Submitted to:

12th International Command and Control Research and Technology Symposium

Track 4: Cognitive and Social Issues

Suggested Topics: Decision-making Sense-making Collaboration

"More than Information Overload: Supporting Human Attention Allocation"

- DRAFT -

Lindsley G. Boiney, Ph.D.

MITRE Corporation

202 Burlington Rd

Bedford, MA 01730-1420

(781) 271-2640

lboiney@mitre.org

Keywords:
Attention
Situation Awareness
Decision Making
Decision Support
Command and Control
Interruptions
Collaboration

Abstract

Human attention, rather than information, has become the critical resource for situation awareness (SA) and decision-making in many command and control (C2) environments. The impact of new information technologies and the evolving nature of missions to demand richer and more complex interactions (joint, coalition, inter-agency) have resulted in new approaches to C2 that place unique demands on human cognition and social processes. These demands go well beyond the need to process increased quantities of information. Pressures on human attention are intensifying as operators must regularly multi-task, accommodate frequent interruptions, attend to numerous information sources and modalities, and scan for unanticipated events. Distributed collaborators must dedicate additional time and attention to team awareness and shared SA, repeatedly recalibrating priorities and roles.

Good information is <u>necessary but insufficient</u> for decision making: information must also be *attended t*o for SA to develop. Technologies such as information filters, alerts, and peripheral displays could potentially support attention allocation. But when applied without a systematic understanding of the domain's demands, technology may unintentionally contribute to overload, attentional tunneling, or ill-timed interruptions. This paper draws from direct field observation of attention allocation behaviors in C2 environments, as well as existing theories of attention, to develop a systems framework that specifies distinct drivers of attention challenges, their interrelationships, and the interactions with information management processes and subsequent decision processes. This framework will enable both characterization and tailored technological support of a domain's attention challenges to improve SA and decision making performance.

Introduction

A recent MIT report on network centric warfare identified *attention allocation* as one of the eight top issues for human supervisory control (Mitchell, Cummings, and Sheridan, 2004). The changing nature of missions, the impact of new information technologies, and the need to work in richer contexts (joint, coalition, and inter-agency) have resulted in new approaches to command and control that place unique demands on both human cognition and social processes. These demands go well beyond the need to process increased quantities of information. Attention pressures are intensifying as operators must regularly multi-task, accommodate frequent interruptions, attend to numerous information sources and modalities, and scan for unanticipated events and threats. These challenges for attention allocation arise across all military services and in Homeland Security and Emergency Management domains. They are being keenly felt in distributed operations and at the tactical edge where systems must gain operator attention without distracting them unduly from current tasking. Human attention is also critical for air traffic management and control. A study of aircraft accidents showed that the most frequent cause of SA-related errors was attention management: the necessary information was *present but not attended to* by the operator (Jones & Endsley, 1996). Human attention, rather than information, has become the critical C2 resource for situation awareness and decision-making.

Operators increasingly find that their roles require them to collaborate on distributed teams. This places additional demands on their attention as they strive to develop sufficient awareness of other team member activities, needs, status and load levels to effectively coordinate and synchronize activities. The challenge is not only to coordinate across distance; as missions involve more joint, coalition, inter-agency and other boundary-spanning participation, the challenges to collaboration include aligning potentially conflicting sub-goals, recognizing differences in culture and incentives, and recalibrating dynamic priorities. It is not surprising then that one of the other top net-centric challenges identified in the MIT report was in fact distributed decision-making. Our framework will show the myriad ways that collaboration processes interact with – and can either disrupt or support - the attention allocation system.

Human System Integration and Attention Allocation

Many technologies such as information filters, visual or auditory alerts, checklists, and peripheral displays have the potential to support attention allocation. But when applied without a systematic representation and understanding of the attention demands in a C2 environment, a technology may unintentionally contribute to overload, attentional tunneling, or ill-timed interruptions. For instance, insufficiently flexible filters can lead to missed information or tunnel vision when the environment shifts unexpectedly. Indiscriminate alerts can distract or interrupt at critical times, and inappropriate cues or displays can contribute to misprioritized attention or information overload.

To appreciate the broad range of challenges for human-system attention management and the way people actually interact with technologies under stressful conditions, it is very valuable to experience immersion in complex C2 environments. The author engaged in three separate weeks of direct over-the-shoulder observation of experienced operators as they carried out tasks in an experimental Coalition/Combined Air Operations Center (CAOC). This direct observation was enriched and integrated with dozens of in depth face-to-face operator interviews, as well as quick questions to operators during breaks or lulls in the activity if they signaled that this was permissible. Due to the classified nature of the experiment, data collection was strictly limited to hand written (and appropriately sanitized) transcriptions of the operators' verbal comments (via phone, headsets, or person to person), chat messaging, desktop application usage, physical movements and gestures, and outward expressions of emotion or stress.

In many cases, an attentional challenge that an operator had described during an interview could be directly observed later on for validation or clarification; conversely a directly observed behavior could often be raised during a follow up interview to better understand the cognitive and/or social motivations behind that individual or team behavior. (On other occasions there was no such opportunity, and clearly many interesting aspects of the attention allocation process may have been missed due to the inability to instrument the environment.) To minimize subjectivity, only those operator behaviors, needs, and workarounds that were repeatedly observed and supported by operator commentary will be described. (See Boiney, 2005 for some additional detail on a subset of the data.) These ethnographic observations are provided in the following sections to motivate and support the attention allocation framework development.

Developing a Framework for Attention Allocation

The ultimate goal in providing this systems view of attention allocation is to bridge the often fatal gap between information *availability* and timely, well-informed *decisions*. There are countless well-publicized examples in which relevant information was present and accessible yet not reflected in the decision makers' situation awareness, including the tragedies of September 11th and aspects of Hurricane Katrina. There are several distinct reasons for good information to fall into the "attention gap" and never inform decision making, including excessive distractions, getting lost in an overwhelming deluge of data, insufficient or excessive trust in particular information sources, confusion over priorities, failures of communication or memory, or critical interruptions.

Our framework will therefore flesh out the Attention Allocation (A2) system that lies *between* the Information Management system and the Decision Making system, developing a better specified and more *integrated* characterization of the attention support needs within a domain, thus enabling technology design and application that is appropriately tailored for improved SA and decision making performance. There are essentially three interrelated subsystems: the Information Management system, the Decision Making system, and the Attention Allocation system. Each of these subsystems is comprised of both technological and human components.

Information Management and Decision Making Systems

The Information Management system gathers data from the environment, fuses and transforms it as appropriate, and generates *information* as its output. The information output has multiple characteristics, including its distribution *rate*, its *quality* (e.g., timeliness, level of uncertainty, trustworthiness, and accuracy), and its transmission *modality* or modalities (text, graphics, audio, or tactile sensation).

The Decision Making system takes that information as a key input to be combined with human cognition, domain expertise, and understanding of the problem context.

Additional synthesis, analysis, and other metacognitive processes (as well as requests for additional information) may be needed for *sensemaking* and the development of sufficient *situation awareness* for effective decision making – the ultimate goal.

The A2 system is strongly influenced by complexities in the decision making environment such as dynamic priorities, distractions, interruptions, and the need to rapidly form trustworthy (yet perhaps unanticipated) communities of interest. As we shall see, the A2 system can be strongly affected by collaboration processes and will therefore be influenced by distinct social and behavioral factors in addition to cognitive demands. What people *actually* pay attention to depends on far more than what they are told is relevant or important.

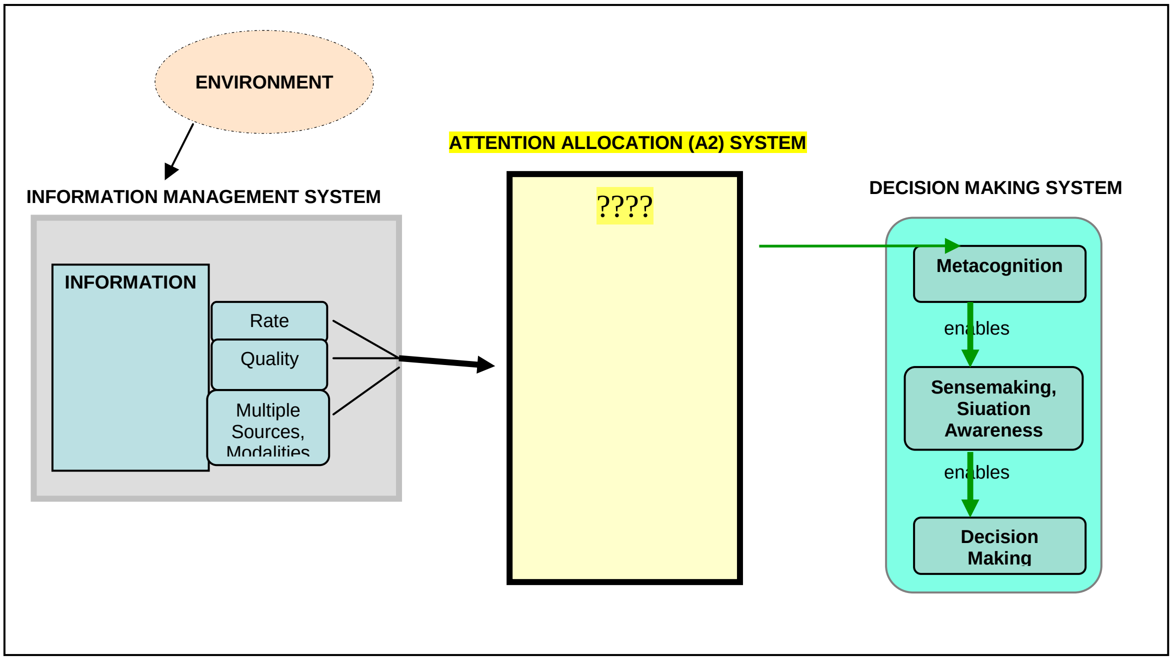


Figure 1

<u>Attention Sharing: Primary and Secondary Focus</u>

Human attention is a finite resource that must be managed and shared between many aspects of the environment. Though multiple pieces of information are sometimes processed simultaneously, as when an operator verbally gives commands to others while updating a graphical display, this attention sharing can only occur within limits. Attention bottlenecks are quickly reached within a single modality like sound or vision (Wickens, 1992), forcing people to resort to scanning some of the sources. In effect, their attention becomes divided between a *primary focus* and a *secondary focus*. Any type of multitasking will require continual reallocation of primary and secondary attentional focus between activities and associated information, using *working memory* to keep track and maintain continuity.

For example, nearly all operators observed in the CAOC had two displays with one devoted entirely to "chat" rooms. Operators had an average of six to eight chat windows open and some had as many as fourteen. Each chat room had its own unique name and set of participants, with its own purported topic such as coordinating with the Army liaison. Operators explained during interviews that they actively participated in only some of the chat rooms they had open, while they "just watched" the others. Though they often had difficulty articulating exactly what they were watching for, they were extremely reluctant to close those secondary windows - even if there was only enough screen real estate to maintain it as a one-inch square window! It became clear this was a means of scanning for increases in room activity levels (using only secondary or peripheral attention); if message traffic dramatically increased in one of these small windows, the quickly scrolling characters of text would catch the operator's eye. He would then enlarge that window so as to be able to read message traffic (giving it primary attentional focus) and see if further action was needed.

Filtering Attention: Dynamic Priorities

Ideally, a set of *priorities* within the A2 system would appropriately filter our attention to incoming information to avoid either too narrow a focus, or an inability to sufficiently focus when bombarded with high rates or multiple sources of data. But in reality, there are distinct challenges and aspects to filtering.

For example, operators could become so engrossed in scanning the multiple chat rooms and cueing other team members to important developments that they themselves got lost in the weeds and neglected other issues. As one operator put it, *"…I get tunnel vision to accomplish the coordination and lose sight of anything else."* This is a significant issue for any attention allocation system. In fact, Endsley et al (2003) define "attentional tunneling" as one of eight *SA Demons:*

> "When succumbing to attentional tunneling, they lock in on certain aspects or features of the environment they are trying to process, and will either intentionally or inadvertently drop their scanning behavior. In this case, their SA may be very

good on the part of the environment they are concentrating on, but will quickly become outdated on the aspects they have stopped attending to." (Endsley et. al, p.32)

An additional complexity arises from the fact that command and control priorities are *dynamic* rather than static, and must be quickly and clearly communicated whenever they change. This is proving a significant challenge in asymmetric threat and homeland security environments. Priorities may also have inherent ambiguities and interdependencies across communities of interest that require attention to social drivers such as trust and cultural norms, in addition to technological concerns, for successful resolution. We will say more about those relationships shortly.

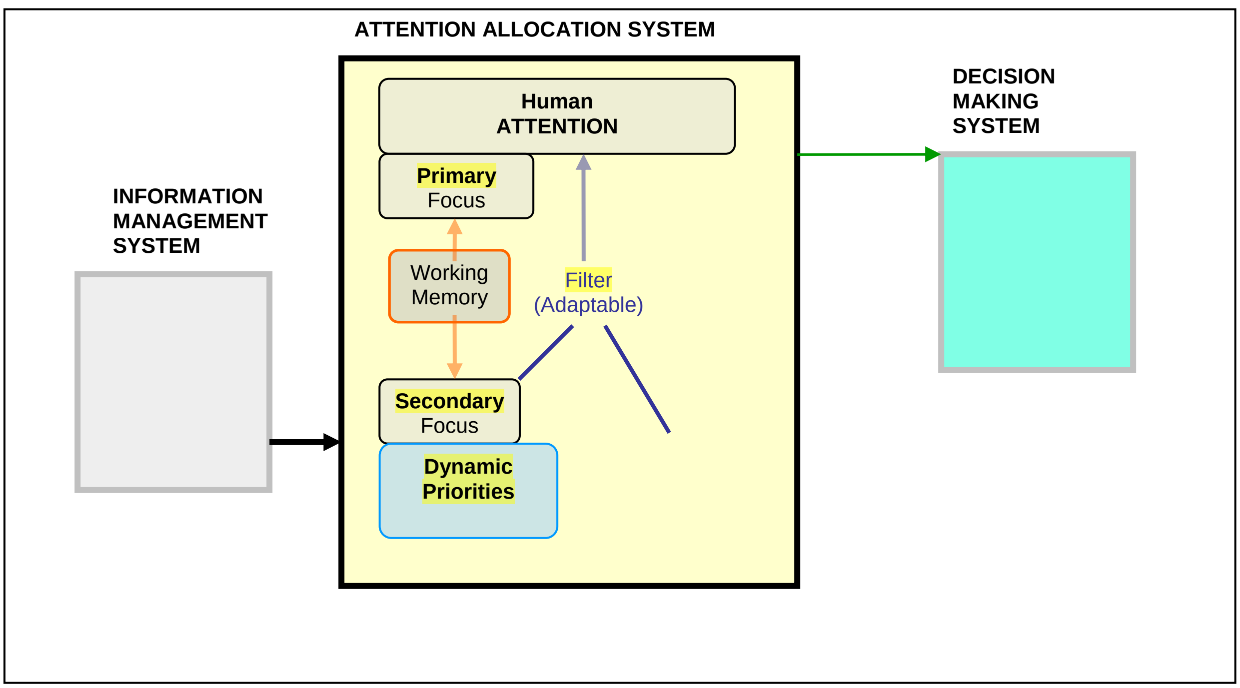


Figure 2

<u>Filtering Attention: Attention Attractors</u>

Not only do dynamic priorities present a challenge in filtering information for human attention, but there are also countless distractions that draw operator attention from objectively higher priority elements to elements of higher inherent interest, which we will call *attention attractors*. These are aspects of the environment that are salient and naturally attract human attention, whether we wish them to or not. They include being drawn to: other human faces and voices (especially those indicating emotion), movement or other changes in the environment (if not too gradual), informal conversation (versus formal language), bright colors, signs of imminent danger, and anything novel or unexpected or unresolved [Kathy Sierra on Passionate Users, SXSW06 Conference].

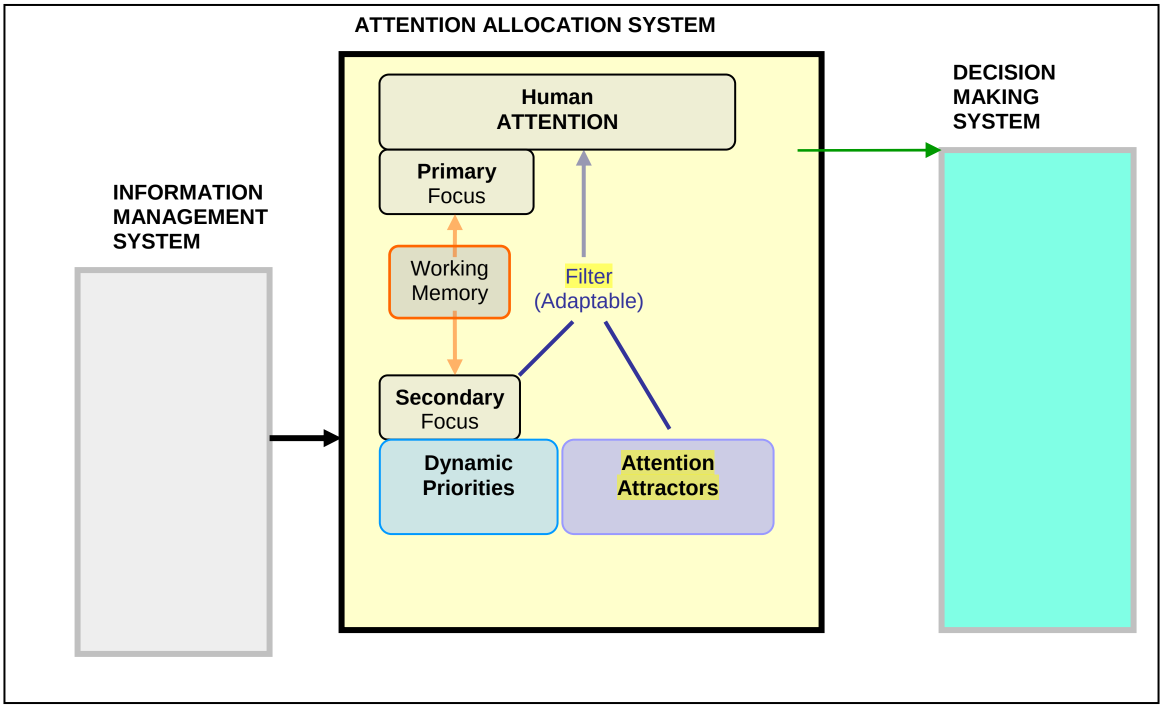


Figure 3

For example, whenever a personnel rescue mission arose within the CAOC, it drew widespread operator attention as evidenced by a significant increase in associated communication levels. These events represented potential danger to a coalition member and elicited an emotional response and desire to help; operators with other roles had to be repeatedly reminded that they could not drop all other tasks in order to focus on these rescue missions.

Another unintentional attention attractor was observed in relation to live video. Operators repeatedly over-attended to displays of live Predator UAV feeds on the large data walls, despite their lack of relevance for most operator roles. Live streaming video was unavoidably more eye-catching and novel than the important but less dynamic common operating picture displays, and the UAV display eventually had to be discontinued.

A third example comes from the C2 literature rather than from the field. An experimental study by Cummings [ref] had the unexpected finding that operators "fixated" on chat over and above more objectively valuable information sources, despite repeated instructions to ignore the low priority chat messages unless their other tasks were completed. This may have been due to the more compelling nature of informal chat conversations, the presence of emotions and social cues within the messages, and discussions of unexpected or unresolved issues – in comparison to the drier and strictly task-related information within the other application. Clearly, what is salient and draws human attention within human-system interaction is a complex process involving more than stated priorities. These attention attractors represent a critical component of the A2 system that must be explicitly recognized as part of the filtering mechanism. As the above examples illustrate, technology may inadvertently distract human attention from objectively more important information.

Filtering Attention: Social and Behavioral Influences on Priorities

Priorities are also influenced by *social and behavioral factors* including trust, culture, incentives, and expectations. For example, people are likely to increase the priority given to information as they develop more trust in its source. In the experimental CAOC environment, there was a great deal of communication related to understanding the background, intent, and thereby the implied trustworthiness of information before deciding whether it was worthy of attention. Developing this understanding became particularly challenging when the information thread passed from human to machine and back to human again:

> "…when operators received data via machine to machine transfer rather than from another member of the team, they could lose the ability to infer important contextual information such as the data's source, pedigree, and why it was being provided at that time. As a consequence, operators sometimes found it necessary to reconstruct some of that meta-information in order to judge the information's validity, provenance, and relevance, and determine how to proceed" (Boiney, 2005).

People's cultural norms, standard operating procedures, or incentive structures may also influence the priorities they assign to information of stated importance (such as a new rule of engagement) if those norms and stated priorities are in conflict ("that ROE was never a show stopper in the past"). These are factors to consider when designing support for attention allocation since they influence what information makes it through the filter of priorities and saliency to gain access to finite human attention, subsequent SA, and decision making. We will say more about these social and behavioral factors when describing the collaboration process, since collaboration has the most significant impact on these factors.

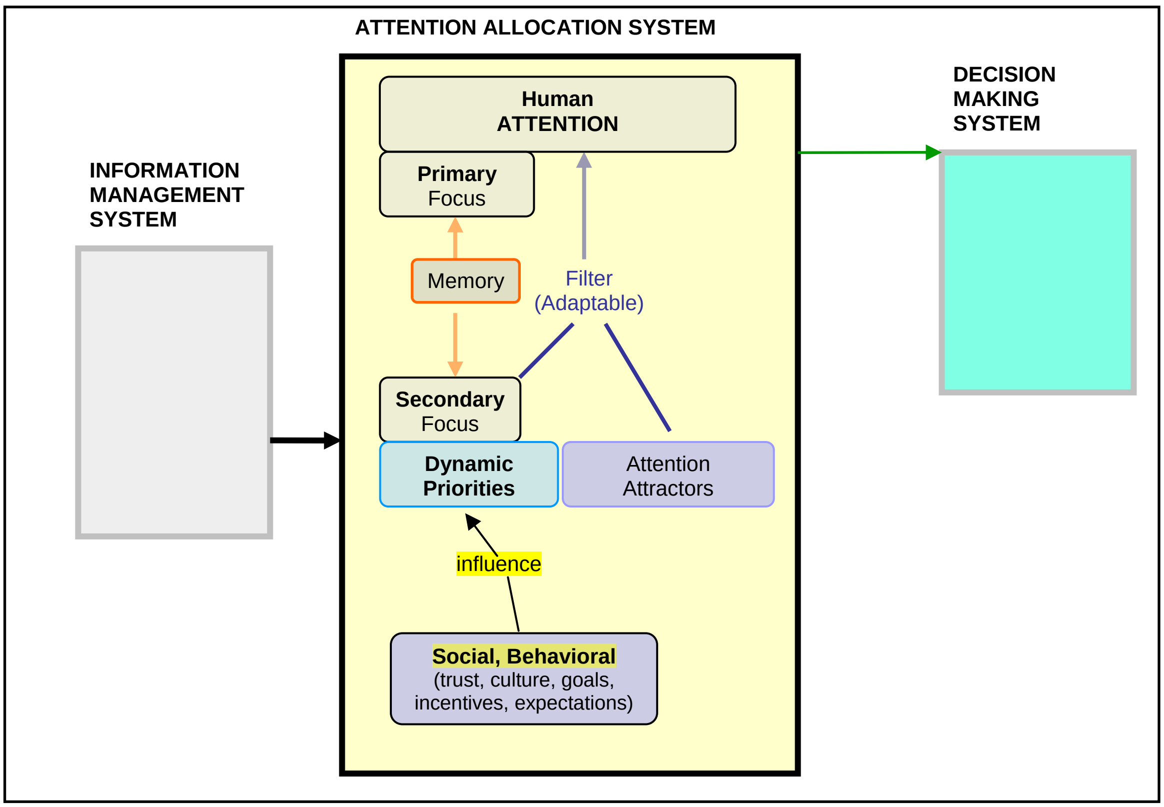


Figure 4

<u>Interruptions: Priorities Reconsidered</u>

A major challenge for the Attention Allocation system is managing *interruptions*. Interruptions are defined here as a condition that motivates switching of tasks. In other words, something occurs that causes the person to rethink his priorities and switch from his current focus to a different one. Since interruptions require people to reallocate their attention and then potentially maintain it over several tasks or "work spheres" (Gonzales and Mark, 2004), interruptions are cognitively demanding and may lead to lapses in working memory, increased stress, or errors in SA. Some interruptions may be particularly ill-timed or disruptive, occurring when an operator is under high cognitive load, in the midst of task-switching, or engaged in a critical task. On the other hand, there can be "good" interruptions that actually contribute to improved SA and decision making. These include interruptions occurring during periods of relatively low cognitive load that alert an operator to updated priorities or new information, thereby avoiding misplaced attention and subsequent errors or wasted effort.

Complex command and control environments are characterized by frequent interruptions due to four main sources: unexpected inputs from the *environment* (such as a fundamentally new source or type of information), data of poor or uncertain *quality* requiring further vetting, *competing sources or modalities* of information, *or collaboration* needs such as synchronization and role coordination.

It is straightforward to envision how new, unexpected types or sources of information from the environment cause interruptions; consider the response to incoming data from a new sensor, or surprising feedback from First Responders at the tactical edge, either of which could cause a reprioritization of what will subsequently be attended to.

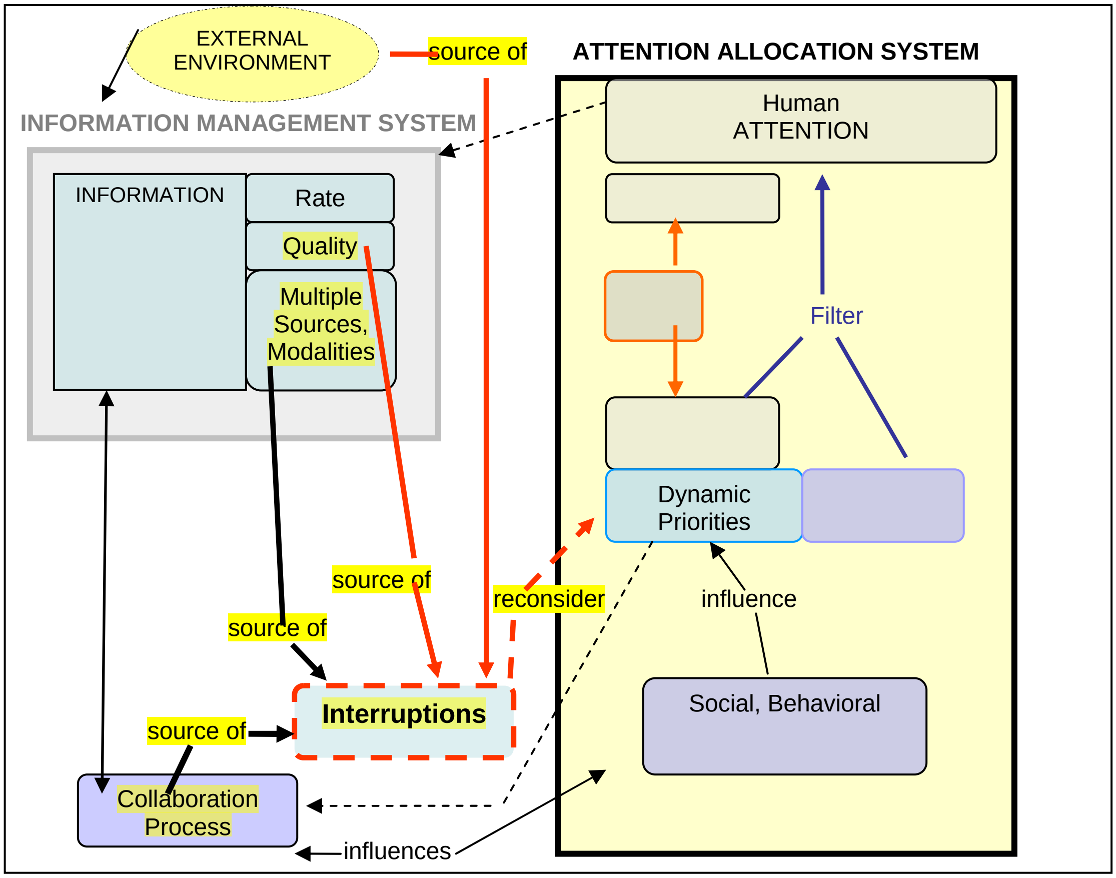

EXTERNAL ENVIRONMENT
source of
ATTENTION ALLOCATION SYSTEM
INFORMATION MANAGEMENT SYSTEM
Human ATTENTION
INFORMATION
Rate
Quality
Multiple Sources, Modalities
Filter
Dynamic Priorities
source of
source of
reconsider
influence
Interruptions
Social, Behavioral
source of
Collaboration Process
influences

Figure 5

Second, we illustrated how considerable attention and time are often spent in an effort to establish the trustworthiness of information. This is a reflection on the information *quality* (or lack thereof) and can be a significant source of interruptions; people must switch tasks and engage in a combination of additional information seeking and/or collaborative discussion until satisfied they can proceed. Notice the potential feedbacks (dotted lines) in the Attention Allocation system from the reconsideration of priorities back to the collaboration process, and again from the A2 system back to the Information Management system.

Third, consider competing information sources or *modalities* as a cause of interruptions. Recall that nearly every operator in the CAOC had two displays, one devoted to email and multiple chat windows and the other filled with an average of four to seven distinct applications. Visible past their personal screens was the front data wall, covered with large displays showing different versions of map-based situational awareness displays and some general status updates in PowerPoint. All operators had a phone and most wore headsets held against one - if not both - ears. In addition, individuals would periodically make announcements through the public address system at the front of the room. Occurring simultaneously were constant telephone conversations and face to face sidebars. Given this multi-modal environment, it is not surprising that in addition to suffering many distractions, operators felt interruptions were all too frequent.

Operators did, however, learn to take advantage of different modalities to more *effectively* interrupt one other. Each chat room supported either text communication or voice communication (presuming others were wearing headsets) to all members of that room. Since everyone's visual channel was already heavily loaded from the various desktop applications, people would use chat's voice capability to quickly grab the attention of everyone in a given room. When used judiciously and for genuinely important events, it appeared highly effective; it was clear as an observer that operators gave higher attentional priority to the audio chat than to the text chat. There is support in the literature for this natural preference. In an experimental study, Gonzales and Mark (2004) found that subjects switched tasks more often due to verbal interruptions, such as visitors or phone calls, than to e-mail or voice mail notifications.

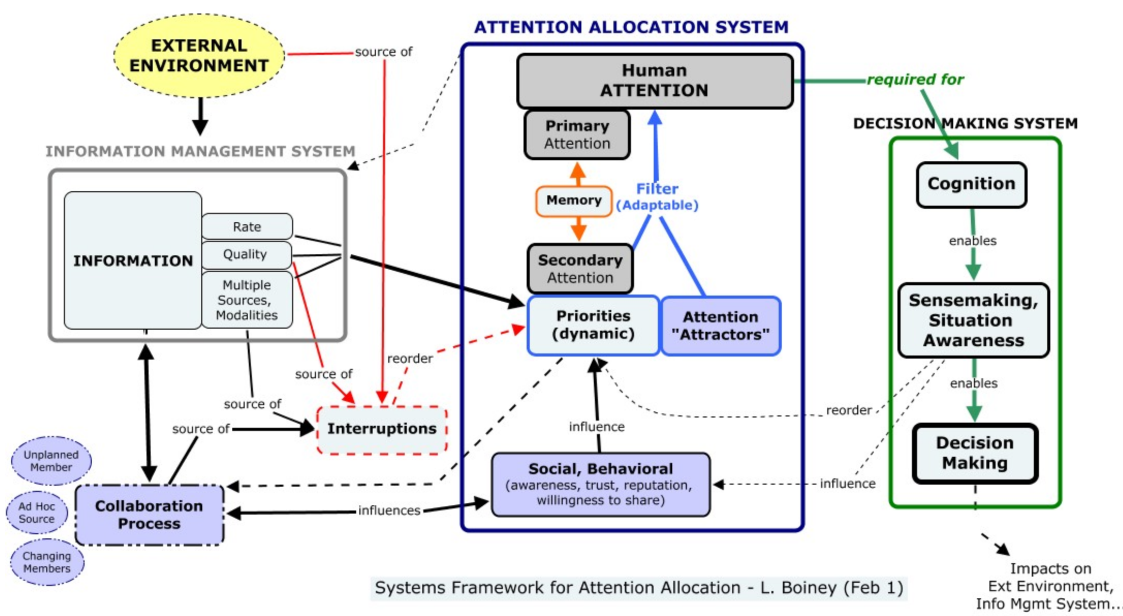
But the operators' auditory interrupts posed an unanticipated problem arising from the perceived need to continually scan for unanticipated events in this domain. The technology enabled operators to have many chat rooms open - both those they assigned primary focus (e.g., actively participated in) and those they assigned secondary focus (e.g., peripherally scanned via much smaller windows) – yet the technology had no mechanism for "minimizing" a room's audio presence as they could with its visual presence. As a result, the operators' auditory channel could easily become overloaded with voices from different chat rooms during periods of high activity and many resorted to removing their headsets. As one operator said, *"I want to be able to mute audio on some of my rooms. I can't focus."*

Collaboration: Interruptions, Social Factors, Priority Shifts, Richer Information & More

The collaboration process is another source of interruptions that can have either positive or negative impact on the Attention Allocation system. An effective collaboration process can provide highly valuable interrupts. For example, co-located operators in the CAOC would often suspend their own activities in order to verbally update a team member they noticed returning to his or her station. They might briefly summarize the activity that had occurred and indicate where among the myriad information sources to find the updates. This required not only time and effort from the cueing operator, but sufficient awareness of teammate roles and status to understand what updates would be valuable and relevant. This willingness to keep an eye out for others' comings and goings and voluntarily cue them to high priority information could help avoid missed information and speed reacquisition of SA after a distraction or interruption. As one operator described it, *"I want at least 7 rooms open - can't fit it all. I rely on the rest of the team for cues."*

For team members who were not co-located, the audio chat feature was a frequently used collaborative cueing technique. In these cases, the goal seemed more to synchronize a group's attention rather than to be sure nothing important had escaped attention. The cueing individual would often use phrases like *"Heads up on…"* or *"Draw your attention to…"* as a preface to the information provided. Though none of this cooperative cueing was part of the official collaborative process or training, it evolved to become a critical part of the cognitive and social fabric of team communication. Unfortunately, we cannot simply hope that effective collaboration processes will emerge; there is a clear need for technologies that support more informative, better timed, and less burdensome collaborative "interruptions" and cues.

Collaboration processes may strongly influence a wide set of *social and behavioral factors* including trust, expectations, cultural norms, and incentive structures. These are critical within the A2 system because they influence then priorities that help filter what gets attended to and folded into the decision making process. While the norms, expectations and trusted sources may be clear within a team having a working history or relatively homogeneous makeup, they may be relatively difficult to discern or potentially conflicting within rapidly forming teams with cross-boundary membership, such as those required to respond to Hurricane Katrina or 9/11.



Systems Framework for Attention Allocation - L. Boiney (Feb 1)

Conversely, a significant shift in priorities, such as that from an unexpected threat or event, can trigger a complex collaboration process that must rapidly incorporate unplanned membership and ad hoc sources (ex: Homeland Security). Reworking dynamic priorities in real time may require additional collaboration, especially when interdependencies between decision making tasks or resources exist. This richer collaboration has the potential to generate richer information and improved SA, but also runs the risk of more interruptions and greater social and behavioral challenges in aligning cultures and incentives, establishing trust, and coordinating priorities for effective attention allocation and decision making.

References

Boiney, L. “Team Decision Making in Time-Sensitive Environments.” 10th International Command and Control Research and Technology Symposium (CCRTS) Proceedings, June 2005.

Bennett, K. and Flach, J. “Graphical displays: Implications for divided attention, focused attention, and problem solving,” Human Factors, vol. 34, pp. 513–533, 1992.

Cowan, N. (1988). Evolving conceptions of memory storage, selective attention, and their mutual constraints within the human information processing system. Psychological Bulletin, 1 04 (2), 163-191.

Cummings, M.L. The Need for Command and Control Instant Message Adaptive Interfaces: Lessons Learned from Tactical Tomahawk Human-in-the-Loop Simulations

Endsley, M. R., Theoretical underpinnings of situation awareness: A critical review, In Endsley, M. R. and Darland, D. J. (Editors) Situation Awareness Analysis and Measurement, Lawrence Erlbaum Associates, Mahwah, NJ (2000).

Endsley, M. R. (1995a). Measurement of situation awareness in dynamic systems. Human Factors, 3 7 (1), 65-84.

Endsley, M. R., & Rodgers, M. D. (1998). Distribution of attention, situation awareness, and workload in a passive air traffic control task: Implications for operational errors and automation. Air Traffic Control Quarterly, 6 (1), 21-44.

Endsley, M. R., & Smith, R. P. (1996). Attention distribution and decision making in tactical air combat. Human Factors, 3 8 (2), 232-249.

Gopher, D., Greenshpan, Y., & Armony, L. (1996). Switching attention between tasks: Exploration of the components of executive control and their development with training. Paper presented at the Human Factors and Ergonomics Society 40th Annual Meeting, Philadelphia, PA.

González, Victor and Mark, Gloria. Constant, Constant, Multi-tasking Craziness: Managing Multiple Working Spheres CHI 2004, April 24–29, 2004, Vienna, Austria.

Horvitz, E., Kadie, C., Paek, T., Hovel, D., Models of attention in computing and communication: from principles to applications, Communications of the ACM 46, 3 (March 2003), 52-59.

Horvitz, E., Koch, P., and Apacible, J., BusyBody: Creating and Fielding Personalized Models of the Cost of Interruption, Proc. ACM Conf. Computer Supported Cooperative Work, ACM, New York (2004), 507-510.

Hudson, James, Christensen, Jim, Kellogg, Wendy A. and Thomas Erickson "I'd Be Overwhelmed, But It's Just One More Thing to Do: Availability and Interruption in Research Management. CHI 2002 20-25 April.

Jones, D. G., & Endsley, M. R. (1996). Sources of situation awareness errors in aviation. Aviation, Space and Environmental Medicine, 67 (6), 507-512.

McCrickard, D. S. and Chewar, C. M., Attuning notification design to user goals and attention costs, Comm. of the ACM 46, 3 (March 2003), 67-72.

Mitchell, P. J., M.L. Cummings, T.B. Sheridan (2004). "Human Supervisory Control Issues in Network Centric Warfare." Prepared for Boeing, Phantom Works, September, 2004. Massachusetts Institute of Technology, Humans and Automation Laboratory.

Moray, N. (1986). Monitoring behavior and supervisory control. In K. R. Boff, L. Kaufman, & J. P. Thomas (Eds.), *Handbook of perception and performance, Vol. II* (pp. 40-1-40-51). New York: Wiley & Sons.

Ocasio, William. 1997. "Towards an Attention-Based View of the Firm." Strategic Management Journal 18 (Summer Special Issue: "Organizational and Competitive Interactions"):187-206.

Parasuraman, R., Sheridan, T. and Wickens, C. "A Model for Types and Levels of Human Interaction with Automation." IEEE Transactions on Systems, Man, and Cybernetics—Part A: Systems and Humans, vol. 30, no. 3, May 2000

Ross, K., McHugh, A., Moon, B., Klein, G., Armstrong, A., Rall, E. "Macrocognition Year One Final Report: High-Level Cognitive Processes In Field Research." October 2001-September 2002 #02TA1-SP1-RT1 October 14, 2002

Sanderson, P., Crawford, J., Savill, A., Watson, M., Russell, W.J., 2004. Visual and auditory attention in patient monitoring: a formative analysis. Cognition, Technology, and Work in press.

Sarter, N.B., 2000. The need for multisensory interfaces in support of effective attentional allocation in highly dynamic event-driven domains: the case of cockpit automation. International Journal of Aviation Psychology 10 (3), 231–245.

Seagull, F.J., Wickens, C.D., Loeb, R.G., 2001. When is less more? Attention and workload in auditory, visual and redundant patient-monitoring conditions. Proceedings of the Human Factors and Ergonomics Society 45th Annual Meeting. Santa Monica, CA: HFES. pp. 1395–1399.

St. John, M., Kobus, D., Morrison, J., and Schmorrow, D. (2004). “Overview of the DARPA Augmented Cognition Technical Integration Experiment”. *International Journal of Human-Computer Interaction*, Vol. 17, No. 2, pp. 131-149.

Watson, Marcus, Sanderson, Penelope, and W. John Russell “Tailoring reveals information requirements: the case of anaesthesia alarms” Interacting with Computers 16 (2004) 271–293

Wickens, C., Helleberg, J., Goh, J., Xu, X., & Horrey, B. (2001). *Pilot task management: testing an attentional expected value model of visual scanning* (ARL-01-14/NASA-01-7). Savoy, IL: University of Illinois, Aviation Research Laboratory.

Wickens, C. “Attention and Aviation Display Layout: Research and Modeling Final Technical Report.” AHFD-05-21/NASA-05-8 December 2005 Prepared for NASA Ames Research Center Moffett Field, CA

Wickens, C., Goh, J., Helleberg, J., Horrey, W., & Talleur, D. A. (2003). “Attentional Models of Multitask Pilot Performance Using Advanced Display Technology.” *Human Factors, 45*(3), 360-380.

Wickens, C., Conejo, R., and Gempler, K. “Unreliable automated attention cueing for air-ground targeting and traffic maneuvering,” Proceedings of 34th Annual Human Factors and Ergonomics Society Conf. Santa Monica, CA, 1999.

Wickens, C., McCarley, J., Alexander, A., Thomas, L., Ambinder, M., and Zheng, S. “Attention-Situation Awareness (A-SA) Model of Pilot Error.” NASA Ames Research Center, Human Error Modeling Project Technical Report.” AHFD-04-15/NASA-04-5 January 2005.

Yeh, M., Wickens, C., Seagull, F. “Target cueing in visual search: The effects of conformality and display location on the allocation of visual attention,” Human Factors, vol. 41, 1999.