

GENERIC SUPPORT REQUIREMENTS FOR COGNITIVE WORK: LAWS THAT GOVERN COGNITIVE WORK IN ACTION

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Research in Cognitive Systems Engineering (CSE) has successfully identified basic requirements that must be met if new technology will be useful to practitioners in context. Synthesizing these basic requirements or support functions is part of a process of debate and consolidation of the foundations of the field after 25 years of productive activity (Klein, 1999; Endsley et al., 2003; Hollnagel and Woods, 2005). This work takes the “Laws that Govern Cognitive Work” which synthesize basic findings and patterns (Woods, 2002; Hoffman and Woods, 2005) and provides the next step—a set of basic requirements or support functions for design. General requirements for effective support can be used to jump start individual development projects in any domain. Debating how to achieve these support functions helps translate the insights of cognitive work analyses into tangible new uses of technological possibilities.

Introduction

Mis-engineering of cognitive work is commonplace. Developers make claims about the future of practice if objects-to-be-realized are deployed. Yet the predicted effects rarely come about; instead as one after action review put it: “virtually every advance in ergonomics was exploited to ask personnel to do more, do it faster and do it in more complex ways” (Cordesman and Wagner, 1996, p. 25). How can we avoid repeating past cycles of clumsy use of technological possibilities?

Leaders of organizations and major development efforts are often frustrated that human factors does not provide ‘basic first principles’ as a foundation to be sure that new technology deployed into operational settings will in fact support decision making. To meet this need Woods (2002) synthesized the research base about cognitive work and about teamwork across people and computers and developed a set of generalizations or ‘laws’ that govern cognitive work by any cognitive agent or any set of cognitive agents (see url: <http://cse.eng.ohio-state.edu/laws>)

Laws that Govern Cognitive Work have an odd quality, like all regularities in control systems—they appear optional. Designers of systems that perform cognitive work do not have to follow them. In fact, we notice these laws through the consequences that have followed repeatedly when design violates them in episodes of technology change (Woods and Dekker, 2000). The

statements are law-like in that they capture regularities of control and adaptation of cognitive work, and they determine the dynamic response, resilience, stability or instability of the distributed cognitive system in question. While developers may find following the laws optional, what is not optional is the consequences that accrue predictably from breaking these laws, consequences that block achieving the performance goals developers and practitioners, technologists and stakeholders set. Respect for the Laws is essential, for in the final analysis: “in design, we either hobble or support people’s natural ability to express forms of expertise.”

What then does past research in Cognitive Systems Engineering tell us about how to support practitioners in context? This is a version of classic dilemma across all aspects of Human Factors—how is work in CSE valuable to the design and development of new systems? One answer is methods for discovering the demands of cognitive work and the strategies of experts. Another answer is to translate research results into design guidelines. This paper utilizes a third strategy—based on basic ‘laws’ or empirical generalizations about joint cognitive systems, the field has and can develop a set of generic requirements or support functions that must be met if a new systems development is to provide useful support for cognitive work. CSE results seed and guide the search for what would be useful—requirements discovery in design and development.

Outline of Generic Support Functions

High performance cognitive work depends on providing support for Coordination and for Resilience. To achieve high levels of performance in cognitive work (in the sense of adaptability—the ability to adapt behavior in changing circumstances to pursue a goal—the key of the first family of the Laws), new systems need to provide:

- Support for Coordination—the ability to coordinate and synchronize activity across agents.

- Support for Resilience—the ability to anticipate and adapt to potential for surprise and error.

Results from studies of cooperative work provide the basic criteria for supporting coordinated activity in terms of anticipation, synchronization, interpredictability, and shared commitment to balance multiple goals (see the review in Klein, Feltovich, Bradshaw and Woods, in press). In previous work on human error a variety of researchers have developed criteria for Resilience in terms of terms of how broadening checks and other forms of cross checks avoid premature narrowing and related vulnerabilities in cognitive work (see Hollnagel, Woods, and Leveson, in press).

Coordination and Resilience are each supported by other functions: Observability (feedback that provides insight into a process), Directability (ability to direct/re-direct resources, activities, priorities as situations change and escalate), Control of Attention (ability to re-orient focus in a changing world), and Shifting Perspectives (contrasting points of view). Table 1 illustrates some of the sub-functions for each of the main support functions.

Table 1. The basic requirements annotated with some illustrative sub-functions.

Support for Coordination—the ability to coordinate and synchronize activity across agents.

- Common ground—shared frame of reference
- Synchronization
- Team work with machine agents
- Interpredictability—building and testing a common ground across distributed agents.

Support for Resilience—the ability to anticipate and adapt to potential for surprise and error.

- Failure sensitive strategies
- Explore outside current boundaries, set, focus, or priority
- Overcome brittleness of automata
- Revise focus
- Balance pressure to narrow/over simplify with comprehensiveness and broadening checks

Support for Observability: feedback that provides insight into a process

- Integrate data based on a model of the process
- Align data to reveal patterns and relationships in a process
- Provide context around details of interest
- Overcome ‘keyhole’/extend peripheral awareness
- See sequence & evolution over time
- See future activities & contingencies
- Shift & contrast multiple perspectives
- Decompose integrations and inferences into sources, process, base evidence

Support for Directability: ability to direct/re-direct resources, activities, priorities as situations change and escalate

- Anticipation/projection
- Models of capability
- Policies for adaptation
- Intent communication

Support for Directing Attention: ability to re-orient focus in a changing world

- Track other’s focus of attention
- Judge interruptability of others
- Pre-attentive reference

Support for Shifting Perspectives: contrasting points of view

- seeding—structure & kick start initial activity
- reminding—suggest other possibilities as activity progresses
- critiquing—point out alternatives as activities come to a close

Generic Requirements in Action

The Generic Support Functions provide a guide for future design projects derived from past results on successful and unsuccessful support for cognitive work.

Coordination across agents begins with the need to establish 'common ground' or a shared frame of reference about the events in the world. This is a form of developing support for observability. One can then develop criteria and test for what forms of observability support building common ground. For example, several lines of recent work (automated surveillance, cognitive science) emphasize the need to capture temporal patterns (Zachs, 2004).

Coordination across human and machine agents is built upon shifting perspectives as the machine and human parts of the system will have different knowledge and data about the situation in the world. For example, in effective human-computer agent coordination, the computer processing results define different perspectives which the human monitor can shift across or contrast.

Shifting perspectives includes roles for agents to help broaden another monitor's view of the situation and trends. Collaborative broadening is based on some combination of *seeding*—helping to structure & kick start initial activity, *reminding*—suggesting other possibilities as analysis progresses, *critiquing*—point out alternatives as analysis matures to a conclusion. Seeding, reminding and critiquing are basic collaborative broadening functions that help us explore outside current boundaries, set, focus, or priority to avoid premature narrowing—resilience (Patterson et al., 2001).

In the case of *Team work with machine agents* research shows that effective cognitive work requires support for Observability functions such as common ground—shared frame of reference and make other agents' models, intent, activities observable. This applies to Event Observability—what events appear to be ongoing in the world. Event observability tests the criteria of (a) how to model complex events against changing background of activity and at different time scales, (b) how to integrate inputs from data sources that vary in modality and in level of autonomy, (c) how to combine multiple information sources into a coherent picture for human monitors. It also applies to Algorithm Observability (making machine agents' models, intent, activities observable to human problem holders)—e.g.,

what is detectable with what boundary conditions by surveillance algorithms.

Research on *Team work with machine agents* also found that effective cognitive work requires support for Directability Functions—how to re-direct agent resources as situations change (delegation). Algorithm Directability provides the means for human monitors or problem holders to re-direct and interact with partially autonomous systems. The greater the autonomy of automated systems the higher the need for responsible people to be able to re-direct the automata as high level resources. For example, as the machine decides how to reconfigure its sensor resources given its targets for 'coverage' or to gather more 'information' for the human monitor; the human monitor will need to redirect the reconfiguration as situations will arise outside the machine's knowledge (brittleness) and where the human has information that is not available to the algorithms.

Directed attention or control of attention is concerned with the problem of how to help decision makers re-orient attention to new significant information even when they are busy with other tasks (Woods, 1995). This support function addresses the criteria of how to direct the attention of human monitors to 'interesting' behaviors or changes in behavior and how to cull out unimportant data and avoid the debilitating consequences of false alerts. Alerting algorithms function as agents that re-direct the attention of other agents—the human problem holder. This is an aspect of designing an effective collaboration in terms of directed attention. People are fundamentally able to assess where another person's attention is focused in order to coordinate when and how to inform them about new events that potentially should shift their focus of attention (e.g., judging interruptibility is a basic aspect of collaboration). To achieve coordination, control of attention requires bi-directional re-focusing where one agent can influence where and on what the human monitor focuses and where the human monitor can choose focus and still receive support from other (human or machine) agents to recognize ongoing events at different scales.

Shifting perspectives has turned out to be fundamental across cognitive work, collaboration, and resilience. For example, revising assessments or avoiding getting

stuck in one view (fixation) is all about supporting shifts in perspective. Cross checks for resilience are about providing means to coordinate and contrast different perspectives provided by agents in different roles (e.g., Patterson et al., 2004). Visual momentum design techniques are about helping people move between different perspectives on data and a reminder to design the different perspectives into the system. Processes of building common ground are at heart a process for monitoring and exchanging perspectives (note this is opposed to the interpretation that a common frame means all agents have the same view). Seeing where some one else is gazing to see where their attention is focused is a fundamental property of cognition that is tuned to being able to assess another's perspective. Judging interruptibility similarly is about assessing another's perspective (where perspective is more abstract). Stance in cooperative work is about another group's perspective -- perspective in an even more abstract sense. Crossing perspectives as people working together combine some core of similar understanding with non-shared understanding due to their own backgrounds, expertise, point of view on the work, which adds flexibility, cross checks, and novel approaches (Hong and Page, 2004).

The functions also provide criteria for evaluation and validation of new systems and guard against common mistakes in designing distributed multi-agent systems.

New Directions in CSE

Generic Support Functions are useful in design and evaluation in several ways:

- ~ As domain independent or generic they apply across different specific settings.
- ~ As general findings they guide/test cognitive work analyzes of specific settings.
- ~ They specify basic criteria to be met if systems are to support cognitive work.
- ~ They seed design with initial hypotheses about what will prove useful.
- ~ They focus development resources quickly on high leverage areas.
- ~ They specify basic requirements to be met during design activities.
- ~ They provide criteria for testing for success in evaluation and validation studies.

The set of generic functions have already proven quite useful in work underway on how to make

automata team players (Sarter, 2002; Ho et al., 2004; Klein et al., 2004) and in considering how to support intelligence analysis. They have provided the starting point for evaluation criteria to test whether new system support intelligence analysis.

Ultimately, the test of CSE as a research strategy is its ability to identify basic requirements for how to support cognitive work that must be met if new technology will be useful to practitioners in context.

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