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Getting Back Up to Speed:

Cognitive Principles for Situation Awareness Recovery

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Abstract

Objective: To provide a principled, theoretical basis to improve interface tools for helping users recover from task interruptions and get back up to speed in dynamic operational tasks. **Background:** Multi-tasking and interruptions that disrupt situation awareness are common to many dynamic operational tasks, from monitoring airspaces and plant operations to conducting tactical missions, civil emergency operations, and even fighting wild fires. Recovering situation awareness following an interruption requires detecting and assimilating changes to the situation that occurred during the interruption, yet humans are notoriously poor at detecting changes, and little attention has been given to designing effective situation awareness recovery tools. **Method:** We synthesize notions of change detection with previous interruption models to create a new model of situation awareness recovery for dynamic tasks. From the model, we derive four cognitive principles for the design of interfaces to support change detection and situation awareness recovery. **Results:** We contrast existing and novel interface tools against the principles and draw out several previously overlooked limitations and design trade-offs inherent in their designs. **Conclusion:** The results illuminate the cognitive and perceptual underpinnings of more and less effective situation awareness recovery tools. **Application:** Consideration of the principles should facilitate the design of more effective tools to help users get back up to speed for these important and high risk tasks.

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Introduction

In nearly all work domains, multi-tasking is on the rise. Yet while multi-tasking can increase efficiency, users pay a heavy price from frequent interruptions and the mental effort entailed in recovering situation awareness. In dynamic operational domains, the loss of situation awareness caused by multi-tasking and interruptions can place operations and people at risk. These domains include situation monitoring tasks such as airspace and plant monitoring and command and control tasks such as SEAL team missions, civil emergency relief efforts, and even fighting wild fires.

Dynamic operational tasks evolve over time and a major part of situation awareness recovery involves finding and assimilating the changes to the situation that occur during interruptions. Unfortunately, while researchers and designers have made substantial progress in the design of situation displays to support real-time system monitoring, support for change detection and situation awareness recovery has been largely overlooked. Designers place too much confidence in users' unaided change detection ability, consequently users are typically left to their own devices to find changes and assimilate their meaning, often with poor results.

Can better interface designs help users get back up to speed for these important and high risk tasks?

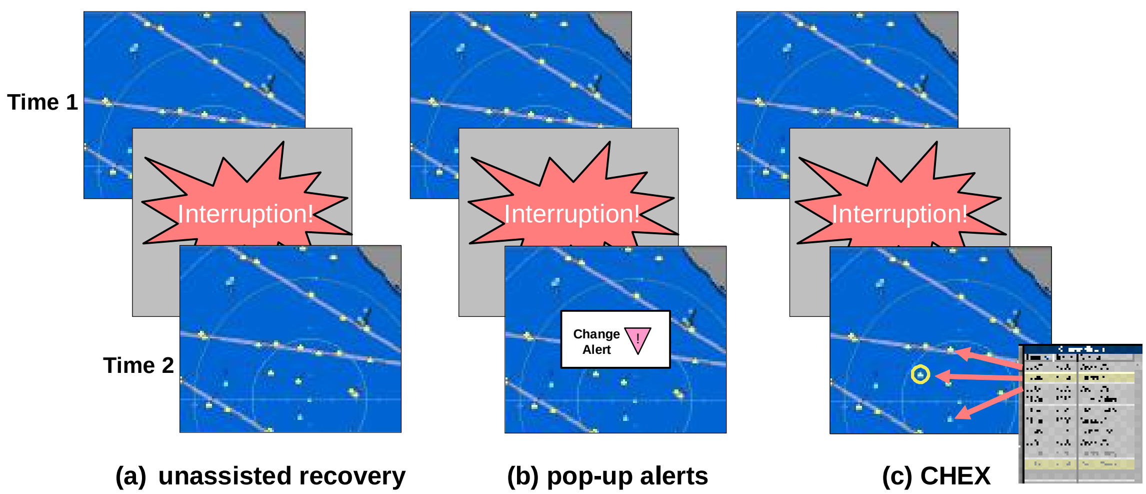
The surprising difficulty of change detection. Finding changes following an interruption is surprisingly difficult. The naïve belief is that any significant changes to a situation will be obvious to the engaged user, and they will pop out. Indeed, most situation displays offer little or no support for change detection. Situation displays seem to be designed with the belief that merely representing the current situation realistically in time will be sufficient to support change detection and the recovery of situation awareness following interruptions. We have called this naïve faith in realistic displays Naïve Realism and laid out reasons for what may underlie it (Smallman & St. John, 2005).

The psychological truth of the matter is far different. An increasingly vast literature on change blindness (e.g. Rensink, 2002) and inattention blindness (e.g. Mack & Rock, 1998) attest to the surprising and commonplace difficulty of detecting changes to dynamic situations. A particularly striking example of inattention blindness is the now famous basketball-gorilla video of Simons & Chabris (1999). Participants are asked to count the number of times a basketball is passed among teammates. While participants focus on counting, a gorilla ambles into view, beats its chest, and ambles off. Remarkably, a majority of participants fail to even notice the gorilla. The attentional phenomena are as common as they are hard to believe. As this example suggests, changes may be especially difficult to notice when attention is engaged elsewhere.

In laboratory change blindness studies, participants typically see two pictures of a scene in which one prominent but extraneous element is changed. When even a short blank screen intervenes between the two pictures – an interruption – the change requires significant time and effort to spot. In real situations, there is no ability to switch back and forth between pictures, and changes may simply go unnoticed until they demand attention, as in "that car just came out of nowhere." Indeed, conversations while driving have been shown to degrade change detection in complex traffic scenes (McCarley, Vais, Pringle, Kramer, Irwin, & Strayer, 2004). Moreover, users are often overconfident in their natural change detection capabilities – they exhibit what others have called "change blindness *blindness*" (Levin, Momen, Drivdahl, & Simons, 2000). In an applied task, participants were both overconfident of their natural change detection abilities and underestimated the utility of automated change detection (Smallman & St. John, 2003).

Because even short interruptions and distractions can make change detection difficult, interruptions can be very detrimental to situation awareness. Changes may be missed or their discovery may be delayed, and trivial changes that are found may delay the search for more important changes. These problems can create dangerous situations in dynamic operational tasks, both for monitoring complex situations and for mission execution. In the domain of air warfare, for example, users monitor complex airspaces for threatening aircraft, and they take a variety of actions to manage the safety of friendly assets. Aircraft changes, such as leaving an air lane, turning inbound, increasing speed, and turning on fire control radar, may indicate a change in the threat level of an aircraft, and they must be detected and evaluated quickly. Currently, these changes must be extracted from a map display (a geographic information system) showing the locations and attributes of aircraft within the airspace (see Figure 1a).

Finding these changes requires careful scanning of the current situation and mental comparison with the remembered state of the situation prior to the interruption. Missed changes or even delayed detection can put friendly assets at risk, yet misses are routinely observed in laboratory versions of this task (DiVita, Obermayer, Nugent, & Linville, 2004; Smallman & St. John, 2003; St. John, Smallman, & Manes, 2005). For example, users who had to detect changes unaided, based only a map display of the current situation and no specialized interface aids, missed as many as 48% of significant changes that occurred during 30 or 120 second interruptions. Even during real-time monitoring, users missed 30% of significant changes (St. John, Smallman, & Manes, 2005). In a related study, participants performing unaided change detection erred 60% of the time in finding the most significant events (Smallman & St. John, 2003). Are there interface design principles that can be applied to mitigate this problem? Interestingly, the naïve application of automatic change alerts, such as those shown in Figure 1(b), do little to improve the situation, as we outline in more detail below. Better, more cognitively informed, designs are required.



(a) unassisted recovery **(b) pop-up alerts** **(c) CHEX**

Figure 1. Three methods for situation awareness recovery, (a) conventional, unassisted change detection, (b) a naïve application of change alerts, and (c) the CHEX situation awareness recovery tool.

In the domain of mission execution, users monitor and may participate in the execution of a mission. Changes include the status and locations of team members and other assets and the status and locations of foreign elements, such as enemy units, refugees, damaged infrastructure, and fire fronts. Some of these changes may need to be extracted from a map display while others may be presented to the user as messages from other team members. The process of extracting changes from the map display again involves scanning and mentally comparing the current situation to the remembered situation. The process of extracting changes reported as messages from team members is much easier, since these changes are presented to the user, but the messages still must be noticed, viewed, and assimilated in a timely and efficient manner. Delayed or missed changes to the evolving situation can lead to dis-coordination among team members and missteps in the execution of the mission that can put the mission and team members at risk (e.g. Talbot, 2004, and similarly in an educational collaborative domain, Carroll, Neale, Isenhour, Rosson & McCrickard, 2003).

While research into decision-making in mission execution tasks is common, much less attention has been paid to interruptions and recovery from interruptions in these tasks. One simple technology for interruption management that has been applied to the mission control domain is radio circuits. In one observational study, team members were observed to coordinate the timing of interruptions by listening for lulls in the conversion over open radio circuits. Radio circuits allowed members to judge the priority of their interruption against on-going conversations (Patterson, Watts-Perotti, & Woods, 1999). While this technology can reduce the disruptiveness of interruptions, it does nothing to facilitate the recovery of situation awareness following interruptions.

Instant messaging, or chat, tools have also become common in distributed military settings (Heacox, Moore, Morrison, & Yturralde, 2004). Chat provides a record of written messages that can be reviewed following an interruption. However, chat has several disadvantages: the arrival of chat messages can be very compelling and disruptive to on-going primary tasks, chat typically lacks organizational structure or message summary information that can be used to prioritize interruptions, and its content is simple text that is disjoint from the situation display (Cummings, 2004)

Given the high stakes and the problems of change blindness, better support for change detection and situation awareness recovery should be a priority. However, researchers and display designers are only beginning to take these problems seriously (Varakin, Levin & Fidler, 2004). Here, we outline a process model of situation awareness recovery that emphasizes the role of change detection, and we derive from the model four cognitive principles for the design of situation awareness recovery interfaces. We describe a family of interface designs, called CHEX (for "Change History EXplicit"), that comply with the principles, and we contrast their performance with a number of current situation awareness tools. Finally, we examine some of the design trade-offs illuminated by the fourth principle. It is our hope that consideration of the model and principles during the design process will lead to more effective situation awareness recovery and better support for multi-tasking. It is also our hope that these considerations will stimulation more research in this under-explored area.

A model of situation awareness recovery

Situation awareness recovery is a broad topic. In order to better organize the research and designs, we briefly describe a new model that organizes situation awareness recovery into four stages: 1) preparing for interruptions, 2) reorienting and retrieving task goals and problem states following an interruption, 3) detecting changes to the situation, and 4) assimilating the changes into the situation and determining appropriate responses (see Figure 2). The model builds on prior models (e.g. Altmann & Trafton, 2002; McFarlane & Latorella, 2002), but it is novel in several respects. First, it emphasizes the difficulties encountered in dynamic tasks, compared to the typical focus on static tasks that do not change during the interrupt, such as programming a device. Second, it focuses on possible interventions and their likely cognitive/perceptual underpinnings at each stage. Third, it integrates the previous cognitive modeling work, couched in terms of goal stacks, with more perceptual work on change detection. Finally, the model calls out the possible errors associated with losses in situation awareness at each stage; these errors are listed below each stage.

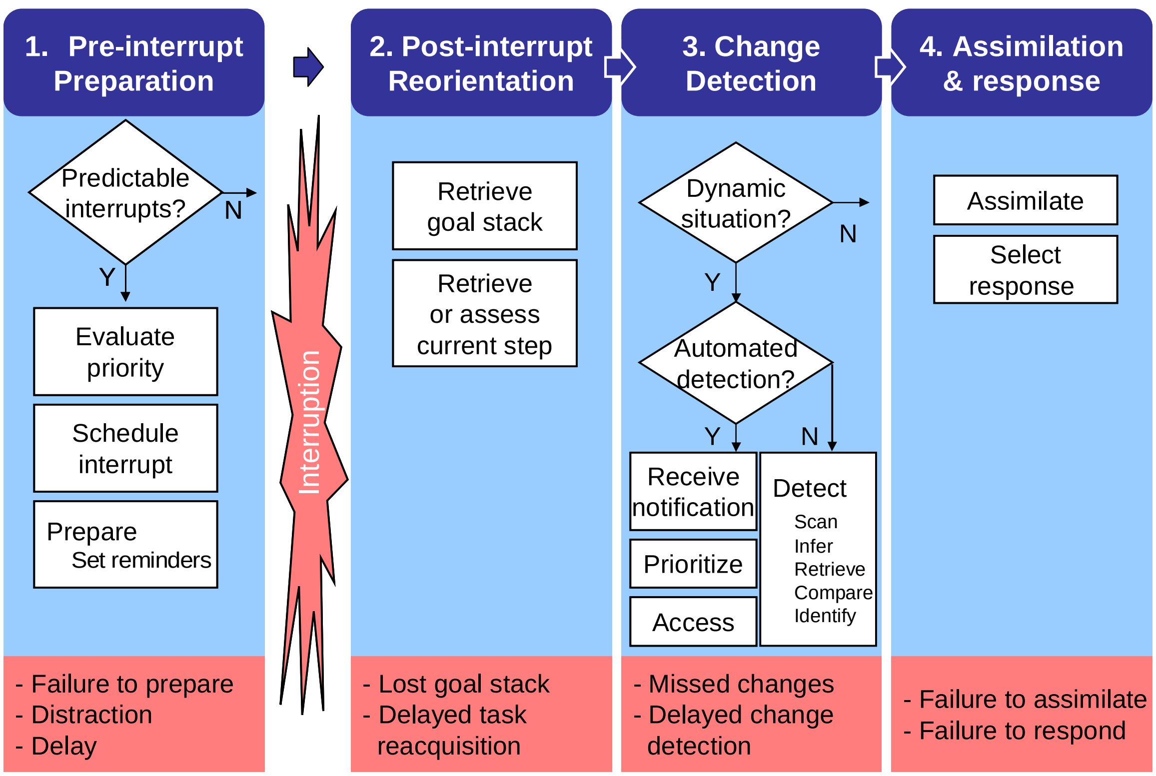


Figure 2. A four stage situation awareness recovery model and the errors that can occur at each stage (bottom).

The first stage involves what can be done prior to an interruption. In some circumstances, it may be possible to schedule and prepare for interruptions. A number of researchers have investigated the benefits of scheduling the timing of interruptions to fall into sub-task boundaries or other lulls in the workload (Dabbish & Kraut, 2004; Iqbal & Bailey, 2006; McFarlane, 2002; Monk, Boehm-Davis, & Trafton, 2004). Others have investigated the benefits of conveying to users the urgency or priority of secondary tasks (Ho, Nikolic, Waters, & Sarter, 2004; Sklar & Sarter, 1999; Watson & Sanderson, 2004). This information can be used by users to determine when to interrupt themselves. For example, Watson and Sanderson (2004) developed a method for conveying the status of anesthesiology data as a continuous background "soundscape". Users could evaluate the soundscape to determine whether a significant change had occurred while performing other tasks. Still others have investigated methods for taking notes and setting reminders to what the user was doing just prior to an interruption (e.g., Trafton, Altmann, Brock & Mintz, 2003; Trafton, Altmann, & Brock, 2005). Errors during this stage include failures to prepare for interruptions that then limit the ability to recover from the interruption, distraction from mundane interruptions during episodes of high workload, and delays in reacting to critical alerts.

The second stage is retrieving the task goal structure and state of the problem ("what was I doing?") when the task was interrupted. It is well know that there are task-switching costs (e.g., Monsell, 2003) and detailed cognitive models of interruption recovery have been developed that illuminate key variables and cognitive mechanisms for goal retrieval (Altmann & Trafton, 2002). Notes and markers, as mentioned above, have been investigated as aids for retrieving task goals.

The third stage of situation awareness recovery focuses on detecting changes that occurred during the interruption. Our focus is on this stage, as it is a neglected problem pertinent to many dynamic operational task domains. The model for stage three is divided into two alternative processes. The right side of the change detection stage (see Figure 2) shows the cognitive processes employed by users who are required to detect changes without assistance from the interface. Unaided change detection relies heavily on retrieving detailed memories of the prior situation. These retrievals, of course, assume that the prior situation was encoded and stored in detail in the first place. However, the phenomenon of change blindness has thrown this assumption into serious question. Rather, modern notions of perception emphasize perception's sparseness and attention only to those details required for current processing (e.g., Ballard, Hayhoe, Pook, & Rao, 1998). Unfortunately for change detection, if memories are sparse, then there is little basis for drawing comparisons with the prior situation. Furthermore, if attention is so fickle, then it may even miss the transients of many changes that occur during monitoring. Viewed this way, it is little wonder that we suffer from change blindness and poor change detection.

Unaided change detection can also require substantial inferencing. Objects in the situation may move during an interruption, and the user must solve the correspondence problem of which objects at locations B through Z in the current situation corresponds with the object at location A in the remembered, prior situation. Over short durations, perception may rely on an array of shortcuts or heuristics to solve the correspondence problem, such as proximity and shared visual properties (e.g., Marr, 1982). However, over longer interruptions, inferences and guesswork are required. Under these circumstances, it may be nearly impossible to solve the correspondence problem correctly, especially if the situation is cluttered with similar-looking objects, as are found in air warfare monitoring displays. Yet, inferring the correspondence of objects from the prior situation to the current situation is necessary for change detection.

In contrast, the cognitive processes involved when the computer automatically detects changes and presents them to the user are shown on the left side of the change detection stage in Figure 2. With automated change detection, the computer can continuously scan the situation and search for significant changes. Automated change detection frees the user from the difficulties of unaided detection and provides the opportunity for prioritizing changes and for choosing the order in which they are reviewed and assimilated into the context.

Of course, automation is no panacea. Automated change detection comes with an array of well known problems of trust and reliability (Lee & See, 2004; Parasuraman & Riley, 1997). For example, the definition of significant change is an important challenge, since very many trivial changes may occur that are of little interest to users. However, in many situations it is possible through task analysis to define a set of simple filters, or “trip wires,” that can bring significant changes to the user’s attention for more sophisticated consideration. If well designed, even simplistic automated detection can actually free up user resources for additional scanning of the display to find further changes and to evaluate the significance of changes. For example, St. John, Smallman, Manes, Feher, and Morrison (2005) used relatively simple rules to evaluate aircraft for their levels of threat, and they then faded the symbols for the less threatening aircraft on the situation display. This display manipulation helped users see the higher threat aircraft easily without having to search the display. Air warfare performance improved substantially.

As the computer detects changes, it must then notify the user that changes have been found. This notification may be more or less distracting, depending on the interface design. Notification also gives the user the opportunity to prioritize changes and choose the order in which they are selected for detailed review and assimilation. The prioritization function may change depending on the requirements of the task. One task may benefit from a chronological review of changes while another task benefits from immediate access to the more significant or threatening changes. The design of the interface can affect how effectively and efficiently users can notice, prioritize, and select changes to review.

Once a change is detected and brought to the user’s attention, it must be interpreted and assimilated into the evolving situation context. This is the final, fourth stage of our model. In terms of Endsley’s (1995) well-known three level situation awareness model, assimilation may begin by comprehending the change itself, then integrating it into the evolving situation context, and finally projecting it’s implications for future states of the situation. Failure at any step may limit or delay understanding and appropriate responding.

Four cognitive principles for situation awareness recovery

The four cognitive principles we discuss here focus on the change detection stage of the situation awareness recovery model, and they map closely onto the steps in that stage. We use the term “principle” because the concepts are described at a generic, functional level that can be instantiated in context-sensitive ways for different tasks. We review support for the principles from a series of experiments in the air warfare and mission execution domains.

The principles lie at the nexus between task demands, cognitive limitations, and interface design. “Almost everything we do requires using some sort of artifact to accomplish some sort of task. […] the interactive behavior for any given artifact-task combination arises from the limits, mutual constraints, and interactions between and among each member of the Cognition-Artifact-Task triad” (Gray, & Altmann, 2001). Accordingly, these principles respond to underappreciated constraints imposed by each – tasks require maintaining situation awareness, which is cognitively challenging, and neglected by existing artifact designs. Reviewing the situation awareness recovery model and considering the principles should help designers produce more effective situation awareness and recovery interface designs.

The four principles of situation awareness recovery are to strive for

1. **Automatic change detection** vs. unaided detection,
2. **Unobtrusive notification** vs. obtrusive interrupts,
3. **Overview prioritization** vs. unstructured message presentation, and,
4. **Access on demand** vs. debilitating clutter from immediate availability.

To help understand the principles, we first describe and then contrast two interface designs, a pop-up alert tool, which generally violates the principles and the CHEX tool (Smallman & St. John, 2003), which was designed to comply with the principles (see Figure 1). Both tools are designed to aid users in monitoring an airspace. A pop-up alert tool is designed to detect changes automatically and notify the user when they occur. The notification works by displaying an alert message in a pop-up window superimposed over the main situation display. The pop-up can be dismissed outright or selected to call up a text description of the new change. The pop-up alert is obtrusive and distracting, and it does not surrender much information until the user goes to the effort of selecting it. Even then, the text information is not integrated with the situation display. Despite these failings, it is a common method for presenting automated change detection information in many current displays.

The CHEX tool also detects changes automatically. Changes are logged to a table displayed in the periphery of the user’s workspace. Each row of the table provides a summary description of one change, including an identification number for the aircraft making the change, the time of the change, and a brief description of the change. The rows may be sorted by any attribute to suit the demands of the user’s particular task. Selecting a row highlights that row, highlights any other changes in the table made by the same aircraft, and circles the location of the aircraft on the situation display. The CHEX tool is unobtrusive and limits clutter on the situation display until the user selects a change for detailed viewing. Once selected, the change information is integrated with the situation display. The CHEX tool has been empirically validated in a series of laboratory studies to be an effective situation awareness recovery tool (Smallman & St. John, 2003; St. John, Smallman, & Manes, 2005).

Figure 3 lists these designs among a number of contemporary tools that can be used for situation awareness recovery. The tools are rated on two of the four cognitive principles: their initial degree of information access (notification) and their eventual degree of information access (once a change is selected for viewing). These ratings were based on a set of attributes identified from good human factors design practice and that we believe will specifically affect the costs of information access in situation displays (see Wickens & Hollands, 2000). For example, in a visual search task of an air warfare-like display, we independently manipulated (i) "for the looking" (available without need to interact with the interface) and (ii) "easy to assimilate" (e.g. analog representation), and showed that both attributes independently improve information access and search times (Smallman, St. John, Oonk, & Cowen, 2001). The table calls out several interesting properties of commonly encountered tools that otherwise might escape notice. It is similar in that regard to a recent taxonomy of collaborative knowledge management tools (Bolstad & Endsley, 2005).

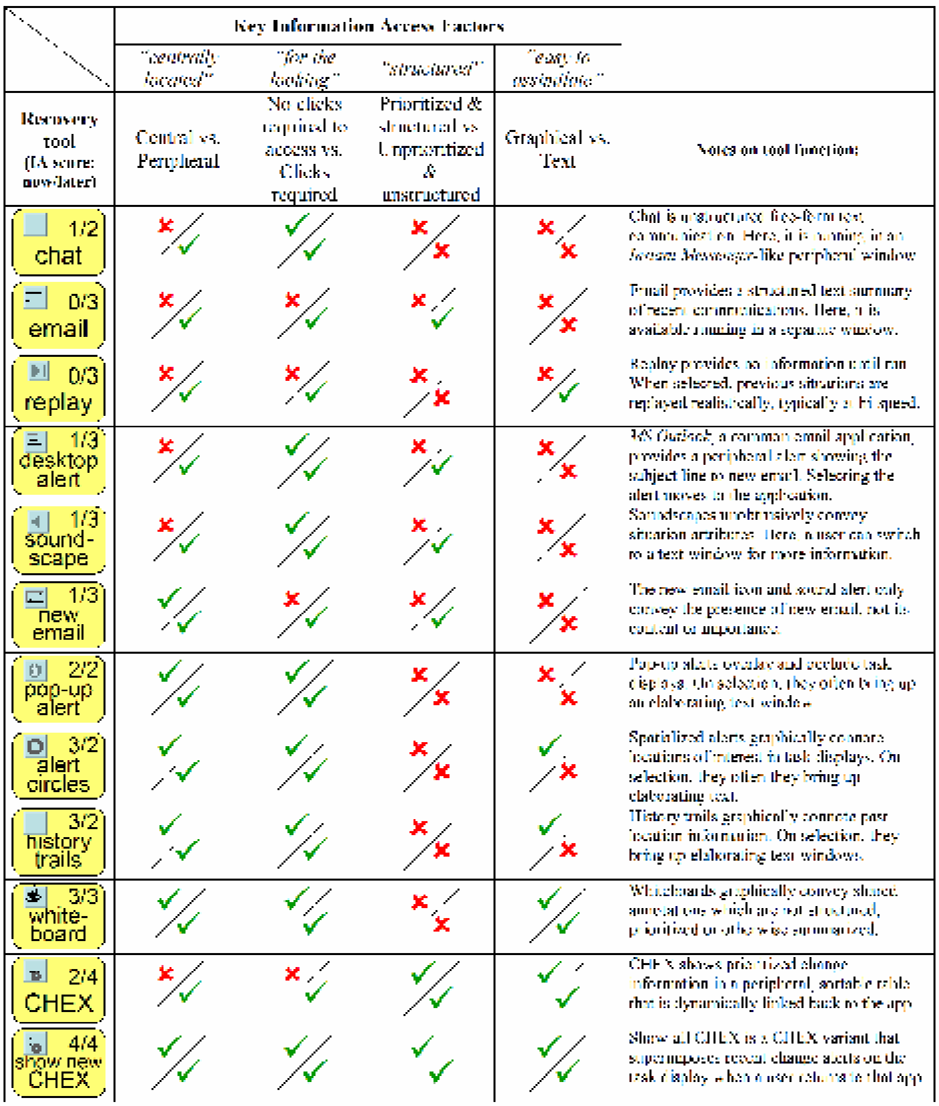


Figure 3. A dozen situation awareness recovery tools compared for the information access (IA) that they afford during notification (now) and once accessed (later).

Principle #1: Automated change detection. Unaided change detection is so difficult that automated change detection is essential. Unfortunately, many situation displays offer no automated change detection support, or only rudimentary interface designs for presenting automatically detected changes, such as pop-up alerts, that violate many of the principles we lay out here. Instant replay, in which a missed episode can be rewound and replayed for the user, is one high tech solution that is sometimes touted as an effective interruption recovery tool. It certainly seems to hold intuitive appeal for many users. In actuality, it is just a sophisticated version of unaided detection, and has proven worse than having no tool at all! Users must still rely on their own poor unaided detection abilities when reviewing the scene as it replayed at high speed, and it distracts the user from real-time monitoring, in effect actually lengthening the interruption (St. John, Smallman, & Manes, 2005).

Principle #2: Unobtrusive notification – "First, do no harm." With automated change detection, a method is required to notify users of detected changes. This notification method should be relatively unobtrusive for three reasons. First, change notification during real-time monitoring may distract from or interrupt other important tasks. Second obtrusive notifications demand attention regardless of their priority. Third, change notification may clutter or obscure other task-relevant information. In this respect, pop-up alerts can greatly harm the user's main task. Even more subtle notification, such as marking changed aircraft within an airspace with red circles can cause significant clutter and distraction (the "alert circles" of Figure 3). Ultimately, clutter and distraction must be weighed against the value of the information provided (see principles 3 and 4). Nonetheless, less distraction and less clutter are always preferable. Obermayer and Nugent (2000) provide a simple taxonomy of alerts that connects to recommended alerting methods, from disruptive alerts for mission critical information to unobtrusive alerts of mundane information.

One less obtrusive notification method is to present alert messages in a consistent peripheral location where they can be noticed in peripheral vision or can be scanned periodically, as done with the CHEX tool. The downside of peripheral alerts is that they may require the user's eyes to leave the situation display in order to scan and attend to the peripheral display. It is well known that if these scans are too frequent, too long, or too far away from the main display, they can disrupt performance. Therefore, if change notification is going to reside in a peripheral display, the display should be easy to notice, contain only brief, summary information for quick viewing, and not be placed too far from the main situation display. Peripheral displays are also disjoint from the situation display, therefore a method is needed to re-integrate the change information with the situation, once the user focuses on the change alert (see principle 4).

Another unobtrusive change notification method is to provide a subtle "new message" sound that distracts only marginally from on-going tasks. The common email and chat new message sounds are examples. A third method is the soundscape approach, described above, investigated by Watson and Sanderson (2004).

Principle #3: Overview and prioritization. Structured and summarized change information, that can be flexibly sorted according to task demands, provides an overview of new changes and can facilitate prioritization. When returning from an interruption, it can be useful to view urgent messages before mundane messages and critical changes before trivial changes, especially if time is limited. As noted above, urgency and topic information are also useful for the scheduling of interruptions.

The air warfare version of CHEX provides a table that summarizes the attributes of recent changes. Users can quickly scan the table to find critical changes or changes on a topic of interest. The table can also be sorted on any attribute or sorted chronologically, depending on task requirements. A CHEX table sorted by criticality allowed users to find the most significant changes faster than when using alternative displays (Smallman & St. John, 2003).

In a mission supervision version of CHEX, the table was replaced by a row of icons, called infobs (after Patrick H. Winston's "information objects", Winston, Porter, Keel, et al. (2004), see Figure 4). The infobs graphically convey important attributes of messages and other changes. The infobs provide an overview that conveys summary situation awareness information, and it allows users to select messages from specific senders or on specific topics easily. In an experiment using this display, situation awareness recovery following interruptions was measured by asking users a series of questions about events that occurred during the interruption. Users were better able to visually scan the infob icons to find summary information and to focus on specific topics than they were able to search through chat messages or whiteboard annotations (St. John, Smallman, & Manes, 2006).

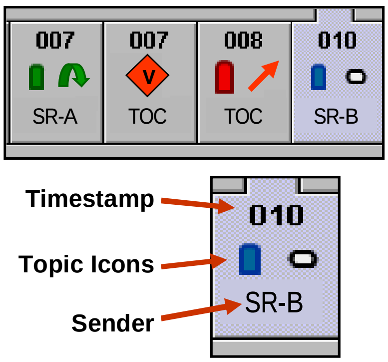


Figure 4. (top) A row of infobs from the mission execution version of CHEX. (bottom) Detail of components of one infob.

Subject lines in email programs provide some limited summary information that can be useful for prioritizing messages. Chat tools, on the other hand, do not provide any summary information. Whiteboard tools, which present annotations on the situation display immediately as they arrive, also provide no summary information or even a chronology of which messages arrived before other messages.

Alert circles that indicate the locations of changes, for example, the locations of changed aircraft in an air warfare task, also fail to provide priority or chronology information. They leave users returning from an interruption with no clear place to begin recovering situation awareness. Therefore, they are distracting and cluttersome, but provide little information in return. In an experiment, alert circles required 29% more time to find critical changes than the less obtrusive, more effective CHEX tool (Smallman & St. John, 2003).

Principle #4: Minimal clutter but maximal access. The fourth cognitive principle is to minimize clutter on the situation display while still providing effective access to the change information. Clutter can make search for important situation information harder and confuse a situation. For example, head-up display clutter can interfere with search in the far field (Yeh, Merlo, Wickens, & Brandenburg, 2003)

The goal to minimize clutter creates an interesting tension with the goal to notify users of new changes and messages and to provide easy access to that information. Integrating notifications into the situation display can make the notifications more meaningful and useful for prioritization. However, integration also creates clutter and distraction – it does harm. As mentioned previously, alert circles integrate change alerts into the situation display, but cause clutter.

In weighing information access against clutter, it is useful to separate access to change information into two phases. The first phase primarily involves notification of a change, and the second phase involves the presentation of details about the change and how it integrates with the evolving situation context. Distraction, clutter, and information availability can be evaluated separately for each phase. Figure 3, above, follows this distinction and focuses on notification. Figure 5, below, also focuses on notification and illustrates the tension and trade-off between access and clutter.

For example, pop-up alerts provide very little important information initially, but substantial clutter since they obscure the situation display. Once selected, they provide only text information that is not well integrated with the situation display. Whiteboards, on the other hand, conflate these two phases by providing all information immediately. Access costs (Wickens & Hollands, 2000) are low, since all information is immediately available for the looking, but at the cost of substantial clutter and little prioritization information. Returning from an interruption can pose a challenge to users who may be faced with a visual spaghetti of overlapping annotations. History trails that mark the path of objects moving across the situation display, and alert circles, pose similar problems, albeit to lesser degrees.

An alternative to immediate presentation on the situation display is access on demand. In the CHEX tool, changes are initially listed in a peripheral table. Hence, the initial notification is minimally distracting and minimally cluttersome, yet the summaries provide substantial information. Selecting a change in the table reveals information about the change within the situation display. We call this on-demand linking of selected information across displays dynamic visual linking. Dynamic visual linking minimizes initial clutter, but it comes at the price of increasing access cost to the information, since it must be selected to make it visible on the situation display.

A wrinkle on the minimal clutter principle may arise from differences in task demands (Miyata & Norman, 1986). When a user is monitoring a situation and performing a variety of situation management activities, presenting all messages directly on the situation display can cause debilitating levels of clutter that interfere with on-going tasks, as well as obtrusively interrupting the user. However, when returning from an interruption, a user may benefit from explicit and highly available change information, since assimilating changes is the primary task at hand for recovering situation awareness.

In the mission supervision task, we found that immediate presentation and availability of new message information was superior to access on demand. In this case, clutter was not minimized, but it was still managed by hiding older messages and making them only available on demand. Meanwhile, new messages where immediately available on the situation display. This tool is called "show-new-CHEX" in Figure 3. The compromise between access on demand and immediate availability that it implements allowed users to more easily view key annotations than did a whiteboard tool with its complete information availability (St. John, Smallman, & Manes, 2006).

It may be that limited immediate availability is worth the price in clutter specifically when users return from interruptions and need to recovery situation awareness, while access on demand, with its lower clutter and less obtrusiveness, is worth the price of higher access costs during real-time monitoring, where other tasks complete for the users' attention.

Evaluating tools against the principles: design-trade offs

Based on the evaluations in Figure 3, we graphed each situation awareness recovery tool based on its initial information access for notification against the degree of clutter it forced onto the situation display (see Figure 5). This graph illustrates principle 4: the design trade-off between immediate access versus clutter. The vertical axis represents the initial amount of access provided by a tool when a change is detected. The numbers on the axis correspond with the numbers in Figure 3. The horizontal axis represents the initial amount of clutter forced onto the central situation display by the initial change alert. A good design inhabits the green, top left region of the graph by providing good access without clutter. A bad design, on the other hand, inhabits the red lower right region by providing poor information access while liberally cluttering the display. Most tools provide either poor access and low clutter or good access and high clutter. The goal, of course, is to provide good access with minimal clutter.

CHEX, for example, provides only moderate immediate access through a peripheral display, but is therefore very low clutter. Whiteboards and show-new-CHEX provide more change information integrated onto the situation display. They therefore provide greater initial information access (moving upward on the graph), but at the cost of more clutter on the situation display (moving rightward on the graph), illustrating the design-trade off along the diagonal.

The arrows in Figure 5 indicate how information access changes once the change is selected and the tool becomes the focus of attention. Continuing with the CHEX example, after selecting an entry in the table, a track is circled and highlighted on the situation display. Thus, centrally located information, for the looking, is summarized and graphically integrated into the task display for an increase in the information access score to four. Figure 5 also illustrates some counter-intuitive and revealing aspects of existing designs. For certain designs, the information access score actually ***decreases***. Alert circles, for example, immediately provide graphical, integrated information about the location of changes, but switch to lower access text descriptions of the changes when they are accessed. Once users have interrupted their main task and accessed a change message, there is little justification for placing continued access overhead on them.

The tension between the desire to inform yet not distract is often felt by interface designers, and we are certainly not the first to note it. For example, Bailey, Konstan, and Carlis (2000) created a two by two matrix of high/low awareness versus high/low intrusion web alert design features. Based on this analysis, they created an adjustable window concept to produce a high awareness, low intrusion alert for web browsing. It functioned by momentarily contracting the main browser window and injecting a small text alert into the window gutter. The feature is similar in several respects to the desktop alert feature that the Microsoft Outlook 2003 email program now employs, and that is included in Figure 3 and Figure 5.

Interestingly, we personally find the desktop alert to be inordinately distracting in spite of its low clutter. This negative evaluation is very likely due to the fact that most email messages are very low priority. Hence, the differential in priorities between the main task and interruptions is another important component for the design of effective interruption and situation awareness recovery tools. The frequency of new messages and the breadth of topics they involve are additional components. Our focus here has been on dynamic operational tasks in which most changes and messages pertain to that task. There is still much to done to address the broader issues of other types of tasks.

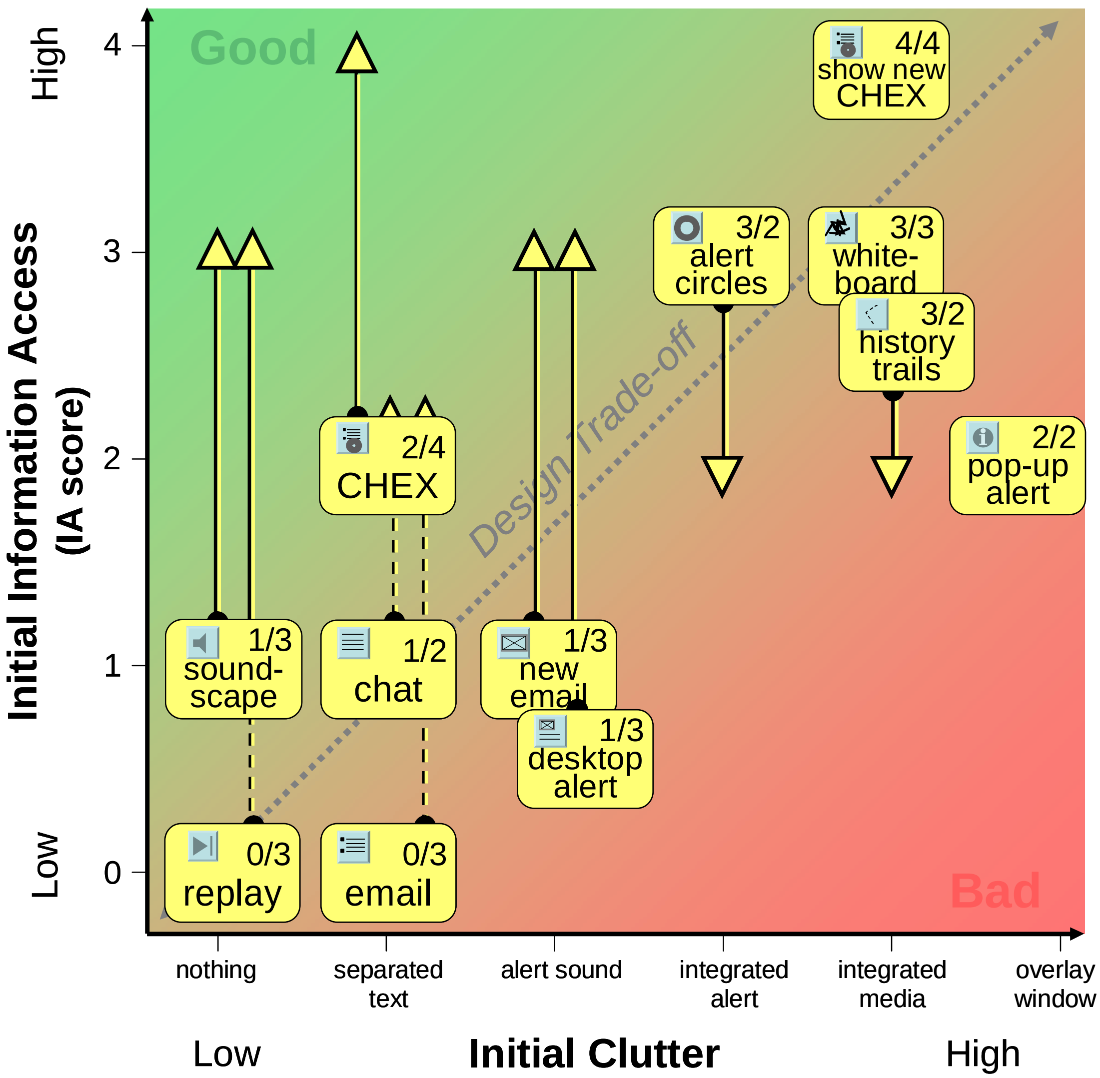


Figure 5. Information access of the situation awareness recovery tools of Figure 3 plotted against their initial clutter.

Summary and conclusions

Dynamic operational tasks require special interface design considerations to support situation awareness recovery from interruptions. We introduced a model of situation awareness recovery to provide an organizing view of different approaches to the topic that can be found in the literature. Support for interruptions and situation awareness recovery can take a variety of forms by focusing on any of the four stages of situation awareness recovery of the model (shown in Figure 2). A crucial stage that is often overlooked is support for detecting changes to the situation that occurred during interruptions, or even during high workload episodes of real-time monitoring. Without support, detection of important changes to the situation may be missed or delayed, placing operations and people at risk.

Focusing on this stage of the model, we derived four cognitive principles for improving interface designs to better support change detection. The first principle is that automated detection of changes, even simple trip wires, is critical for supporting user's poor unaided change detection capabilities. The remaining three principles follow from the first. Given automated detection, methods are needed to notify users of detected changes without unduly distracting them, help users prioritize viewing the changes, and provide access to the information with minimal clutter. Figure 5 illustrates the tension inherent in principle 4 between providing access to change information and the clutter that can result. The goal is to minimize clutter while still providing excellent information access. Our CHEX solution has been to move notification to a nearby yet peripheral display where summary information about changes is logged. From there, access on demand via dynamic visual linking integrates individual changes back into the situation display where they can be interpreted and assimilated within their context.

We have found this approach to work well within an airspace monitoring task. Within a mission execution task, however, a somewhat different trade-off between access and clutter was found to work better, namely providing immediate and integrated access to new messages while still allowing access on demand to older messages. Careful consideration of users' needs and task demands is central to determining the best trade-off.

Our hope is that consideration by designers of these principles will help to drive the invention of more effective situation awareness recovery tools. Additional principles are bound to be discovered that will further guide the invention of superior tools.

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