Subthreshold Data Cognition: Adaptive “Mitigation” Strategy

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Abstract

As increasingly large volumes of critical disparate data and imagery provide crucial information, operators require more sophisticated and enabling visualization tools to promote efficient cognition. There is a challenge to design interface elements to declutter and prioritize information. This reduces operator fatigue and stress. One might conclude that a significant reduction in workload results from "hiding" all irrelevant information and providing only the information that is pertinent. The problem with this approach is that what is important, changes rapidly within typical missions and between operators.

The operator must distill the correct tasking at the right time with the most pertinent information, even as screen clutter, visual noise and disruptive (maladaptive) change blindness challenge the operators’ ability to direct the mission. Change blindness (disruptive) is the inability to detect, due to eye movement, image shift, transients or other disruptive visual events, what should be obvious changes between two images or image sequences (Simons & Rensink, 2005). Gradual change blindness (non-disruptive or adaptive) is the inability, due to the slow nature of the change, to detect what would normally be an obvious change between two images or image sequences.

Currently, there are two primary types of peripheral awareness indicators; discrete (stoplight) and real-time (constant visible change) that introduce visual noise. TransLumen displays objects that aggregate multivariate data on a single object conveying dynamic changes in information without the intrusion of visual disruption and visual noise that cause transients unless defined thresholds are exceeded. The operator has more time to concentrate on high value information, reducing the operators’ workload, increasing the accuracy of mission decisions and enhancing operator trust of the technology. Keeping secondary information current and persistent without attracting a user's focus of attention unnecessarily is accomplished by "unobtrusive change" embedded in peripheral awareness indicators.

TransLumen uses a subthreshold method of change similar to that of "gradual change blindness", one that does not cause a disruption such as a saccade, a transient or a spike in visual signal strength. This transformation, while unobtrusive, is dynamic and provides continually updated information. However, if an alarm threshold is crossed a discrete change such as flashing may be invoked to prompt immediate focus and attention to the indicator. Intelligent timing and cueing of object changes and alarm states will help mitigate information loss. The result is the correct and timely recognition of changes in the visual display.

1 INTRODUCTION

This paper will address how subthreshold extreme gradual change (STEGC), which produces a series of imperceptibly changing images (Siefken, 2000), can serve a role in interruption mitigation, which may be defined as the process of eliminating distractions that detract from operators’ focus and attention on their primary task. The method that will be described uses Extremely Low Attention Demand Information Systems (ELADIS) as the overarching environment, and in which situation awareness is enhanced by the implementation of peripheral awareness tools that have been augmented by subthreshold extreme gradual change.

2 CHALLENGES TO ADDRESS

As the human operator is tasked with more supervisory functions due to the proliferation of sensors and other distributed data sources represented on displays and control systems, the operator must distill the correct tasking. This must be accomplished at the right time with the most pertinent information, even as screen clutter, visual noise and disruptive (maladaptive) change blindness challenge the operators' ability to direct the mission.

Increasing the number of items on a display increases the amount of time required to locate an item and therefore, efficiency and perhaps even accuracy decrease with increasing levels of information. In response to clutter, configurable (object) displays organize *related* information (Woods, Wise & Hanes, 1981), but not all information is related, nor related in the same way across differing contexts. In an effort to maximize the use of display real estate, designers often utilizes digital readouts. The effort may prove to be a false economy, as flashing digital readouts for one dimension (e.g. airspeed) provide ineffective rate-of-change information for that same dimension, (e.g., acceleration) requiring a second digital readout. Color-coding, highlighting, intensity-coding and other visualization techniques offer a mechanism for consolidated information presentation (Yeh & Wickens, 2000). Nevertheless, currently available graphics technology applications limit the manner in which changes in hue and saturation appear, potentially resulting in distracting, discontinuous noise.

A major source of visual interruption is caused by stimulus-driven change detection. One way to mitigate interruption of this type is to cause changes to occur so gradually that human visual motion-energy detectors are not triggered. If an indicator is serving as a secondary event monitor, for example, when a stoplight indicator changes in a discrete and abrupt manner from green to yellow, this is immediately noticed, detracting the operator from the primary task. By slowing the rate of change to subthreshold levels, this change will not detract an operator's attention from a primary task.

2.1 Scenario Example One

The operator will ultimately manage more mission sensitive tasks in more complex operations potentially combined with other related or non-related task assignments. For example, an operator of Unmanned Vehicle (UxV) operations is tracking multiple UxVs with other manned and unmanned vehicles in the same space. It is the controller's responsibility to know where his vehicles are, what they are doing, and what they should be doing both currently and in the future. The controller must also consider the location, apparent movement of other vehicles, as well as safe areas, keep-out zones, and dedicated corridors created for deconfliction. As more such layers of critical information are depicted on the displays, the operator's stress and fatigue will increase and performance will be diminished. For example, with fatigue there would a greater potential to fail to detect changes in information, or even fail to detect the presence or absence of information. A dangerous assumption of contemporary display design guarantees that it will not scale to the anticipated demand. This assumption is the need to replicate physical structure and organization on display surfaces. In the case of a UxV mission, this may mean separate displays for separate vehicles.

In military applications, the details of these objectives change in real time, and the priority allocated to achieving the mission objectives vs. preserving the unmanned vehicle asset will vary from mission to mission. Physically distributed mini-control centers must push information to other individuals in the network. Yet, coordination in timing and synchronization in action across centers will mean the difference between success or failure in emergency situations. As more tasks are put upon the controller or operator, these assets will be put at risk. Along with the cost of conserving air vehicle assets, ground mission command and control centers also have infrastructure costs that need to be mitigated. As the UxV system evolves, there will be demands for providing easier deployments for smaller unit set up and tasking. Mobile or smaller ground mission equipment requirements will need to provide adequate situation awareness and support to the controller despite the reduction of available screen real estate.

3 NON-CONFLICTING PRESENTATION OF SECONDARY AND TERTIARY INFORMATION

One way to keep secondary information current and persistent without attracting a user's focus of attention unnecessarily is to exploit "unobtrusive change" as a peripheral awareness indicator. Symbology driven by subthreshold extreme gradual change displayed objects or peripheral awareness tools can present aggregated multivariate data conveying dynamic changes in information without the intrusion of visual disruption and visual noise. Change in appearance can reflect change in meaning so that a desired distraction is informative and functional rather than an accidental consequence of limitations in graphics technology. The operator would then have more time to concentrate on high value events, thus reducing the operators' workload, increasing the accuracy of mission decisions and enhancing operator trust of the technology.

Applying new methods of change similar to that of "gradual change blindness" that do not cause a disruption such as a saccade, a transient or a spike in visual signal strength will create transformations that while unobtrusive, are dynamic with the capability of providing continually updated and predictive/trending information. However, if an alarm threshold is crossed a discrete change such as flashing may be invoked to prompt immediate focus and attention to the indicator. Intelligent timing and cueing of object changes and alarm states will help mitigate "change blindness" in this context. The result is the correct and timely recognition of changes in the visual display.

Transition between primary states is accomplished by limiting the rate of change in the graphic. This results in an imperceptible change to the graphic, which looks static when in fact it is dynamic and constantly changing. In cases where the need for accuracy and efficiency is greatest, contemporary, real-time display technology produces flickering or buzzing displays with overly responsive, discrete changes in appearance. Subthreshold extreme gradual change augmented peripheral awareness indicators will decrease operator overload. They can create an easily understood indicator across all operators' basic cognitive differences and capabilities by using already learned colors, symbols etc. providing more information dissemination opportunities.

Subthreshold extreme gradual change mitigates the distraction of stoplight and real-time data displays. The technology can be modular, permitting a straightforward replacement of existing technology without requiring a complete redesign of the operator interface.

In defining the set of relevant independent variables, we have examined the existing literature on selective attention in a dual task paradigm. This literature examines distractor salience, similarity between distractor and primary tasks, task loading and onset asynchrony between state changes in the distractor and primary tasks. Behavioral measures such as response time and percent correct may be sensitive to task loading (Lavie, 1995; Lavie & Fox, 2000). Somewhat paradoxically, it is the lower-load conditions that may be subject to distraction. (Eltiti, Wallace & Fox 2005) suggest that a simple identification task at the rate of one decision in three seconds comprises a moderate load, which can be impacted by the properties of the distracting task.

The three presentation technologies (stoplight, real-time and subthreshold extreme gradual change) represent the continuum of discrete to continuously portrayed state changes. The stop light technology represents only three states (nominal, caution and alert) and provides the largest magnitude in color change. The real time presentation has more states, which permit smaller apparent color changes. However, depending upon display hardware and presentation logic, as few as four changes per second using real time technology has a buzzing appearance. The subthreshold extreme gradual change technology has the highest fidelity and, therefore, permits the smallest apparent color changes. Noise suppression logic is inherent in subthreshold extreme gradual change technology and prevents transient data spikes from resulting in large instantaneous color changes. However, the potential for distraction in any presentation technology is an additional function of the event stream and the mapping of the presentation scale to the event stream. For example, stop light technology is maximally distracting when the monitored dimension changes frequently relative to the stop light scale.

The literature suggests that the relative onset between changes in one cue and changes in another impacts the degree of interference, with sensitivity appearing somewhere in the region of 100-400 msec (Müller & Rabbitt, 1989). That is, in order to detect distraction of the secondary task it should change to a critical level within 100 to 400 msec prior to an event. Depending upon the asynchrony, distraction should appear as a delayed response to an event, or perhaps even false alarms. Distraction would then appear as a delayed response to the event. To maximize the potential for capturing distraction, we would examine secondary task critical onsets from 100-150 msec before an event.

3.1 Scenario Example Two

Subthreshold extreme gradual change technology when applied to peripheral awareness indicators such as bars, objects or gauges that graphically depict the current status, alarm state and trend of the user's data may convey important, but secondary, information that needs to be monitored due to potential status changes. These changes could promote the secondary task to primary task status. For example, an operator/controller is monitoring weather across a broad geographic area. The primary task is to monitor multivariate data input from sensors, satellites, cameras and other devices. The operator will monitor, analyze and classify any unusual activity that will impact vital supply deployments due to critical weather patterns.

Some of these elements can be modeled into primary task monitoring, analysis and action while others can be aggregated into additional subthreshold extreme gradual change indicators. In current displays, information is reflected via gauges, numbers, stoplight indicators or real-time presentation. The new technology can aggregate the elements of wind speed, humidity, fog, temperature, surface temperature, barometric pressure and other meteorological aspects that aid operators during disastrous events. A peripheral awareness tool may also incorporate comparison swatches such as lagging or predictive, maximum or minimum indicators to aid the operators' ability to recognize trending information as it dynamically, but unobtrusively, changes. A key multivariate aggregator can be user-defined for weather elements that effect disaster recovery operations and logistics. Typical monitoring of environmental aspects will be detailed, but secondary, unless threshold violations occur. The indicator cue will be embedded into color-coded cell objects on the display screen. As the graphic in Figure 1 below conveys, data will map to multivariate Meteorological Data sources. This map will be aggregated by a rules based or other form of intelligence. The indicator will show change over time without disruption or visual noise.

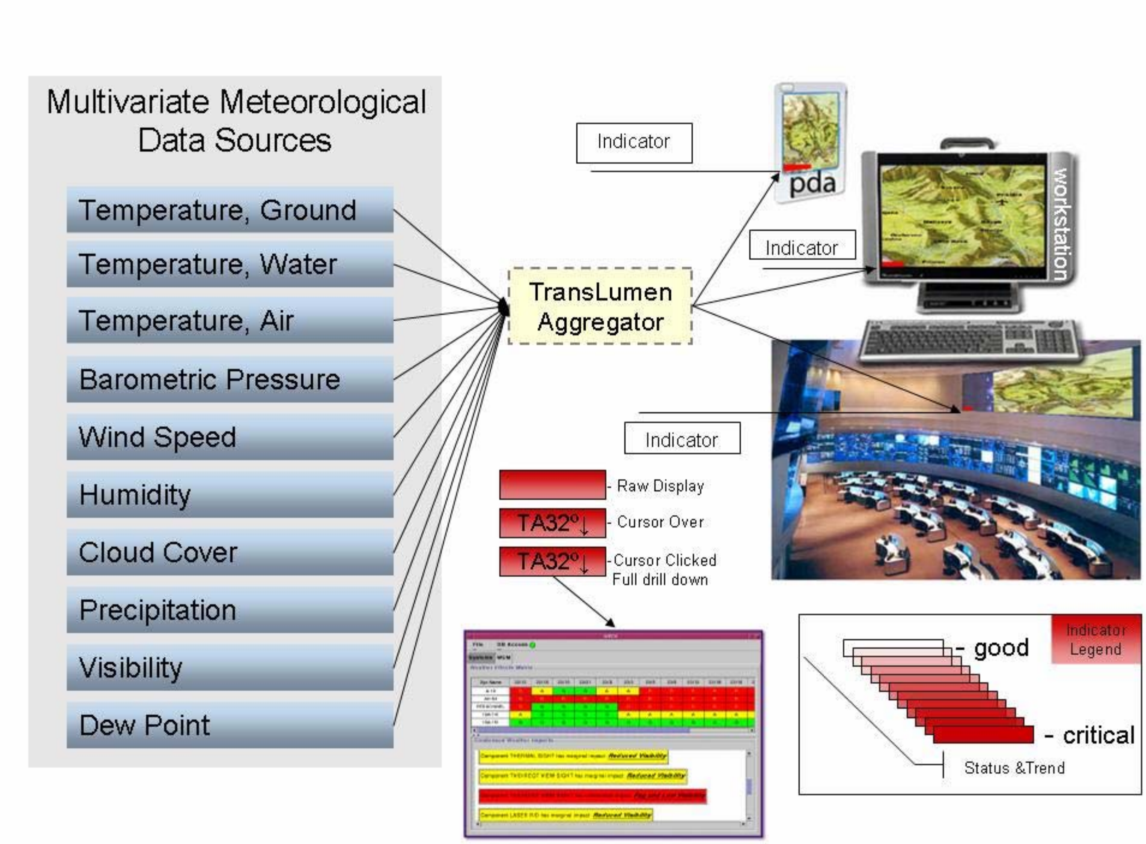

Figure 1. Indicator data flow

Workload balancing is optimized when an operator is not in an overload or underload tasking environment. Current technology lends itself to visual attentiveness testing for load conditions by using subthreshold extreme gradual change combined with keystroke or CPU usage as examples. Peripheral awareness tools with such capability will aid the operator, increasing the level of arousal during slack times, which upon sensing underload the indicator could implement training lessons appropriate to the current environment. Operator cueing can take the opposite approach to reducing visual noise during times of extreme stress. Future workload balancing will be augmented by neurophysiologic and biometric monitoring combined with advanced artificial intelligence.

One of the most significant forays into the peripheral awareness tools arena has its roots in Microsoft Research including works such as MSR-TR-2001-83 Sideshow: Providing Peripheral Awareness of Important Information (Cadiz, J., Venolia, G., Jancke, G., & Gupta, A. 2002). Some of the results of this research are currently able to be seen in Microsoft Vista's™ Sidebar.

Six primary design principles were used in the original Sideshow.

- make it always present
- minimize motion
- make it personal
- make it extensible
- support quick drill-down and escape
- make it scalable

In considering what might help comprise the ideal peripheral awareness tool the preceding list should serve as a good starting point. It would be a visual indicator or gauge that graphically, through color, luminance, texture, shape, position and size among other attributes, can present the current status, alarm state and trend of the user's data. This data may be secondary information that needs to be monitored for status changes. These changes could promote the secondary information to primary importance if not investigated in the user-selected order as dictated by the hierarchy or relative value in the cue. The peripheral awareness tool should be persistent and pervasive within the user environment without disruption. The need for trust and persistence would eliminate the use of an invisible state.

Training should be minimal based on the graphic design, which may include custom imagery, and the degree of autonomy desired. The indicators may be an avatar, chart, button, gauge or virtually any other graphic design that best portrays the information to be conveyed. The indicator would be implemented as a skin, widget, gadget, applet, ticket or panel, and may be freely positioned on the desktop or presented through AJAX, Java, Microsoft's Vista™ Sidebar, Apple's Dashboard, Yahoo!'s Widget Engine, Google's™ Desktop Sidebar and other environments. Full custom implementations would allow virtually any desktop or screen object such as a background, scrollbar, taskbar, frame, button, image or icon to be used. The indicator could also be used to query and provide potential solutions (from both local and distributed sources) to information provided through drill-down as alarm thresholds are crossed.

With today's wider computer displays (16x9 ratio) and higher definition these principles combined with subthreshold extreme gradual change and aggregation provide an excellent environment for the display of secondary or tertiary information. Aggregation of data allows for the indicator to be persistent (always present through visual cues) and scalable, while subthreshold extreme gradual change allows for the most dynamic yet non-disruptive presentation of information attainable. The ideal design should also offer personalization and be capable of handling multivariate data that is both accessible yet provides easy nondestructive egress.

Currently there is work being conducted with approximately 30 variables that impact individual operator response times. There are three overlapping elements effecting response times. They include Environmental, User and Image variables, including but not limited to the variables in Table 1.

Table 2. Environmental, User and Image Variables

Environmental Variables	**User Variables**	**Image Variables**
Viewing Distance	Hyper reactive	Color
Brightness	Stress level	Shape
Adjacent luminosity	Level of interest	File format
Ambient conditions	Fatigue level	Luminosity ranges
Angle of view	Color response	Contrast
Screen	Visual acuity	Object Size
Adjacent Colors	Attention span	SOA (stimuli onset asynchrony)

4 ADVANCING PERIPHERAL AWARENESS TOOL CAPABILITY

Decluttering visual displays by aggregating multivariate data of supporting secondary tasks and having persistent but transient free dynamic monitoring, will free up the operator to make better decisions in complex environments. The technology leap to advance the visual “system” as a whole requires the combination of lower level autonomous decisions and task-based principles for organizing information with subthreshold extreme gradual change. Development of automated threat assessment algorithms that are both sophisticated and reliable has long been a goal for aiding situation awareness generally, and air defense in particular; (St. John, Manes, Smallman, Feher & Morrison, 2005).

Current UxV systems, for example require at least one human operator per monitoring tasks; however, emerging systems will have a single operator managing several physical monitors, which have a great deal of self-adaptive capability, within mission-defined limits. Intelligent vehicles in emerging systems have, and will have, very well monitored, redundant, and self-healing subsystems. They will report to the controller when they are experiencing degradation, the nature of the degradation, and the impact on performance. It is the responsibility of the controller to monitor this status, to report it when necessary, and to consider it when making decisions about the monitoring interface capability to continue its task or accept retasking.

With subthreshold extreme gradual change augmented trending software combined with intelligent agents, different streams of data are represented on displays while conserving screen real estate, improving human cognitive capabilities and mitigating a level of bandwidth constraints through aggregation. With the next generation of symbology, enhanced with added functionality, training will be minimized for operators with diverse backgrounds.

The ideal indicator would also be a collaborative environment capable tool imbued with the means of monitoring large volumes of disparate data provided by both local and remote applications including web services. Local data examples include such resources as system health, disk usage, CPU load and network usage. Remote data examples include command and control information such as security, environmental conditions, opponent strength within an area and first responder resource availability. With mobile devices and the proliferation of screen technology, the capability of following the user anywhere presents other challenges, which includes the requirement for scalability and conservation of screen real estate without compromising information flow and integrity. Other remote or external data sources may include the stock market, sports statistics and e-mail. Any or all of the previously mentioned data could be simultaneously monitored by just one indicator. If desired by the user, multiple indicators should also be deployable on a single desktop and allow the nesting or categorization of like data.

Peripheral awareness tools could be augmented with both wetware and noninvasive neurophysiologic monitoring and feedback and combined with other technologies including subthreshold priming if relevant. All of this should be accomplishable on existing screens without compromising the current view.

5 CONCLUSION

Interruption mitigation is one of the more important issues faced today in data cognition. As the human operator interfaces with display technology, and as more critical disparate data and imagery are used to provide crucial information, operators need superior visualization tools to increase their cognition and situational awareness of events and trends that are not immediately apparent. This needs to be accomplished without distracting/interrupting the operator from the most immediately important primary task. Decluttering and visual noise reduction must take into account real-time task assessment and prioritization of threats and other data as well as information reliability and capabilities of the automation system. This may be achieved reliably through the replacement of stoplight and real-time indicators with intelligent, aggregating, subthreshold extreme gradual change technology. Advanced algorithms provide the underlying method used for controlling the rate of change in subthreshold extreme gradual change augmented tools.

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