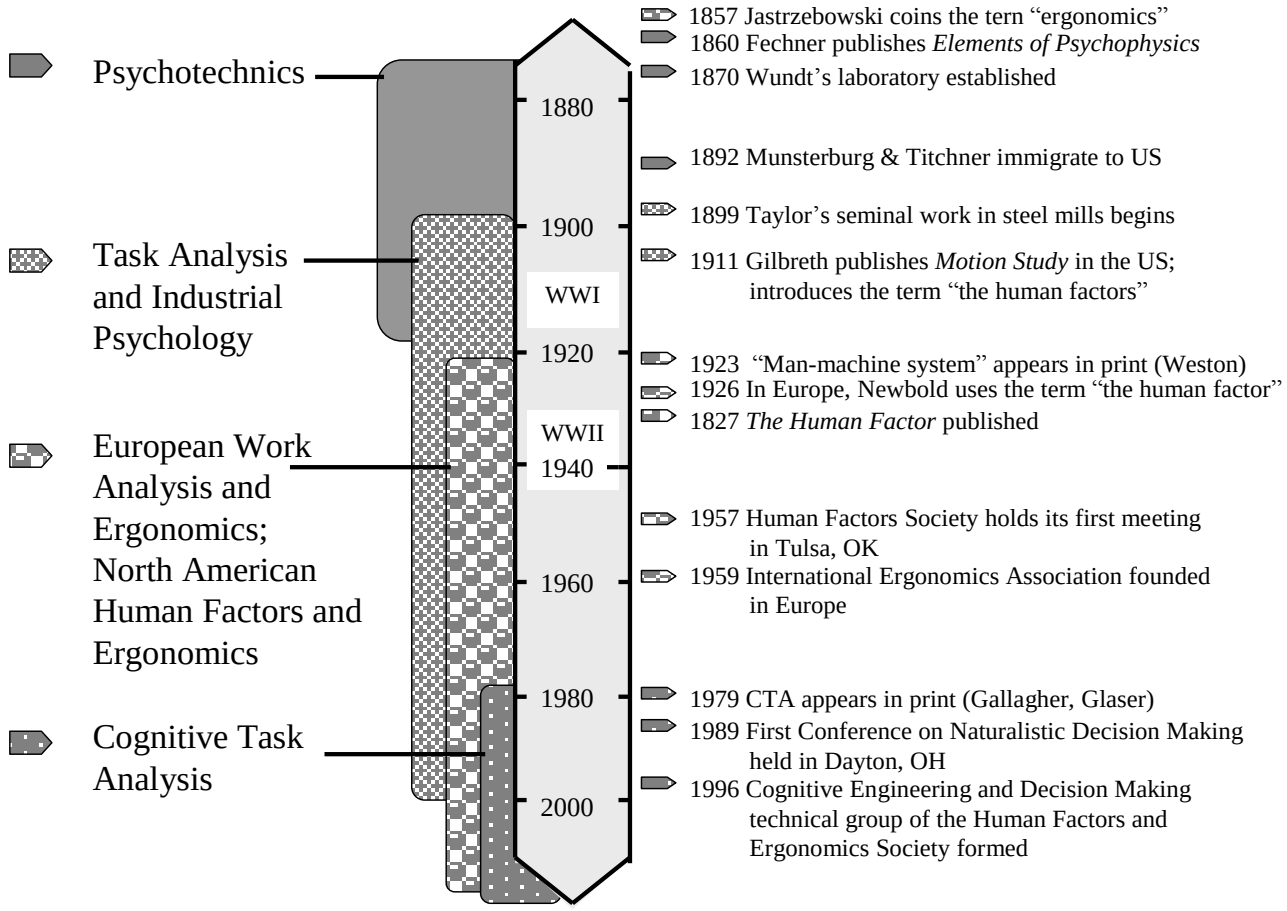

Figure 1. **Timeline of precursors to CTA. Adapted from Hoffman and Militello, 2008**

their technique "systematic post-experimental retrospection" (see Boring, 1953; Ruger, 1910). Participants would complete a task and then work through it a second time, retrospecting about what they had thought or perceived the first time through. In modern times, cued retrospective interviews (sometimes leveraging videotaping) achieve the same goal. Rather than actually working through the problem a second time, participants watch a recording of the incident and retrospect about what they thought or perceived as the incident unfolded.

These techniques spread to the US as a result of Hugo Münsterburg's move to Harvard University in 1892. Self-report methods such as introspection and retrospection have since fallen in and out of style several times throughout history (see Fernberger, 1937). Not long after Titchener and other scientists influenced by Wundt established their laboratories, a next generation of psychologists in the US grew up under the influence of behaviorially-oriented psychologists, such as John B. Watson, and industrial psychologists Frederick W. Taylor and Frank and Lilian Gilbreth in the early 1900s. Just a few years later, interest in self-report methods arose yet again as evidenced by this quote from Samuel Fernberger (1937):

> In recent years in psychology in America there has been a fashion to magnify 'objective' techniques and to look askance at any technique which might be considered to have a subjective basis. It seems to me that the fashion is beginning to change and that some of the 'subjective' techniques are again beginning to attain importance in current psychological methodology. Let me hasten to say that I have no quarrel with objective techniques nor with some of the magnificent results which have been obtained by them. The present paper is an attempt to reconcile some of the differences between the proponents of the two different points of view in the hope that psychologists will realize that all of us are working toward the same ends and that we are all working in the same scientific universe. (p. 207)

While Wundt's students were exploring the use of introspection and retrospection, researchers in Poland and Russia were conceptualizing the field of ergonomics to include "physical, aesthetic, rational, and moral work" (Jastrzebowski, 1857). This included raising issues of adapting machines to man and raising questions about the development of a standard cockpit for aircraft (Lomov & Bertone, 1969). This perspective, in which work is studied so

that technologies are designed to better support human performance, is echoed by current CTA researchers.

During this same time period, industrial psychology was referred to as "Psychotechnics" (see Meyerheim, 1927), which was promoted especially well by Wundt's student Walter Moede (1930). Psychotechnicians in Europe were introducing the idea of applied psychology and developing instruments to measure aptitudes for personnel selection and training. They studied the practices and methods of proficient workers and developed apparatus to measure reaction times and errors. These early psychologists investigated cognitive factors such as general intelligence, memory, spatial reasoning, concentration, visual discrimination, logical analysis, and mechanical aptitude (von Drunen, 1997, Gundlach, 1997).

1899 to 1920s: Task Analysis, Time and Motion Study

The notion of studying work via task analysis is firmly rooted in Taylor's (1911) Time and Motion Study. Taylor began by focusing on directly observable and easily measured aspects of work, but over time, found that the cognitive aspects of work could not be ignored. As Taylor's methods were advanced via the work of Frank and Lillian Gilbreth and others, mental operations such as "search,' "select," "inspect," and 'plan" were included in the analysis.

Time and motion study firmly established the concept of studying work via observation of workers in context – a strategy and perspective that is core to modern CTA practice. It also relied on the study, in particular, of the work of experts at a given skill, practice, or trade, often in a simulation of their workplace. The study of cognitive elements of work – although largely limited to measuring time spent doing the physical work – increased the visibility of cognition, even in predominantly physical tasks. This laid the foundation for a wider range of task analysis methods.

1923-1960s: Man-Machine System, Human Factors

After World War I, Britain's Industrial Fatigue Research Board published a report by H.C. Weston (1923) foreseeing the need for a human factors research program:

> The introduction and development of power-driven machines has effected an enormous savings of time and energy, not only by increasing the rapidity of production through substitution of mechanical power for human effort, but also by changing the character of the manipulations which remain to be performed by the operative. So great has this economy been, that is has brought with it a tendency to overlook the possibility that, while industrial machinery may be admirably adapted to the performance of its mechanical functions, it may be incompletely adapted to the needs of the human organism, upon whose efficient co-operation it depends for its productive use. (p. 71).

Weston went on to advocate for the importance of considering the human during the design phase in order to avoid injury and accidents. He specifically mentions the need to determine the "physiological and psychological facts" so that they can be considered during the design process (Weston, 1923, p. 73). This call for the identification of cognitive challenges so that they can be supported in the design of technology can be seen today in the writing of many CTA practitioners and cognitive engineers.

The basic concept of the man-machine system was visible in the industrial psychology community as early as the 1930s. Strategies for representing work in the form of flow charts and task decompositions can be found in Barnes (1937/ 1949) and Mundel (1947). Although most CTA techniques have moved away from linear task decompositions, these early attempts to create representations of how humans and machines interact are important precursors to knowledge representations used in modern CTA.

Over the years during and after World War II, human factors became increasingly visible as a discipline. Wartime initiatives funded a range of research on complex cognitive tasks such as aerial gunnery, radio coding operations, radio detection and ranging, and voice communications. These and other research programs led to the expansion of task analytic methods, as well as simulator- and lab-based studies of cognitive elements that would drive the design of cockpits, weapons, and communication technologies. By the late 1950s, the Human Factors Society was formed in the US and the International Ergonomics Association was founded in Europe.

MODERN PERSPECTIVES ON CTA

As evidenced in this very brief historical review, many aspects of modern CTA were, in fact, examined and studied long before the term *cognitive task analysis* first appeared in print in the late 1970s (Gallagher, 1979):

- Retrospective interview techniques
- Studying humans at work
- Studying cognition
- Studying experts
- Reducing error
- Designing technology to support humans

These elements have re-formed and emerged across a number of modern research threads, each of which could be characterized as using CTA methods.

For example, *Cognitive Systems Engineering* is a research thread that emerged, in part, as a reaction against the idea that technology was to be designed to make up for human shortcomings (Hollnagel & Woods, 1983; Woods & Roth, 1988). Instead, cognitive engineers advocated for a systems approach in which technology is evaluated in terms of usability, usefulness, and understandability. CTA methods are used to analyze the work system and inform the design of systems, taking into account human operators, technologies, and the work environment.

A research thread emerging from the *sociological and enthnographic literatures* includes situated cognition, distributed cognition, and situated design. Communities of practice associated with this thread include sociology of scientific knowledge, ethnography of work, and sociology of the professions. These communities reacted against approaches within cognitive psychology that decontextualize cognition via controlled laboratory experiments using artificial tasks. Concerns that this approach distorts the phenomenon to be studied led sociologists to emphasize methods having ecological validity. These researchers rely on a combination of field research, interviews, activity analysis, and actually living/working within the cultures they are studying. While the term "strong ethnography" is preferred and the phrase CTA does not appear in the sociological literatures, this research thread has much overlap with CTA, both in methods and in approach to design.

Cognitive Work Analysis represents yet another modern research thread with strong links to CTA. This thread can be traced to European Work Analysis and Activity Analysis conducted in France, Belgium, the Netherlands, Denmark, and Sweden, becoming prominent in the 1960s. In response to concerns about the safety of nuclear power plants following the Three Mile Island incident, a community of practice largely influenced by the work of Jens Rasmussen at the RISØ Institute developed a framework for analyzing complex sociotechnical systems in order to create safer and more effective designs. A key feature of Cognitive Work Analysis is an emphasis on creating designs based on constraints. The resulting designs seek to make real-world constraints visible to human operators so that they may make well-informed decisions even in unanticipated circumstances. This is in contrast to more traditional, prescriptive approaches which provide stepwise procedures for operators to follow. Although stepwise procedures were traditionally seen as a means to allow management to define the most efficient and safe workflow, well-defined procedures often become brittle in unanticipated circumstances, resulting in inefficiencies and safety problems (Woods, Sarter, & Billings, 1997). CTA is recommended as one of several analytic tools used within the cognitive work analysis framework.

The *Naturalistic Decision Making* research thread has served as a forum for researchers developing and refining CTA methods for a range of research problems and applications. This community reacted against the use of normative, prescriptive models of decision making as a basis for training and system design. In an effort to better understand how decision making happens in the real world – particularly when the decision maker is experienced and operating under time pressure and risk – this community has focused on developing CTA methods. Bi-annual conferences are held in which researchers from a range of disciplines come together and share CTA methods, findings, and resulting applications (Hoffman, 2007; Klein et al., 1993; Klein and Zsambok, 1995; Schraagen et al, 2008). Applications that have emerged within this research thread include the Recognition-Primed Decision model (Klein, 1998), as well as training and technologies designed to support decision making under stress across a range of domains.

Another CTA-related research thread, *Human-Centered Computing*, (Hoffman, Hayes, and Ford, 2001) emerged within computer science as the limitations of machine-centered designs became increasingly visible. These researchers noted the kludges and work-arounds operators developed to accommodate technologies in the workplace (Koopman and Hoffman, 2003). This community began to articulate goals quite different from the traditional artificial intelligence goal of building computers to emulate humans. Instead, they focus on using technology as a means to amplify and extend human capabilities. Consistent with the other research threads addressed here, Human-Centered Computing practitioners take a systems approach, and base system design on the results of CTA studies.

SUMMARY AND CONCLUSIONS

One can see that CTA is in many ways a re-formation of methods and perspectives that have been present in one form or anther throughout modern history. Notions of human-machine as a system, notions of the importance of studying experts, and such phrases as "human factors" all have a rich (and unfortunately, largely forgotten) history going back much longer than many might suppose (Hoffman and Militello, 2008). The seeds of modern CTA can be seen in research conducted over one hundred years ago. This in no way diminishes the accomplishments we have seen in the last 30 years, or the changes wrought by the computerization of "cognitive work." Strategies for studying cognition in the context of work have been refined and tailored to the challenges of the modern workplace. The rediscovery and reassembly of these important themes into modern CTA allows us to continue to advance our understanding of cognition as seen through humans operating in teams and with complex technologies in a dynamically changing world.

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