Special Issue

Situation Awareness: Context Matters! A Commentary on Endsley

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The construct of situation awareness (SA) and Endsley's 1995 model of SA are considered in the context of the history of the struggle to determine the role of matter (situations) and mind (awareness) for both basic and applied cognitive science. This struggle is framed in terms of two alternative views of the underlying semiotic system. The dyadic view puts the focus on structures of mind. This view leads to a dualistic ontology in which mind and matter tend to be considered as two distinctive systems. The triadic view puts the focus on mind as a means for adapting to the functional demands of situations. This view leads to a monist ontology whereby mind and matter interact as a single system shaping human experience. As a result of Endsley's model, today the debate is framed in terms of SA.

Keywords: situation awareness, topics, cognitive work analysis, methods, cognitive systems engineering, naturalistic decision making

Although the term *situation awareness* (SA) is relatively new, the questions that it raises about the nature of cognition are not new at all. It is important to realize that debates over the nature of mind (i.e., awareness) in relation to matter (i.e., situations) did not begin with the publication of the Endsley (1995) model. In fact, these debates can be traced back to the earliest days of recorded philosophy (e.g., Plato's *Myth of the Cave* is a prototypical example). More recently, debates about the relations between mind and matter have been prominent in the development of a science of mind (e.g., Benjafield, 2010). Today, the question is far from settled, and in fact, the question has broadened beyond a focus on individual people to include speculations about the potential for thinking machines (e.g., Newell & Simon, 1972; Wiener, 1948; Winograd & Flores, 1986) and for sensemaking in sociotechnical organizations (e.g., Hutchins, 1995a; Weick, 1995). The goal for this commentary is to place the construct of SA into the larger context of applications of cognitive science to the design and management of sociotechnical systems.

With respect to current discussions of SA, I believe it is useful to compare two paradigmatic views of cognition that have roots in the field of semiotics (i.e., the science of signs or meaning making). The history of cognitive science has been a continuous struggle between two views of the underlying semiotic system. As illustrated in Figure 1, one paradigmatic view frames questions about cognition in terms of a dyadic semiotic system, and the other frames questions about cognition in terms of a triadic semiotic system.

These different semiotic frames suggest different models of cognition, as reflected in Figure 2. The dyadic semiotic frame tends to lead to models that treat cognition as a collection of processes that can be localized as internal stages or modules within an agent. (Note that I use the construct of *agent* in the most general sense, so that a team, an organization, or a computer might be considered an agent.) For example, the dyadic perspective would tend to frame questions about experience and learning in terms of data storage processes (i.e., memory, knowledge, the engram). This view typically represents memory functions as specific stages (i.e., boxes) in an information-processing (IP) system (e.g., Kantowitz & Sorkin, 1983; Wickens, Lee, Liu & Gordon-Becker, 2004). In the dyadic paradigm, *meaning* is synonymous with *interpretation*, referring to a *state internal to the agent*.

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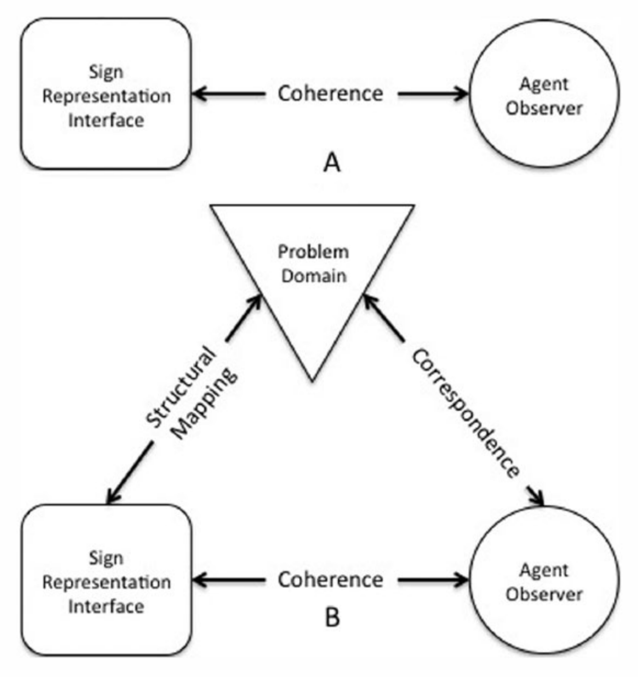

Figure 1. Illustrations of two perspectives on semiotics are shown. The top image (A) represents a dyadic perspective that originated with Saussure. The bottom image (B) represents a triadic perspective that originated with Peirce.

The triadic semiotic frame suggests models that treat cognition as a function that is distributed over an agent and its ecology. For example, the triadic perspective frames questions about experience and learning in terms of dynamic, distributed relations between an agent and its ecology (e.g., remembering, attunement to invariants, resonance). The triadic model uses a tuning-fork metaphor whereby learning is seen as a resonance or coordination of internal structure (e.g., associations in a neural network) with external structure (e.g., physical or social events; E. Gibson, 1969; Rumelhart & McClelland, 1986). This model provides a frame to ask how a cockpit remembers rather than how a pilot remembers (Hutchins, 1995b). In this context, the physical layout of the space and properties of tools are considered components of the cognitive system (Hutchins, 1995b). In the triadic paradigm, *meaning* is defined in terms of *functional significance or utility*. Thus, meaning is an emergent property of the agent-ecology dynamic. J. Gibson (1979) introduced *affordance* as a construct to represent this sense of meaning, reflecting the opportunities for and consequences of actions for a specific agent in a specific ecology—independent of whether the agent recognizes or chooses to pursue those opportunities.

The next sections draw from the history of psychology to illustrate how the debate between dyadic and triadic approaches has shaped perspectives on both basic and applied cognitive science. Then I will attempt to situate Ensley's (1995) model and to assess its impact and significance within the historical context.

STRUCTURALISM VERSUS FUNCTIONALISM

In the beginnings of psychology in the United States, there was a debate about whether it would be best to frame questions around the "structures" of mind or the "functions" of mind (Angell, 1907; Titchener, 1898). In essence, *structuralism* involved viewing mind as an object of study, apart from the physical and social ecology. In contrast, *functionalism* involved viewing mind as a capacity for adapting to the physical and social ecology.

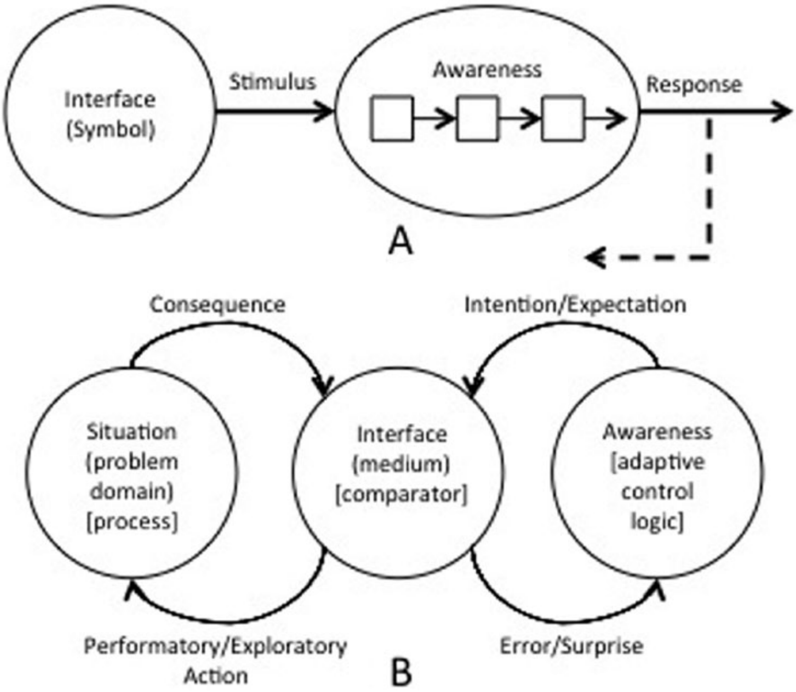

Figure 2. Two images of a cognitive system are shown. The top image (A) illustrates a model based on a communication channel metaphor consisting of a series of information-processing modules internal to an agent. The bottom image (B) shows a closed-loop dynamical system that emphasizes the adaptive coupling between situation and awareness in which each is simultaneously being constrained by and constraining the other.

An example that R. Watson (1978) uses to illustrate the structuralism perspective might be useful. A straight stick that is partially submerged in water will appear to be bent, even though there is no actual bend in the stick. Structuralism focuses on the experience of the bent stick, with little concern for the physical stick. Thus, structuralism focuses on the "percept" as the object of study and asks why it looks bent—perhaps starting with the retinal image. Borrowing from Mace (1977), one could say that structuralists are interested in *why we see the stick the way we do*. Early structuralists, such as Titchener, saw introspection as the primary method for exploring the fundamental elements of mental chemistry from which our percepts are constructed.

In contrast, functionalists were interested in the relation between the beliefs about and uses of the stick and the actual shape of the stick. Again, borrowing from Mace (1977), one could say that functionalists were interested in *how we come to know the stick as it is* or how we learn to use the stick successfully (e.g., to spear fish). Functionalists were interested in the closed-loop coupling of perception and action that enabled people to discover and adapt to the way the world is (e.g., Dewey, 1896).

Thus, structuralism was compatible with the dyadic semiotic system view, focusing on the elements and processes *inside the agent* that combine to determine the isolated human experience of the *bent stick*. Functionalism, however, adopted a triadic semiotic system view that included the straight stick as the source of the information, the percepts resulting from interaction (e.g., bent when partially in water), and the ultimate beliefs about the stick that result from these interactions (e.g., that the stick is actually straight).

Historically, structuralism, as advocated by Titchener, eventually fell from favor, due to the heavy reliance on the introspective method. In the United States, *behaviorism* temporarily became the dominant paradigm for experimental psychology. In essence, behaviorism took functionalism to an extreme position in which focus shifted exclusively to contingencies on the *situation* side of the triadic semiotic system, eliminating mind or *awareness* as a construct of interest (J. Watson, 1913). For this period of time, experimental psychology in the United States lost its mind.

Outside the United States, however, there was less pressure for researchers to conform to the dominant behaviorist paradigm. Two notable voices who continued to pursue issues of awareness and whose works presage later insights associated with SA were Bartlett (1932) and Piaget (1923/1959). Bartlett's work on memory illustrated the impact of the cultural context on how people understood and remembered stories. Bartlett acknowledged the triadic semiotic dynamic by choosing the verb *remembering* as the title for his book, rather than the noun *memory*, which was preferred by structuralists.

Piaget (1923/1959) also emphasized the functional dynamics of mind associated with cognitive development with constructs such as schema, assimilation, and accommodation. *Assimilation* represented the process in which a *schema* formed by previous experiences would guide initial actions and expectations in novel situations. *Accommodation* reflected how feedback resulting from the consequences of actions (e.g., error) and expectations (e.g., surprise) would lead to new schemas that were better tuned to the demands of the novel situations.

CYBERNETICS AND THE REEMERGENCE OF MIND

In the years during and following World War II, there was enormous progress in the development of communication systems, automatic control systems, and computing systems. A result was that machines could now accomplish many functions that had been done exclusively by humans in the past (e.g., tracking a moving target, predicting future states of the target, or following a complex set of instructions). Inspired by theories of information and control (e.g., Wiener, 1948), psychologists began to reconsider issues of mind using communication channel and computer metaphors (e.g., Miller, Gallanter, & Pribram, 1960; Neisser, 1967). These metaphors were reinforced by developments in linguistics that formalized language in terms of formal rules (e.g., grammars) for symbol processing (Chomsky, 1965).

These developments in technology and linguistics inspired the IP paradigm, in which mind was equated with symbol processing and cognition was modeled as a series of IP stages that were analogous to modules or programs within a computer. This model led to an explicitly dyadic semiotic perspective in which the input was treated as arbitrary (there was no interest in the stick itself), and the focus of science was on the transfer functions, programs, or rules within each of the component processing stages.

As with structuralism, programs within the IP paradigm involved the assumption that research on illusions, capacity limitations (e.g., bandwidth), and violations of normative logic would provide the best insights into the internal constraints associated with each processing stage—encoding/perception, attention/memory, decision making. Within the IP paradigm, researchers adopted the block diagram to represent the cognitive system, with individual boxes representing the distinct component stages in the agent's head. Then researchers picked a box and began experimentally drilling down to uncover the internal constraints associated with each box. Thus, the pendulum swung back from an extreme functionalism that trivialized the awareness component of the triadic semiotic (i.e., behaviorism) to an extreme structuralism that trivialized the situation component of the triadic semiotic (IP), resulting in a decidedly dyadic perspective.

The early development of engineering psychology and human factors was intimately linked to the development of the IP paradigm. Researchers sought to characterize the limitations of human agents so that these limitations could be taken into account when designing work systems. In fact, human factors researchers marketed their services by emphasizing that humans tended to be the weakest link in these systems. For example, Kantowitz and Sorkin (1983) wrote,

> Indeed, many human factors analysts believe that minimizing human error is the

> primary goal of any human factors design. If people never made errors, there would be little need for a science of human factors. (p. 30)

Through the 1970s, the IP paradigm emerged as the dominant paradigm for experimental psychology and its application through engineering psychology and human factors. However, there were several significant voices who were concerned about the consequences of trivializing the situations and who advocated for a triadic semiotic perspective. Most notable among them were Brunswik (1956) and J. Gibson (1979). Both advocated for an *ecological psychology* in which the situation (i.e., ecology) was included as an essential component within a closed-loop dynamic.

Brunswik (1956) explicitly recognized the triadic semiotic system in his lens model, in which the information for judgments about the world was examined from the perspective of both internal constraints associated with the agent (*cue utilization*; e.g., how the agent sees the stick) and external constraints associated with the situation (*ecological validity*; e.g., how the stick actually is). In the lens model, ultimate *achievement* is a joint function of the agent's weighting of evidence and the structural mapping of that evidence within the situation. Additionally, Brunswik's emphasis on *representative design* of experiments emphasized the importance of taking the situation into account when designing empirical experiments. In describing Brunswik's approach with respect to implications for applied cognitive psychology, Goldstein (2006) wrote,

> He warned against replacing the functionalist study of organisms' adjustment to the world with a focus on quasi solipsistic "encapsulated" organisms in isolation. Indeed, Brunswik implied that such a trend had already gone too far when he wrote, "Psychology has forgotten that it is a science of organism-environment relationships, and has become a science of the organism" (Brunswik, 1957, p. 6). In this comment he presaged the critique of cognitive science to be leveled some 35 years later by Donald Norman (1993), who caricatured its nearly sole focus on internal processes as resulting in a theory of cognition as "disembodied" and cut off from the world in which it is embedded. (p. 14)

J. Gibson's (1979) adoption of a triadic perspective seems to have been motivated, in part, by the challenge of developing training programs to teach pilots to land during World War II. Classical texts on perception tended to focus on illusions and seemed to suggest that the perceptual judgments necessary for consistently safe landings were well beyond the perceptual abilities of humans. However, Gibson learned from expert pilots (Langewiesche, 1944) that angular position of the focus of expansion with respect to the horizon directly specified relative motion of the aircraft in relation to a desired glide path. Working with colleagues in mathematics and physics, he quantified the properties of optical flow fields related to aircraft motion (Gibson, Olum, & Rosenblatt, 1955). In addition to the construct of affordance, mentioned earlier, J. Gibson's (1979) hypothesis of *direct perception* showed that structural mapping from representations (e.g., optical flow fields) to situation or event dynamics (i.e., affordances) made it plausible that people could learn to skillfully pilot aircraft. In other words, J. Gibson hypothesized that there was ample information available for people to explore and learn to *see the world as it is.*

Another notable voice advocating for a triadic framework for cognitive science was Neisser (1976). This fact is a bit ironic, because Neisser (1967) was instrumental in formulating the dyadic IP paradigm. However, in his later book, Neisser (1976) explicitly recognized a triadic framework with his *perceptual cycle.* The closed-loop, three-component cycle is essentially the same as the triadic semiotic system illustrated in Figure 1. Numerous people have acknowledged Neisser's perceptual cycle as fundamental to the articulation of the construct of SA (e.g., Adams, Tenney, & Pew, 1995; Smith & Hancock, 1995).

ADAPTING TO COMPLEXITY

Despite the concerns raised by proponents of ecological psychology, through much of the

1980s, the IP paradigm reigned supreme. Then the larger scientific zeitgeist began to change. In linguistics, Lakoff and Johnson (1980, 1999) put language back into an ecological context with the hypothesis that semantics might be grounded in experiences in the physical world through metaphor. For example, they wrote, "What we are saying about grounding is that we typically conceptualize the nonphysical *in terms of* the physical—that is, we conceptualize the less clearly delineated in terms of the more clearly delineated (Lakoff & Johnson, 1999, p. 59).

In cultural anthropology, Suchman (1987) offered the hypothesis that

> however planned, purposeful actions are inevitably *situated actions*. By situated actions I mean simply action taken in the context of particular, concrete circumstances. . . . The circumstances of our actions are never fully anticipated and are continuously changing around us. As a consequence our actions, while systematic are never fully planned in the strong sense that cognitive science would have it. Rather, plans are best viewed as a weak resource for what is primarily ad hoc activity. (p. viii; italics in the original)

Hutchins (1995a), another anthropologist, would later be even more direct in his criticism of the dyadic framework associated with the IP paradigm:

> Having failed to notice that the central metaphor of the physical-symbol-system hypothesis captured the properties of a sociocultural system rather than those of an individual mind, AI and information-processing psychology proposed some radical conceptual surgery for the modeled human. The brain was removed and replaced by a computer. The surgery was a success. However, there was an apparently unintended side effect: hands, the eyes, the ears, the nose, the mouth, and the emotions fell away when the brain was replaced by a computer (p. 336)

The scientific zeitgeist at the end of the twentieth century was also impacted by the development of nonlinear dynamical models that caused people in the physical (e.g., Shaw, 1984) and biological (e.g., Langton, 1989) sciences to look at the world in new ways that challenged conventional scientific assumptions about causality and reductionism (e.g., chaos, fractal geometries, self-organization). For example, Kugler and Turvey (1984) suggested self-organization in social insects as a useful metaphor for understanding skilled motor coordination. Models of self-organization illustrated how the behaviors of social insects simultaneously shaped and were shaped by their physical ecology (e.g., the creation of a pheromone field—a kind of stimergy) in such a way that highly organized structures (e.g., elaborate nests) emerged. Consistent with Suchman's (1987) intuitions, mentioned earlier, there was no need to hypothesize a central agency or an underlying plan to account for the organization. Rather, macrolevel organization emerged as a result of dynamical closed-loop interactions at the microlevel.

Changes were also happening in the field of computer science. The development of distributed parallel processing and neural networks opened up new ways to think about computations (e.g., Rumelhart & McClelland, 1986). These new computer architectures were no longer controlled by prepackaged sets of instructions or rules. Rather, the neural networks were *trained* through a closed-loop iterative process of exposing the networks to exemplars with feedback relative to the concepts that they represented. The classical block diagrams that represented the modular design of classical computer systems no longer fit this form of computation. Rather, the image began to emerge of fields or networks of elements that would self-organize and adapt to the training contingencies.

For those interested in applied cognitive science, the practical value of advanced computing technologies was coming under increasing scrutiny. Although there is little doubt that advances in information technologies led to efficiencies and reduced certain sources of error, negative side effects and new sources of errors also became apparent (e.g., Billings, 1997). In part, the problems could be linked specifically to how the new technologies were implemented or designed (e.g., Sarter, Woods, & Billings, 1997), and in part, the problems stemmed from the increases in the complexity of the work that these new technologies enabled (e.g., Perrow, 1984).

This scrutiny led to increased awareness of the limitations of computers and increased appreciation for the capacity of humans for dealing with the unanticipated variability that was an inevitable product of complexity. Consistent with Suchman's (1987) intuitions, people began to appreciate that it was impossible for rule-based programs to anticipate all contingencies. Thus, rule-based approaches (e.g., programs or fixed procedures) were increasingly seen as *brittle*, and the creative problem-solving ability of humans was recognized as a valuable resource. For example, Hollnagel and Woods (1983) wrote,

> Through increased automation, the nature of the human's task has shifted from an emphasis on perceptual-motor skills to an emphasis on cognitive activities, e.g., problem solving and decision making. (p. 384)

Woods (1991) explicitly recognized the need for a triadic semiotic framework:

> Performance is a joint function of the nature of the cognitive demands posed by the domain, the nature of the representation of that domain available to the problem solver and the characteristics of the problem solving agent. (p. 175)

To recognize the shift in emphasis from the human as the weakest link (e.g., a source of error) to the human as a valuable asset (e.g., a creative problem solver), a new label for applied cognition emerged. The *human factors* label was replaced with the label *cognitive engineering* (Norman, 1986; Rasmussen, 1986) or *cognitive systems engineering* (Rasmussen, Pejtersen, & Goodstein, 1994).

Rasmussen (1986) outlined a comprehensive framework for cognitive engineering that explicitly recognized the triadic nature of the underlying semiotic dynamic. He introduced the *abstraction hierarchy* as a framework for describing the situation component of the triadic system with reference to its role within the overall functional dynamic. In the abstraction hierarchy, the physical and organizational constraints of work domains are situated within the context of functional goals and values. This context helps to make the functional means-ends constraints and the associated implications for the interface (i.e., representations) and the awareness (i.e., abilities) components of the triadic dynamic explicit. In contrast to the emphasis on activity with traditional task analysis, the abstraction hierarchy emphasizes the functional constraints that shaped the field of possibilities. Thus, *work analysis* took priority over *task analysis* as an approach to ground the construct of meaning in the work domain (Naikar, 2013; Vicente, 1999).

Rasmussen (1986) introduced the *decision ladder* and the associated distinctions of *knowledge-based, rule-based*, and *skill-based* processes (SRK) as a way to characterize the awareness component of the triad relative to the other two components (situation and interface). It is important to note that the SRK distinctions refer not to distinct internal processes but rather to qualitatively different types of *achievement* (à la Brunswik) based on structural mappings from the situation to the interface (i.e., signal, sign, or symbols) and the sensitivity (e.g., cue utilization) of the agent to those relations.

Thus, within the triadic approach, it became clear that the quality of performance (e.g., the SRK nature of processing) depended critically on how the constraints in the work domain were represented in the interface. For example, Woods and Roth (1988) write,

> The difficult and critical [display] design problem . . . is what is a useful partial isomorphism between the form and the content of a representation. To accomplish this the designer first must determine what constraints between the symbol and what is symbolized should be established, and what techniques for analyzing the domain semantics can specify these constraints. . . . A second design problem is how to map the chosen aspects of domain structure and behavior into characteristics of the representation so that the domain semantics are directly visible to the problem solver. (p. 29)

Rasmussen and Vicente (1989) adopted the label *ecological interface design* (EID) to characterize the triadic approach to interface design, acknowledging the intellectual debt to J. Gibson's (1979) earlier intuitions about the possibilities for direct perception. The implications of EID for interface design are more fully explicated in two recent texts (Bennett & Flach, 2011; Burns & Hajdukiewicz, 2004). Also, Leveson (1995, 2011) has extended the insights of cognitive engineering to consider the implications for the design of software to support adaptation in complex work domains.

Another impact of advanced technologies on the nature of work was the increasing opportunities and demands for cooperation among people. Thus, it became necessary to consider sociotechnical organizations as the cognitive system (e.g., Hutchins, 1995a; Weick, 1995). Researchers began to recognize that just as rule-based programs were brittle in the face of complex problems, so too were highly centralized, hierarchical organizations. Observations of high-reliability organizations helped researchers to recognize the value of self-organization for robust adaptation to complex risks (e.g., Rochlin, La Porte, & Roberts, 1987).

ASSESSING THE CURRENT STATE OF THE ART

It is important to understand that the preceding account of history is biased by my own beliefs with respect to where both basic and applied cognitive science should be going. If it is not yet apparent, I have a strong bias and I have long argued for the triadic paradigm (e.g., Flach, Hancock, Caird, & Vicente, 1995). Yet, despite the trends described in the previous section, I think the case could be made that the dyadic perspective is still a powerful force in cognitive science and that the IP paradigm remains the dominant framework (e.g., in the texts commonly used to train human factors engineering, such as Wickens et al., 2004). Also, increased emphasis on neuroscience and neuroergonomics (Parasuraman & Rizzo, 2007) could be evidence of a move toward an increasingly dyadic perspective, wherein the focus is on biological structures inside the agent's nervous system rather than on the larger functional dynamics.

Thus, I believe that the field is in the midst of a paradigmatic struggle between the dyadic and triadic perspectives. Table 1 summarizes some of the key distinctions between these two perspectives, and Figure 3 suggests that this struggle is not simply a debate between alternative models. Rather, this is a debate involving fundamental metaphysical assumptions about the nature of mind (ontology) and the role of science (epistemology). The dyadic semiotic system reflects assumptions that mind and matter are fundamentally different kinds of things, requiring separate sciences. Thus, it reflects an ontological and epistemological dualism. On the other hand, the triadic semiotic system reflects a monist ontology whereby the phenomenon of human experience is a joint function of mind and matter.

Today I believe there is a fog of war associated with this struggle between different metaphysical frameworks in which people use the same words (e.g., *meaning*) to refer to very different things (e.g., interpretation versus functional significance). Unless the underlying paradigmatic assumptions are made explicit, there is likely to be confusion, where often there are illusions of agreement or disagreement, where arguments will endlessly circle the same tree without convergence, and where empirical experimental results often lead to contradictory conclusions.

Thus, in taking stock of the Endsley (1995) SA model, an important question is whether the model and associated writing helps to bring clarity or whether it adds to the confusion associated with this paradigmatic struggle. From the very beginning, I have had mixed feelings about the construct of SA (Flach, 1994, 1995). These mixed feelings are not specifically directed at Endsley's work but, rather, reflect a broader concern about the state of the art, relative to my beliefs about the value of a triadic perspective. Rather than targeting Endsley's work specifically, I would like to also consider Klein's (1993) recognition-primed decision (RPD) model. In this way, I want to emphasize that I think it is a mistake to frame this discussion as a debate between models (e.g., Endsley's SA model vs. Klein's RPD model vs. Weick's sensemaking model). The important questions are at the metaphysical level, and it is important to make them explicit before we can have productive discussions with respect to the various models.

TABLE 1: Attributes of Dyadic and Triadic Semiotic Perspectives

Variable	Dyadic	Triadic
Metaphors	Communications system; symbol processing computer, rule-based grammars	Tuning fork, adaptive control system, self-organization of social insects
Meaning	Interpretation; exclusive property of mind/awareness	Functional significance; emergent property of the interaction between mind/awareness and matter/situation
Explanatory model	Causal (e.g., particle collisions)	Circular Dynamics/Emergence (e.g., field interactions)
Organizational model	Hierarchical centralized control	Distributed adaptive control
Normative models	Logical, based on validity of the reasoning process (i.e., form of the argument)	Pragmatic, based on the consequences of actions
Basis for generalization	Structuralism: Fundamental elements; properties of the whole determined by elements	Functionalism; holistic dynamical constraints; elements both shape and are shaped by the dynamical field
Naturalistic methods	Task analysis to describe physical and mental activities of agent.	Work analysis to describe means-ends constraints of situations.
Experimental methods	Emphasis on internal validity in order to isolate fundamental elements from situational confounds.	Emphasis on external (ecological) validity to ensure that the dynamics of the experimental context are representative of the natural situations.

A TIME OF CONTRADICTIONS

Let me begin by saying that I believe that Endsley and Klein both share my belief that a triadic semiotic perspective is necessary to understand the phenomenon of SA. Both researchers demonstrate a clear and consistent commitment to connect their research with human experience in the context of complex work domains in order to inform design and improve system performance. Both researchers recognize the value of observations in natural work settings and the importance of explicitly linking empirical work with the work domain through representative design of experiments (e.g., in carefully designing Situation Awareness Global Assessment Technique questions to highlight the semantics of the target work domain). Finally, there is a clear emphasis in the work of both researchers on human capabilities and expertise and the potential contributions of humans to increasing the resilience of sociotechnical systems. This approach is in contrast with the emphasis on human limitations (e.g., workload) of traditional human factors approaches. In sum, it seems very clear to me that the phenomena of interest to both Endsley and Klein are the dynamics of triadic semiotic systems.

My initial concerns about SA as articulated by many human factors psychologists was that the construct would be used to support conventional wisdom with respect to the IP paradigm and the associated methods based on isolating specific internal stages of processing (Flach, 1994). I was concerned that the work was being marketed under a new label (*SA* replaced *workload*) but that the work was being framed using the same dyadic perspective of the IP paradigm. My concern with both Endsley's (1995) SA model and Klein's (1993) RPD model is that, in contradiction to their intentions, both use representations for their models that invite dyadic interpretations consistent with the IP paradigm.

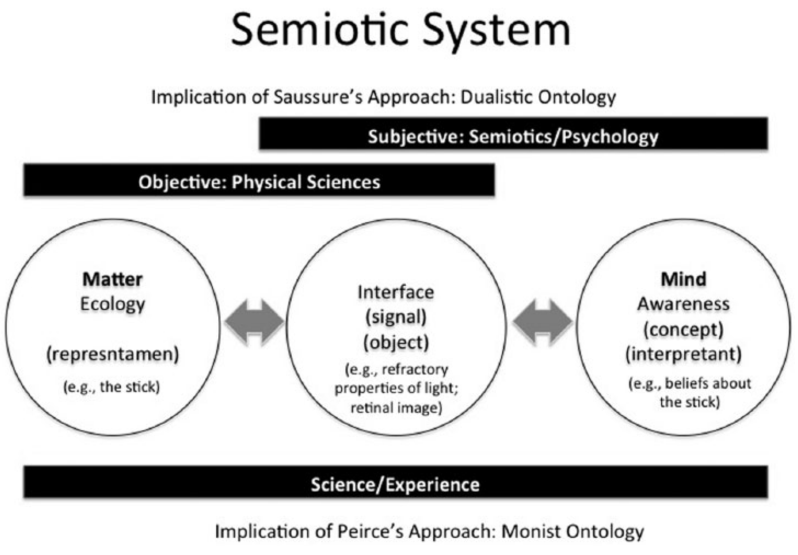

Figure 3. This diagram illustrates that the choice of semiotic framework implies both ontological and epistemological assumptions about the nature of a phenomenon and the implications for science. The dyadic semiotic model implies a dualistic ontology and distinct sciences or epistemologies. The triadic semiotic model suggests a monist ontology and a unified science for addressing both situations and awareness.

For example, in Figure 1 of Endsley's (2015) target article, the shaded box (containing the three levels of SA, the decision process, and the performance of actions process) is shown as distinct from the task/system factors on one side and the individual factors on the other side. I would like to take this as evidence that Endsley is explicitly recognizing the underlying triadic semiotic dynamic with these three distinct regions. And further, by placing the box containing the SA and action components in the middle, she is recognizing the significant role of interface representations in shaping the cognitive dynamic, consistent with the intuitions of Woods (1991), Rasmussen and Vicente (1996), and many others (e.g., see Bennett & Flach, 2011).

However, many have interpreted Endsley's representation of SA in the context of the IP paradigm, where the boxes represent internal stages of processing. Thus, the different levels of SA could be (and often are) interpreted as specific internal stages of processing. Endsley (2015) acknowledges the confusion that this interpretation creates when discussing Fallacy 2 (the model is a data-driven IP model), Fallacy 6 (SA is all contained in working memory), and Fallacy 7 (the SA model represents only a Cartesian "in-the-head" view of the world and does not encompass the wider sociotechnical environment).

Thus, the block diagram representation that Endsley chose for her model may actually contribute to the confusion. Not only does it invite criticisms based on false interpretations associating the model with conventional IP models, as noted in her target paper, but the model may also be used inappropriately to confirm conventional assumptions associated with the dyadic IP paradigm, leading to misapplications and generalizations. In fact, the reason for the large number of citations to the Endsley model may be that it allows people from both sides of the paradigmatic debate to project their assumptions onto the model. Thus, the large number of citations may not be correlated with what I think is the signal (i.e., that triadic semiotic perspectives are demanded), but rather, it may reflect the noise (i.e., that the term *SA* is ambiguous, meaning different things to different people as a function of their different assumptions about the underlying semiotic system).

I think there are similar problems with Klein's RPD model. Similarly to Endsley, Klein (1993) used a classical block diagram to represent his model, and the diagram suggests that all the feedback loops are closed inside the head, rather than through situated action, inviting people to think about the processes associated with RPD as being "in the head." For example, Kahneman (2011) uses an internal-agent metaphor to talk about the processes associated with RPD or intuitive decision making (i.e., System 1). This type of pedagogy reinforces the dyadic assumptions of conventional IP approaches, rather than challenging them.

Consider Klein's (2003) account of the fire commander who *intuitively* decides to order his men to leave a burning building only moments before the floor collapses. Although the commander attributed his intuitions to ESP, careful analysis by Klein based on retrospective interviews with the commander suggests that the intuitions were based on numerous sources of information/feedback (e.g., the response of the fire to the actions of directing the hoses; the direction of the radiant heat flow; the muffled sounds of the fire). From a dyadic perspective, Klein's observations are evidence for subconscious processing internal to the commander's mind (e.g., implicit knowledge). This interpretation reinforces dyadic IP models of cognition.

From a triadic perspective, Klein's (2003) observations are evidence that the commander's intuitions were grounded in the inconsistencies between the external cues (emanating from a fire on the lower floors), actions (directing the hose), and the expectations associated with both the commander's initial hypothesis (that the fire was on the upper floors) and his actions based on that hypothesis. This interpretation of Klein's example suggests an abductive style of reasoning consistent with triadic models of semiotics (Peirce, 1982) and consistent with Piaget's (1923/1959) constructs of assimilation and accommodation. Thus, the closed-loop coupling of hypothesis, action, and perception/feedback allowed the commander to correct an initial impression and to come to see the fire as it actually was. The fact that the commander could not initially articulate the reasoning might reflect the fact that the decision emerged from the triadic semiotic dynamic, as opposed to being an explicit rule embedded in an internal procedure. Indeed, the interaction may have been skill based in that the link between the information and the action/decision did not require conscious awareness, as is often the case with perceptual-motor skills. A triadic closed-loop model extrapolated from Brunswik's (1956) lens model, such as proposed by Kirlik (1995), would be one way to model this dynamic.

Not only do the diagrams we choose to represent our models matter, but the words we choose also matter. Endsley (2015; Endsley & Jones, 2012) uses the term *goal-directed task analysis* (GDTA) to describe a methodology for discovering the "meaningful" constraints associated with a work domain. It seems very clear from the context that Ensley is using *meaningful* in its triadic sense (i.e., functionally significant). For example, she wrote,

> The concept of meaning is foundational to SA and the Endsley 1995 Model, along with the ability to determine what is meaningful for a given operational role which makes this approach stand out from approaches that talk about meaning, but offer no a priori way to determine it. (p. 14)

Unfortunately, Endsley (2015) fails to acknowledge the important distinction that other cognitive engineers have made between task analysis and work analysis (Naikar, 2013; Vicente, 1999). The point of this distinction is to do exactly what Endsley calls for: to establish an a priori basis for grounding the concept of meaning in the pragmatic operational demands of a particular work domain. By ignoring this important precedent in the literature, Endsley opens the door so that people who adopt a dyadic perspective will associate the "goals" as elements in the heads of individual agents rather than functional objectives and values associated with the work dynamic. I believe that by acknowledging the distinction between task analysis and work analysis, Endsley could instead amplify the signal with respect to the value of a triadic framework.

Other terminology that I believe adds to the confusion associated with the debate between dyadic and triadic approaches are terms such as *human centered* and *user centered* (e.g., Billings, 1997; Endsley & Jones, 2012). I think this terminology invites people to focus exclusively on the awareness component, implicitly suggesting a dyadic framework. Flach and

Dominguez (1995) suggested the term *use centered.* The term *use* is an attempt to emphasize that the functional dynamic includes all three components of the triadic semiotic system. Flach, Mulder, and van Paassen (2004) attempted to provide a counterweight to conventional tendencies to put SA in the head by calling for more attention to the construct of *situation*. In particular, they point to the insights that Gibson (1979) and Rasmussen (1986) offer for modeling the situation as a component within a triadic dynamic.

CONCLUSION

I would like to think that the popularity of Endsley's and Klein's models is evidence of growing acceptance of the triadic semiotic perspective. But I am afraid that the popularity might actually be evidence that the models have been articulated in ways that allow people on both sides of the paradigmatic struggle to claim the models as their own (or conversely to criticize the models). If my fears are justified, then the models are actually contributing to the confusion rather than clarifying.

As far as the paradigmatic struggle between dyadic and triadic perspectives, when the struggle is placed in the larger historical context, no one person should be given too much credit or too much criticism for driving or impeding progress toward a more productive resolution of the metaphysical debate. I believe it is not hard to trace elements of constructs like SA (that seem quite fresh and contemporary) to at least the beginnings of psychological science, if not farther back to fundamental philosophical debates (e.g., between Plato, Aristotle, and the Sophists; Pirsig, 1974).

Also, I fear that many of the contrasts that Endsley (2015) draws in the target paper in this issue between specific models are not productive. In some sense, I think Endsley is missing the metaphysical forest for the trees. Many of the models that she cites are attempting to frame questions about applied cognitive science as a triadic semiotic system. Also, most of the criticisms of the Endsley model are based on misinterpretations of her model as representing a dyadic framework. In this respect, this is a tempest in a teapot, where people who agree about the most important things are arguing over trivialities. Note, however, that these trivialities with regard to metaphysical debates may have nontrivial consequences with respect to the politics and funding of science.

With respect to the construct of SA, I think there is no doubt that the construct has definitely been a focal point for contemporary debates over the relations between mind (awareness) and matter (situations) and the implications for both basic and applied cognitive science. However, in the fog and friction of the contemporary debate, I think it is difficult for any contemporary researcher to determine whether the prevalence of this construct in the literature represents an approaching resolution of the paradigmatic struggle or whether it is simply symptomatic of the current confusion.

In sum, it seems clear to me that both Endsley's and Klein's work provides strong support for Peirce's (1982) triadic semiotic model. It seems clear to me that both share Peirce's desire to understand how awareness develops to support successful adaptations to situations. However, it is unfortunate that both chose conventional block diagrams to represent their models (and conventional labels like *task analysis* and *human centered*). Historically, such representations have been aligned with the decidedly dyadic view associated with the IP paradigm. The boxes in these models strongly suggest that the components represented can be isolated as structures (objects) located inside the agent (Stappers & Flach, 2004). Representations matter! I fear that the representations used by both Endsley and Klein are misaligned with their intentions, interfering with their ultimate message and thus contributing to the fog and friction associated with the ongoing struggle to establish a paradigm for a cognitive science that matters.

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