An Integrated Model of Macrocognitive Work and Trust in Automation

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Abstract
Conceptual models of trust in automation range from lists of factors that are believed or known to have a causal influence, to conceptual diagrams that express a hypothetical causal relation between trust and the operator's prediction of the automation's behavior. The unified theory presented here is more complete. Trusting is modeled as a phenomenon that emerges from multiple interacting and parallel processes. The integrated model is a reasonable starting point for computational modeling that would capture the richness of expert cognition and re-planning, and simultaneously allow for the modeling of reliance and trust in the automation that mediates the cognitive work.

Introduction
The focus of this paper is on macrocognition, that is, the ways in which cognition adapts to complexity in sociotechnical work systems (Cacciabue and Hollnagel, 1995; Klein et al., 2003). This includes modeling the reasoning of domain experts, an enterprise that was stimulated initially by the advent of expert systems, entailing studies of domains spanning a great variety from weather forecasting to industrial process control to emergency management (Schragen, et al., 2008). The subject matter for macrocognitive studies is processes such as sensemaking, problem recognition, mental projection to the future, collaboration, identification of leverage points, adaptation, and maintaining common ground. This subject matter distinguishes macrocognitive research from "microcognitive" research (e.g., the laboratory study of millisecond shifts of attention, the retrieval of items from short-term memory). The study of cognition at both scales, and using diverse methodologies, is obviously necessary for a complete cognitive psychology. This paper concerns itself with two primary macrocognitive theories. One is a theory of sensemaking and the other a theory of replanning.

During the era of expert systems, psychologists started to study whether people tend to believe that a computer's outputs must always be correct. More recently, technology has increased in complexity, depending on higher levels of knowledge and skill on the part of operators. Technologies trigger automation surprises and spawned new forms of error (Koopman and Hoffman, 2003; Woods and Hollnagel, 2006). People often mistrust their computer technology.

A number of conceptual and computational models of trust in automation have been proposed, having the goal of capturing the variables that might influence the dynamics and development of trust in automation. Some models are lists of causal factors and dimensions, some are mathematical models (e.g., Khasawneh, et al., 2003; Lee and See, 2004). Models typically regard trust as a state; the goal is to predict or estimate values or levels of trust, or of trust "calibration."

These classes of models, models of cognitive work and models of trust, have yet to be integrated. The integration presented here is intended to capture: (1) The reasoning sequences in which problems are solved and people make sense of situations as a part of their cognitive work, and (2) The operator's reasoning about the trustworthiness and reliability of the technologies that are mediating the work. I rely on the Data/Frame model of sensemaking and the Flexecution model of replanning to forge this integrated model. I show how the integrated model can be used as a new method for analyzing results from cognitive task analysis. In addition, the unified model is suggestive of architectures for computational emulations.

Sensemaking
The Data/Frame model of sensemaking (Klein, Moon and Hoffman, 2006a,b; 2007) is presented in Figure 1 (below). In this model, "frames" can be understood as conceptual approximations to more formal notions of frames.
anywhere, though as I say, it is often triggered by sur-
closed loops. The sensemaking process can commence
there are no input and output arrows in Figure 1; it is all
and not the rule (see Hoffman and Yates, 2005). Thus,
decision is "made"), such causal chains are the exception
with a clear-cut starting point ("surprise" is often the trig-
walk, 2008). If one looks at those sorts of models one sees
various loops (e.g., testing an hypothesis by searching for
additional data) but the models are basically all causal
chain, input-output models. A premise of the macrocogni-
tive approach is that the functions of macrocognition are
all parallel, essentially continuous, and interacting.
Sensemaking often proceeds in fits and starts; there can
be gaps, distractions, and multi-taskings. Beginnings and
endings can be anything but clear-cut. While there may be
instances in which reasoning seems to follow a sequence
with a clear-cut starting point ("surprise" is often the tri-
ger to problem solving) and an apparent stopping point (a
decision is "made"), such causal chains are the exception
and not the rule (see Hoffman and Yates, 2005). Thus,
there are no input and output arrows in Figure 1; it is all
closed loops. The sensemaking process can commence
anywhere, though as I say, it is often triggered by sur-
prise. But even in that case, some sort of frame must have
"been in mind" earlier, otherwise there would be no
anomaly to notice.

The Flexecution Model of Replanning

The assumed nominal case is that a plan is made de novo
and then followed lock-step, but this is widely understood
to be the exception to the rule. The more typical case is
continual re-planning (Klein, 2007a,b), as has often been
expressed by military leaders such as Publius Syrus (~100
BC) who commented, It is a bad plan that admits of no
modification. But more than this, the flexecution model
recognizes that in complex reasoning and problem solv-
ing, people clarify and adapt their goals while pursuing
them. This distinguishes the Flexecution model from oth-
er models of dynamic or adaptive planning:
Planning-as-problem-solving generally relies on a set
of well-understood representations and mechanisms,
such as planning graphs, task networks, search in a
state space, chaining, type hierarchies, and con-
straints on variables (Allen, Hendler and Tate, 1009:
Bacchus, 2001; Weld, 1999). These mechanisms and
approaches seem to run into difficulty when faced
with the intractability of large, messy, real-world
problems. For such planning problems, the state
spaces aren’t completely predefined, and planning
requires human decision making based on
knowledge and sensitivity to context (Klein, 2007a,
p.79).

Within AI, a main planning strategy is to find provably
correct sequences of actions that will accomplish the
(well-specified) goal (Allen, Hendler, and Tate, 2000).
Kambhampati (2007) has noted that this work assumes a
complete domain model that is specified in advance, in-
cluding goal utilities, an assumption that may sometimes
be warranted but which is too restrictive for many situa-
tions.
The Flexecution model is depicted in Figure 2 (below).
The Flexecution model does not assume that there are
"start" and "stop" points. Studies of how people reason
about complex indeterminate causation (Hoffman, Klein
and Miller, 2011) have shown that there are often no
clear-cut starting or halting points in reasoning about
complex causation. The closed loop at the top is the coun-
terpart to the topmost closed loop in the D/F model.
Likewise, the other loops in the Flexecution model are
counterparts to those in the D/F model. The two concep-
tual models are cut of the same cloth, one describing how
people make sense of complex situations, and the other
describing how people act on the basis of their under-
standing. But there is more.

Working the Technology

Macrocognitive work involves observing and acting upon
the world. These activities are mediated, in whole or in
part, by the technology (sensors, computational systems,
displays, etc.). When conducting macrocognitive work
people have to devote time and effort to making sense of
their technology as well as making sense of the observed
or controlled world. A challenging aspect of trust in au-
tomation is that activities supporting the primary tasks are
necessarily understood and managed through the mediat-
ing artifact—that is, the sensors, displays, computers, and
so forth. Figure 3 (below) presents the most straight-
forward combination of the Data/Frame and Flexecution
models specifically tailored to express the dynamics of
trust in and reliance on automation.

The Unified Model

Issues of trust reside in the interplay of sensemaking the
world and sensemaking the technology, whereas issues of
reliance reside in the interplay of flexecuting the work
and flexxecuting the technology. Sensemaking of the ob-
served/controlled world depends on sensemaking of the
technology. Flexecuting one's actions on the ob-
served/controlled world depend on the ability to flexexecu-
Putting the Integrated Model to Work

The integrated model has a real use: It enables us to chart paths in a cognitive task analysis, tracing the worker's attention as it moves from activity to activity in the cognitive work. And along with it, both trust and reliance can morph. There are many methods of task analysis, some dating to the early 1900s, that trace reasoning processes in order to generate task or hierarchical goal decompositions (see Crandall, Klein and Hoffman, 2006; Endsley, Bolte and Jones, 2000; Rasmussen, Pejtersen, and Goodsetin, 1994; Shepherd, 2001). Methods involve observing and measuring performance at work, and asking workers questions about what they are doing and why. The results are used to describe reasoning sequences in terms of cognitive categories of states, procedures, and goals (e.g., "observe," "decide," "act", etc.). These are concatenated into hierarchies of tasks and sub-tasks and their associated goals. (For a history of task analysis, see Hoffman and Militello, 2008.) Cognitive task analysis is widely used to inform the creation of intelligent systems, work methods, web sites, and interfaces (Diaper and Stanton, 2004; Hollnagel, 2003; Jenkins, et al., 2009).

None of the process tracing methods has language that unifies the analysis of macrocognitive work, the analysis of trust in automation, and the analysis of reliance on automation. Using the integrated model, protocols can indeed be coded in terms of activities such as "questioning the frame for making sense of the observed world while flexexecuting the interactions with the technology." A re-analysis of protocols of the reasoning of expert weather forecasters, originally collected by Hoffman, et al. (2006), has revealed interesting sequences and patterns, such as the tendency for preservation of a frame to be preceded by questioning the frame, as the model predicts. There are instances where action plans underwent major revision related to justified mistrust in the technology. There were many cases of sensemaking of the artifacts, especially understanding the weather radar. It might be assumed that if attention has to shift away from the quadrant of sensemaking the world—that is, attention shifts away from the primary task goals and has to focus instead on making sense of the technology—that the cognitive work would suffer due to distraction and increased mental workload. The re-analysis of the weather forecasting case suggests that this assumption may be incorrect. The forecaster's awareness of the capabilities and limitations of the technology, and methods for coping with such things as limited or sparse data, seem to mesh seamlessly as sensemaking of the observed world progresses. This hypothesis deserves further study.

The unification of the Data/Frame model of sensemaking and the Flexexecution model of replanning permits the analysis of macrocognitive work and simultaneously the analysis of the dynamics of trusting. A conceptual architecture of this sort is perhaps a necessary foundation for attempts at computational modeling at the work system level.

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References


Figure 1. 
The Data/Frame Model of sensemaking.

Figure 2. 
The Flexecution model of replanning.
Figure 3.
Combined Data/Frame and Flexecution models that express the dynamics of trust in and reliance upon automation.

Figure 4.
A model that integrates sensemaking of the observed/controlled world and sensemaking of the technology, with flexexecuting in the task work and flexexecuting with the technology.