Preattentive Attributes in Visualization Design: Enhancing Combat Identification

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Abstract

The process of Combat Identification (CID) demands that objects in the battlespace be quickly and accurately characterized to maximize combat effectiveness, and to protect the lives of friendly forces and non-combatants. Because stressful situations can inhibit cognitive abilities, human machine interfaces (HMIs) designed for combat use must be built to optimize the display of relevant information. Psychophysical responses of the human visual system known as preattentive processing may hold some of the keys to building systems that quickly and accurately convey battlespace information to war fighters. Background information and research is presented regarding preattentive processing and preattentive attributes, supporting its use in HMI design. Practical examples showing HMI applications of preattentive attributes are illustrated, and relevant design implications discussed.

Preattentive Attributes in Visualization Design: Enhancing Combat Identification

The U.S. Joint Chiefs of Staff (JCS) define combat identification (CID) as "… the process of attaining an accurate characterization of detected objects to the extent that high confidence and timely application of military options and weapon resources can occur." (2003, p. I-4). While a topic of much debate, the overarching goal of CID is more than avoiding fratricides; the goal is to win conflicts, and win them decisively (Dittmer, 2004). As one measure of CID effectiveness however, statistics show that fratricide incidents accounted for a minimum of 10% of the total U.S. casualties in World War II, Korea, Viet Nam, and the first Persian Gulf War (Shrader, 1982; Steinweg, 1995). Conflict on the modern battlefield involves a myriad of participants, including joint and multi-national forces, heterogeneous enemy factions, civilians and non-combatants. In an era characterized by rapidly moving forces and weapons that can strike targets with very high precision at unprecedented ranges, the difficulties of Command and Control (C2) have increased tremendously. This results in increased opportunities for targeting errors, and in fact, it has been asserted that the nature of modern warfare, however technologically advanced, actually raises the risk of fratricide (Defense Update, 2004; Rasmussen, 2007).

As U.S. and coalition forces transform to a network-centric warfare paradigm, increasingly, weapons systems are more dependent on external sources for precise targeting information and firepower is routinely unleashed on distant coordinates provided by remote sensors and network sources (Rasmussen). The *kill chain* in a network-centric environment can only be as strong as its weakest link; thus it is imperative that the human-machine interface (HMI) at every connected level, from sensor to shooter, be designed to maximize the warfighter's ability to comply with the JCS' dictum to quickly and accurately characterize the detected objects in the dynamic tactical situation that unfolds before them.

History provides well-known examples of instances where flaws in the design of system interfaces were found to be causal in the loss of innocent lives. In 1988, the U.S.S. *Vincennes* shot down an Iranian airliner filled with civilian passengers, killing all aboard. Though the system was found to be operating normally, an overly complex and poorly designed weapons control interface was blamed for the tragedy, as the weapons system operators were unable to accurately characterize and interpret the aircraft's actions in a timely fashion (van den Hoven, 1994; Lerner 1989, Cummings, 2006). More recently, during Operation Iraqi Freedom, the confusing and overly complex interface design of the Patriot air defense artillery system, along with inadequate crewmember training, and *automation bias* (Mosier and Skitka, 1996), were implicated in two separate fratricide incidents, resulting in the inadvertent destruction of British and U.S. fighter aircraft, killing three aircrew members (Mares & Giammanco, 2005; Cummings). In technology-dense environments, it has often been the case that when errors occur, they are attributed to the human operators. However, some researchers indicate that very often the fault lies with the design of the systems themselves (Perrow, 1984; Norman, 2002).

Decision making in high stress environments

Following the *Vincennes* incident, the US Navy initiated the TActical Decision Making Under Stress (TADMUS) project, spending over 10 years researching the problem areas that emerged from the incident (Hawley, 2006). The aims of the program were to: analyze decision making strategies used by people in stressful situations; determine the ways those strategies sometimes fail; and to prevent these failures (Hair & Pickslay, 1993). The Navy found that Situational Awareness (SA) plays the key role in decision quality in the command and control domain, and that SA is built upon tactical experience and expertise (Cannon-Bowers & Salas, 1998). However, other research indicates that as the primary visualization tool for assessing a tactical situation, the weapons system's HMI is supremely important; indeed, in a command and control context, system HMI usability may be the primary determinant of SA (Bolia, Vidulich, Nelson & Cook, 2004). The Navy further concluded that operator training must necessarily emphasize the development of adaptive decision-making skills. Anomalous events must be introduced regularly into training regimens, encouraging weapons operators to be able to respond flexibly and effectively to non-routine events (Cannon-Bowers & Salas). Conversely, however, it has also been asserted that at a certain point, no amount of pre-selection and training of personnel can compensate for a flawed HMI or system design (Crisp, McKneely, Wallace, & Perry, 2001). Clearly, in complex socio-technical systems such as command and control, with decisions that are sometimes made under extreme stress, there are multiple potential points of failure.

Stress is not exclusive to the military domain; in their study of medical decision making in level 1 trauma resuscitation wards, Xiao & Mackenzie (1997) determined that stressful environments are characterized by the following: "Fast-changing, complex and uncertain situations…in which the performance in decision-making carries high stakes…in which critical decisions have to be made under extreme time pressure…in which decisions are made and carried out collectively by multiple individuals in a team setting" (p. 12). When people are required to make rapid, important decisions in stressful environments, research has found that the effect of stress on the quality of decision making typically results in two types of outcomes. When stress is moderate, vigilance increases to a constructive level, and search, situational appraisal, and contingency planning are all improved. Under excessive stress, people become hypervigilant, resulting in incomplete search, appraisal and contingency planning, thus leading to errors of omission or commission (Janis and Mann, 1977; Xiao & MacKenzie). In the words of U.S. veteran Colonel David Hackworth: "fear, nervousness, excitement and exhaustion numb the mind and cause miscommunication and misunderstandings. These circumstances are a recipe for error" (Defense Update). In his book *Emotional Design*, Donald Norman (2004) confirms that negative affect can inhibit cognitive functioning, and concludes that “…Things intended to be used under stressful situations require a lot more care, with much more attention to detail” (p. 26).

Preattentive processing

With the knowledge that high stress and negative affect severely limit our ability to accurately perceive the world around us, it might be ideal if there were some way to design interfaces that in some measure bypass conscious cognitive processes altogether in environments that can be expected to produce extreme stress. It makes sense that if we can understand the psychophysics of human perception, as well as the information needs of our prospective system users, we can present data in such a way that the most salient points emerge clearly from display. Conversely, a failure to account for these needs can render our data in a confusing or even misleading way (Ware, 2000). Perhaps Edward Tufte said it best: “Confusion and clutter are failures of design, not attributes of information” (1990, p. 53).

One possibility for making systems maximally understandable with minimal mental effort may lie in the exploitation of certain known psychophysical responses of the low-level human visual system known as preattentive processing. Researchers have identified a limited set of basic visual attributes that both real and on-screen objects can possess, which are perceived very accurately and rapidly by the human visual system (within about 200-250 milliseconds), completely outside of conscious thought or reasoning (Treisman & Gelade, 1980). There are several conflicting theories about how and why this phenomenon actually works; for an excellent overview of the primary theories, the interested reader is directed to *Perception in Visualization*, by Christopher Healey (2007).

Current research regarding human visual processing suggests that there are two distinct mechanisms for processing visual information (e.g., Treisman & Gelade, 1980; Theeuwes, 1993). The preattentive mechanism appears to be characterized by a relatively unlimited capacity which works in parallel to process information very quickly and accurately, such that test subjects are able to complete preattentive tasks with very little effort, such as detecting targets from non-targets.

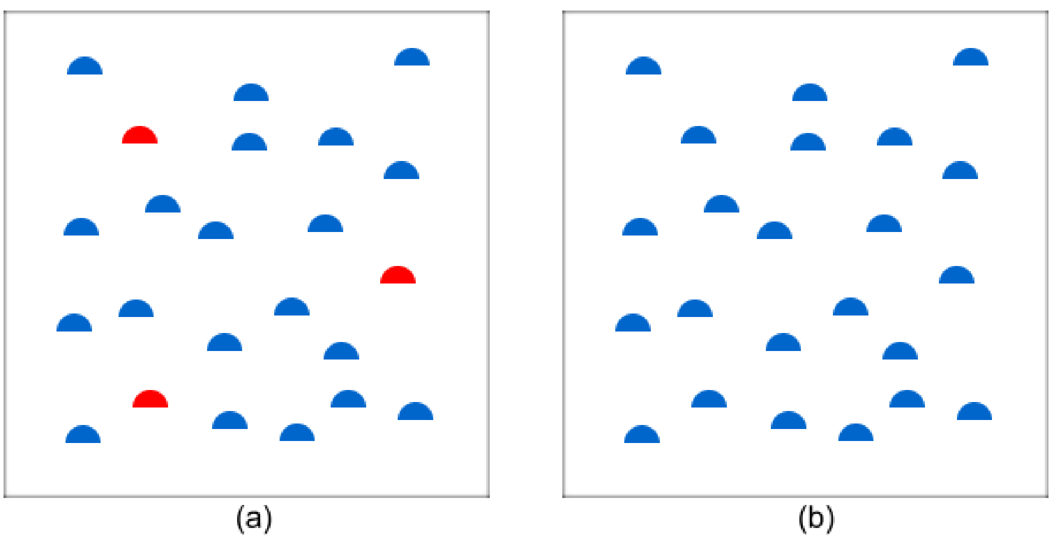


Figure 1. Example of a simple search for targets based upon a difference in hue. (a) Targets are present among distractors of same shape, yet are easily detected preattentively. (b) Targets are absent.

The other processing mechanism is termed *attentive*, and is characterized by a much slower, limited-capacity serial allocation of attentional resources (Theeuwes; Healey). It is hypothesized that utilizing carefully selected preattentive properties in HMI design, particularly for those aspects that characterize primary track attributes on a C2 display, will lead to visual presentations that provide faster, more accurate interpretation, and thus more efficient and effective action, with fewer errors.

In order to be detected preattentively, a target object must possess a unique visual property that non-target objects, called distractor, do not have. These unique properties are sometimes referred to as *basic* or *primitive features.* Visual search is most efficient when the target object possesses at least one basic feature that the surrounding distractors do not have (Theeuwes;Wolfe, 2001). In Figure 1, the low-level visual system is able to preattentively detect the targets based upon their possession of a difference in hue relative to the distractors present. In Figure 2, the preattentive visual search is enabled through the target's possession of a difference in the basic feature of shape.

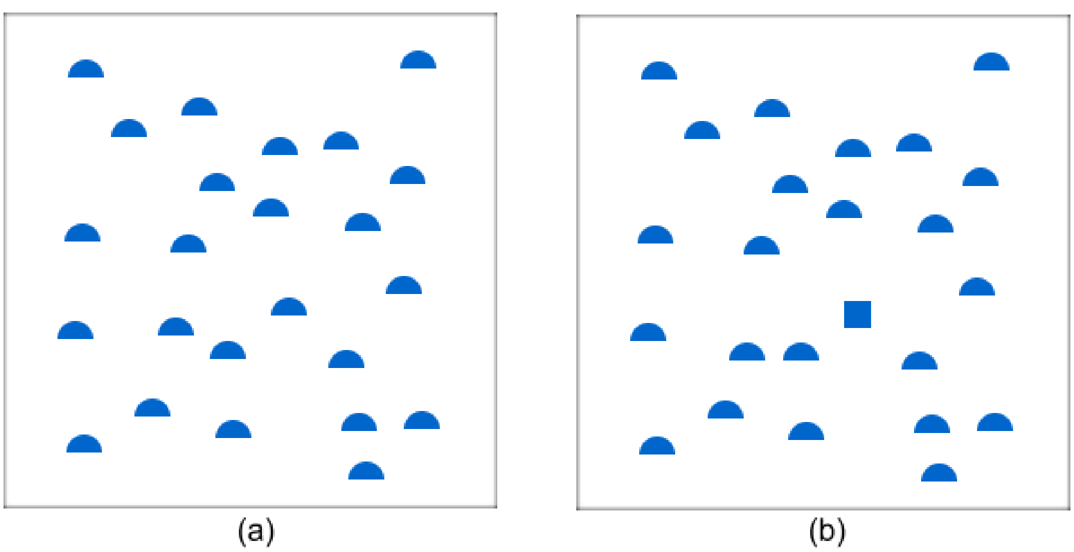


Figure 2. Example of a search for a target based upon a difference in shape. (a) Target is absent. (b) Target is present among distractors of the same color, yet is easily detected preattentively.

In the real world, a target will possess several basic features, and non-target distractors may share some of those attributes. Targets that possess a combination of basic features that are shared with surrounding distractors or non-targets, are known as *conjunction targets*, and are generally considered *not* able to be detected preattentively (Wolfe; Treisman; Healey).

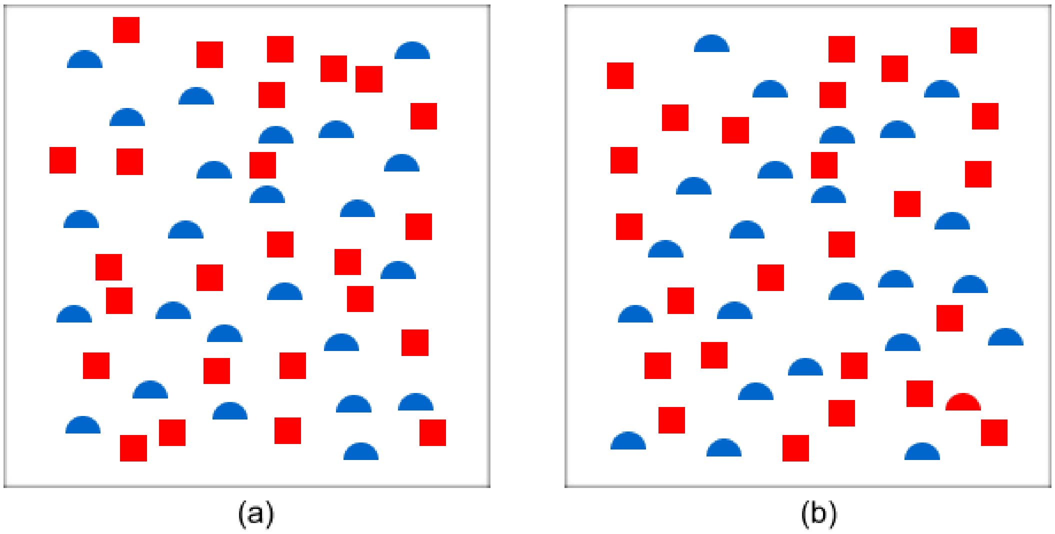


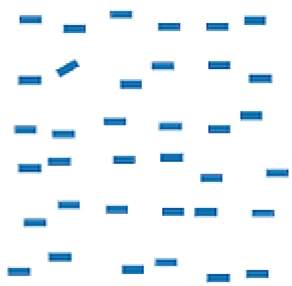
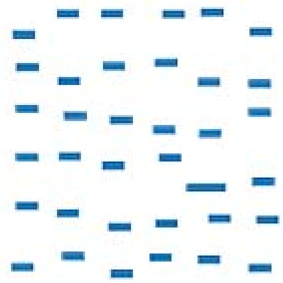
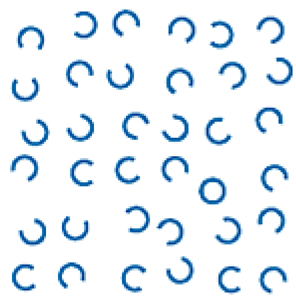
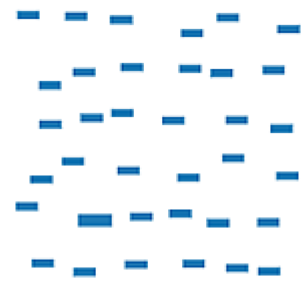
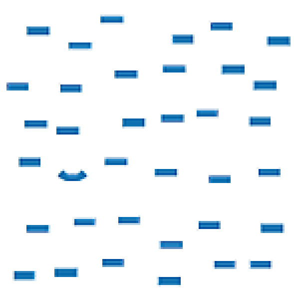
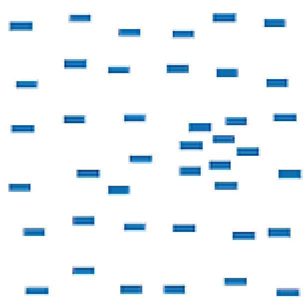
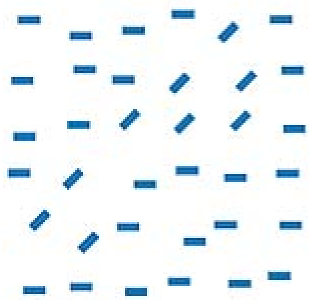
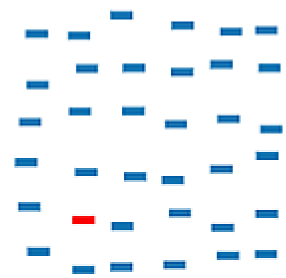
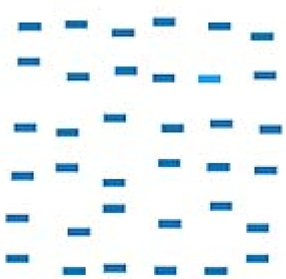
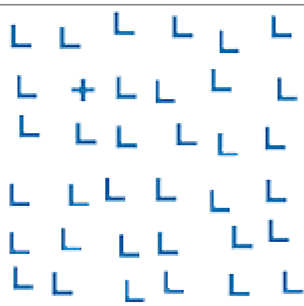
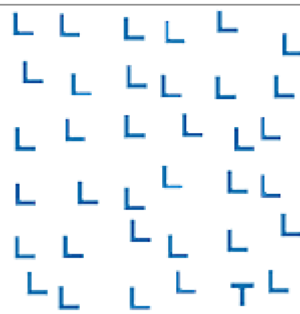
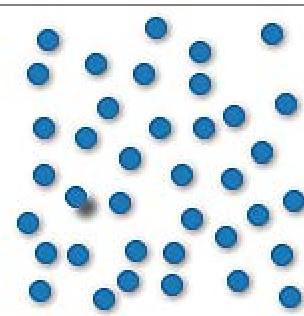
Figure 3. An example of a search for a conjunction target – a red half circle. A target which possesses two basic features, one of which is present in each type of distractor, renders this a post-attentive, serial search task. (a) Target is not present. (b) Target is present.

Preattentive variables in visualization design: Practical application

"In fact, what we mean by information - the elementary unit of information - is a difference which makes a difference" (Bateson, 1972, p. 459). With respect to CID and the Joint Chiefs' mandate to accurately characterize detected objects, the question becomes: *what are the differences that make a difference in swiftly and accurately characterizing tracks during the CID process*?

Table 1

A partial listing of preattentive basic features. Table and feature depictions adapted from *Perception in Visualization*, by Christopher G. Healey, located at: http://www.csc.ncsu.edu/faculty/healey/PP/index.html. Used with permission of the author.

 Orientation	 Length / Width	 Closure	 Size
 Curvature / Shape	 Density / Contrast	 Number / Estimation	 Color / Hue
 Intensity / Brightness	 Intersection	 Terminators	 3D Depth

There are a great many attributes that tracks can possess which will be more or less tactically important at any given time, based upon the context and specific C2 domain involved. What follows is a compilation that grew out of discussions with several military C2 operations experts regarding those characteristics that are most salient to the topic of CID. Given that the domain these operators were most familiar with is that of the air-breathing threat, this section may apply primarily to the airborne arena; however, the reader may find applicability across C2 domains. Of note, the airborne domain has used a form of cooperative tracking / Blue Force Tracking-style technology for over 60 years, via the use of the Identification Friend or Foe / Selective Identity Feature (IFF/SIF) system which the British deployed during WWII. Thus, air domain operators likely have some valuable lessons learned in the use of cooperative systems in the CID process (Rasmussen, Dittmer).

The illustrations used for the figures in this section are from actual fielded C2 systems that utilize the Raytheon Solipsys Tactical Display Framework (TDF) visualization toolset. The intent of this paper and the practical application examples shown, is not to prescribe definitive solutions, but to forward the discussion of scientifically-based C2 display design such that the developer community is better able to support the process of accurate and timely CID, and thus the needs of the warfighter.

Track Identification

If an operator had a completely accurate picture, with all tracks correctly identified, this might be considered an optimal situation. This is due to the simple fact that in most or perhaps all military standard symbol sets, each identification type is delineated by use of a unique shape or color, or most likely both. Thus, strictly regarding the display of identity symbols, the possibility of having conjunction targets that confound swift parallel search activities should be minimal. However, with the addition of real-world, potentially cluttering data such as flight routes, airspaces, boundaries, sensor plots, track histories, charts and other imagery, etc., it makes sense to further augment a track's ability to be easily distinguished.

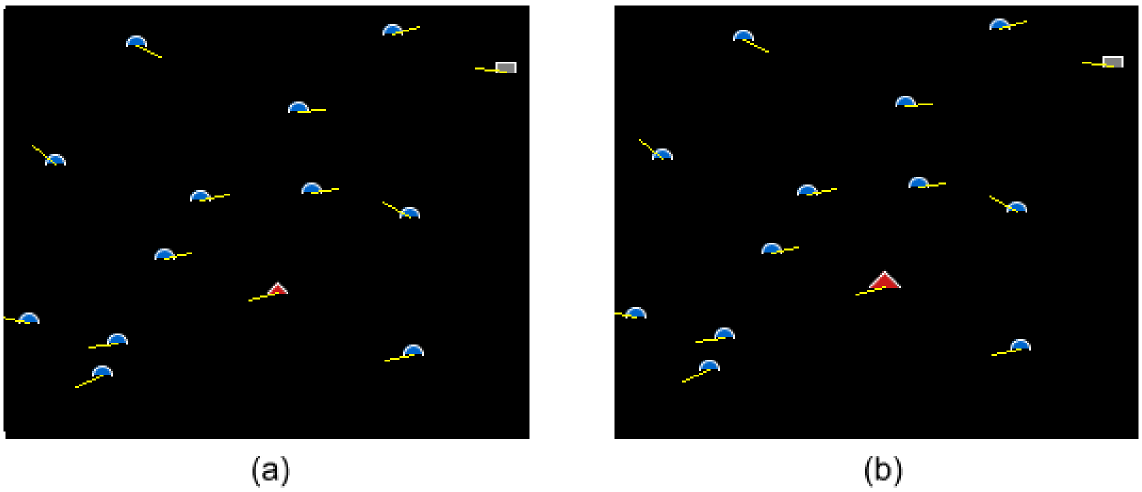


Figure 4. An example depicting variable symbology sizing to make a hostile air track more salient. (a) Target is scaled identically to non-target tracks; (b) Target is scaled 200% larger than non-target tracks, improving target saliency.

In Figure 4, this is accomplished through increasing the target track's symbol size. While it is somewhat common to provide an overall adjustment for symbology size, the implication here is that *individual categories* and identities should be made to be adjustable for size. Thus, for example, one could elect to make Hostile Air tracks larger than any other track symbols, if that suited the needs of the mission.

<u>Track Heading</u>

A track's heading communicates a great deal to the trained operator, as it potentially signals a target's intent. All other factors being equal, target heading alone could induce a decision to employ weapons, and by necessity must be an integral part of any decision to determine hostile intent (Nguyen, 2006). In Figure 5, screenshot (a) shows a portion of an air picture depicting, among non-targets, three aircraft with an assigned Link 16 platform of *Fighter*, using Military Standard 2525b (MS-2525b) symbols, while (b) shows the identical picture using the Raytheon Solipsys-designed Iconic Naval Tactical Data System (NTDS) symbol set.

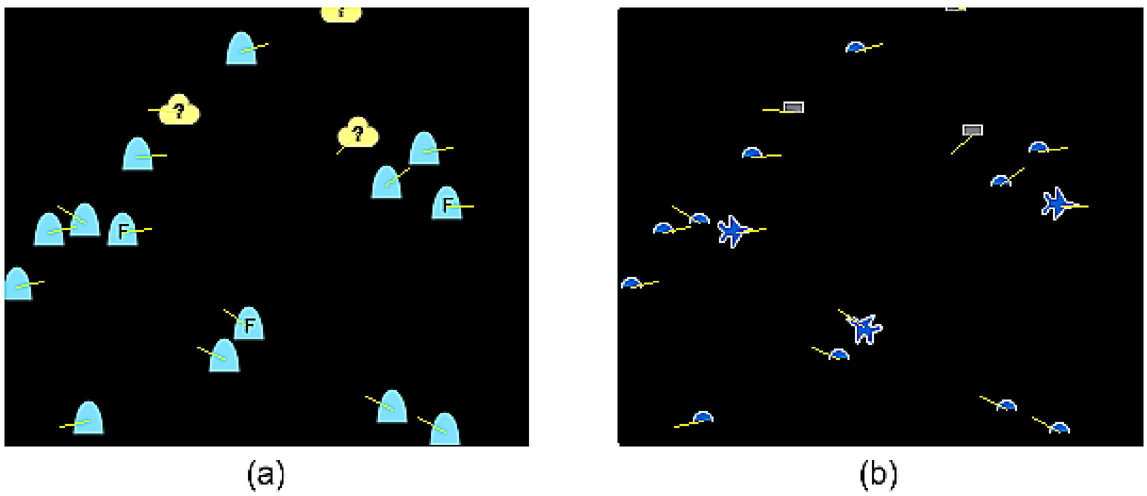


Figure 5. An example contrasting two symbology sets with regard to communicating target heading. (a) Three targets (Fighter aircraft) depicted using the MS-2525b symbol set. (b) Identical air picture as depicted by Raytheon Solipsys Iconic NTDS symbols.

Preattentive processing research (Treisman & Gormican, 1988) supports the notion that since the Fighter aircraft depicted in screenshot (b) have an iconic shape that is radically different from the other Friend-class tracks present, aircraft platform recognition will be much more rapid than in screenshot (a), wherein the depiction of Fighter platforms is less easily distinguished from surrounding friendlies, through the relatively subtle addition of the MS-2525b *F* modifier. The less evident benefit of the use of iconic symbols that is relevant here is that track heading is communicated rather directly through the symbol itself. Because there is a natural nose and tail to the iconic symbols, orientation automatically changes to reflect track heading. Compare this to MS-2525b symbols and indeed, any symbol set where the symbol orientation never changes; heading in these cases is communicated solely via the track “vector stick”. The iconic NTDS symbol shows an obvious change in orientation, and thus research (e.g., Wolfe, et al., 1992) would suggest that iconic symbols will communicate track heading, not to mention track platform, much more quickly than standard non-rotating symbols. The use of iconic symbols in military C2 symbology sets is an area that warrants further research.

Track Altitude

Altitude for an individual track, and vertical speed information (whether the track is ascending or descending, and at what rate over time) is often critical in the characterization of an object in the battlespace (Nguyen). Regarding vertical speed, the weapons crew aboard the U.S.S. *Vincennes* was apparently unable to accurately characterize the Iranian airliner’s actions in the vertical dimension, which appears to have been a major factor in their engagement decision (Cummings). In Figure 6 below, (a) depicts altitude information for two tracks, presented solely with text.

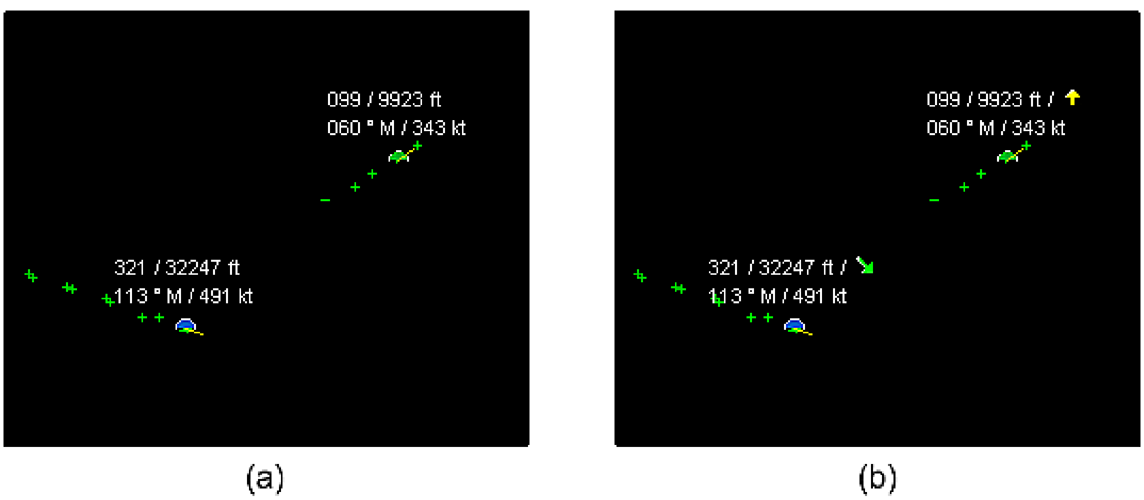
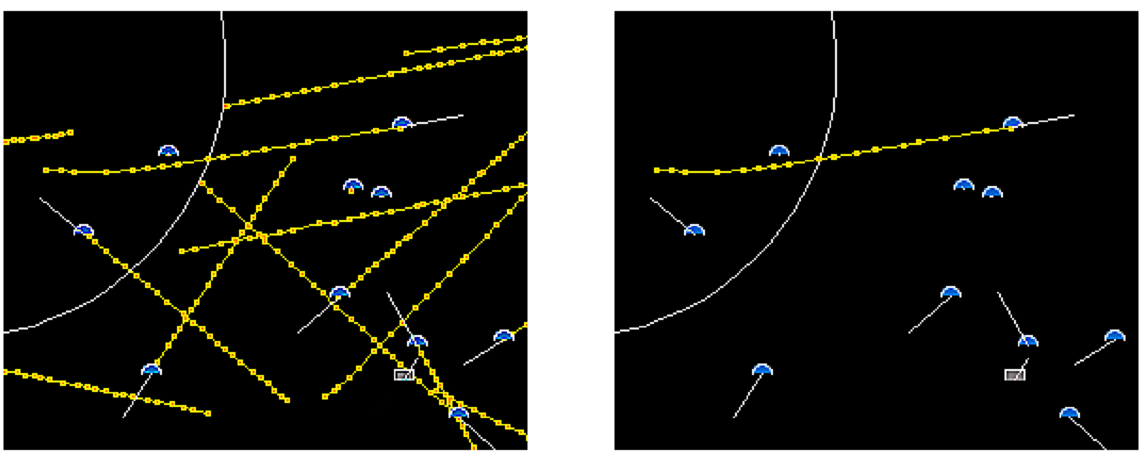


Figure 6. An example contrasting use and non-use of an icon designed to preattentively communicate track vertical speed trend information. (a) Track altitude information presented solely via text; trend information would need to be determined manually, over time. (b) Identical track textual information, but with vertical speed indicator icons shown next to altitude information, providing ascent or descent information at a glance.

In (b), both tracks augment the standard textual altitude information with vertical speed icons, which communicate trend information. The green arrow indicates a normal rate of descent; the yellow arrow communicates a greater than normal rate of ascent. The user may define in Preferences the desired change rates in ft/min or m/sec to use for each category. The categories include descending or ascending at normal, greater than normal, and much greater than normal rates, as well as level flight. Each condition is represented by unique indicator icons that vary in both shape and hue. Using the preattentive attributes of shape and hue to communicate rapidity of altitude change, research supports the notion that the operator captures at a glance what would require precious minutes and cognitive resources to do through diligent observation of the 2D display (Treisman & Gormican).

Track Location

Another primary attribute that can offer tangible evidence of target intent is track location. Of particular interest is the changing location of the track over time, which the author refers to as track history. Having a lengthy track history available provides the operator a way to characterize potential future track actions as a result of understanding what the track's behavior was in the past.



(a) (b)

Figure 7. An example illustrating the need to support history trails on not simply all tracks, but for individual tracks as well. (a) Track display showing history trails on all tracks. (b) Identical track picture with a history trail displayed for only a single track of interest.

The ultimate goal regarding the display of track history is for the operator to be able to determine a track's point of origin, which can assist tremendously in CID. Every attempt should be made to retain track history for the life of the track in the system, and perhaps beyond, as tracks often drop out of coverage for any number of reasons, only to reappear a short time later. For optimal utility, information about the state of the track in question should be available by interacting with track history points anywhere along the route of travel, providing the ability to determine track characteristics at any displayed point in the past.

Figure 7 (b) illustrates what may be a non-obvious point with regard to track history display, which is that it is not enough to simply support the display of track history such that is on or off for all tracks; to be maximally interpretable and to utilize track history as a preattentive attribute, support should be provided to display history trails for a single track of interest, or some other limited subset of the total system tracks.

Presence of Friendly

Very early in the CID process, and continually throughout the Find-Fix-Track-Target-Engage-Assess (F2T2EA) cycle, assessment must be made to check potential targets for Presence of Friendly (POF) attributes; at any time the kill chain can be broken to prevent fratricide when POF is detected (Dittmer; Rasmussen; Hebert, 2003). Thus, it is critical that cooperatively told POF attributes, such as IFF Mode 1/2/3 returns, Mode IV, Mode V, Blue Force Tracking, Joint Blue Force Situational Awareness, or any other cooperative tracking or ID characteristics are displayed to the operator in an unambiguous, preferably preattentive manner. POF characteristics can manifest themselves in at least two ways – in the IFF/SIF portion of the signal coming from sensors organic to the weapons system being employed, or as information attached to system symbology, whether local or remote via data links.

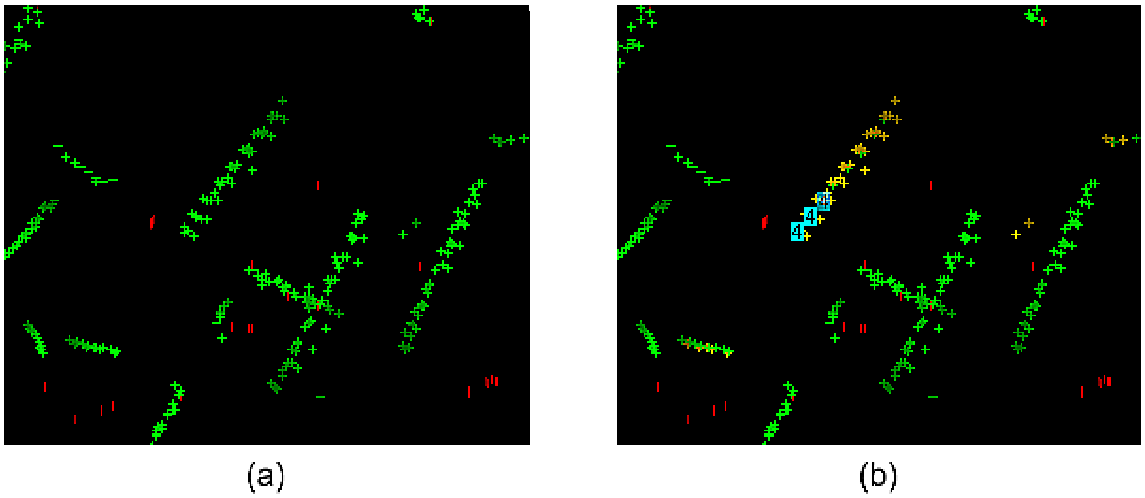


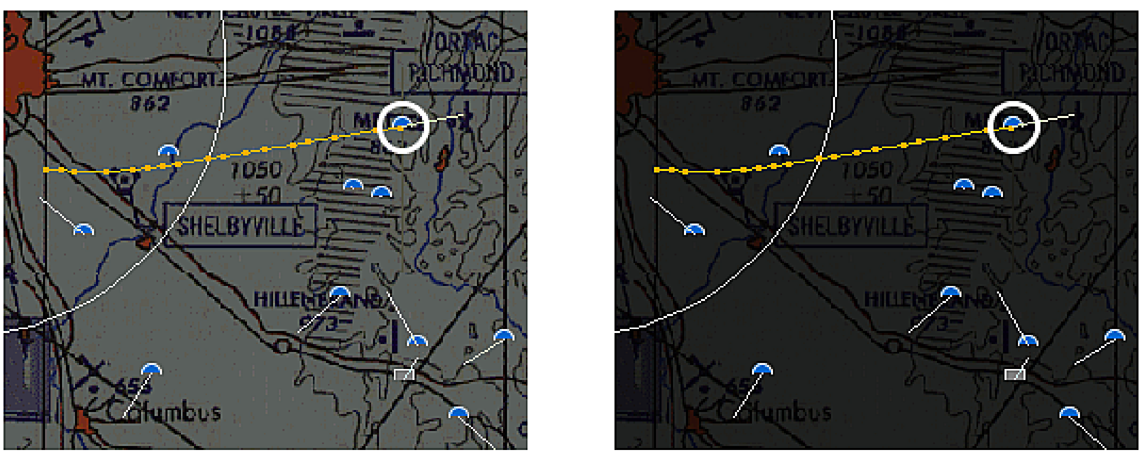
Figure 8. An example depicting effectiveness of communicating friendly IFF/SIF information. (a) Radar sensor plots without distinguishing coloration. (b) Identical track picture using preattentive attributes of hue and shape to distinguish IFF Mode 2 (orange), and unique Mode IV symbol (cyan).

In Figure 8, two potential display configurations are contrasted for efficiency of communicating IFF/SIF information. Illustration (a) does not distinguish individual IFF modes by color, nor does it display results of Mode IV interrogations in the plot depictions. Illustration (b), in contrast, depicts radar sensor plots which utilize the preattentive attributes of hue and shape to distinguish a friendly aircraft from the myriad other aircraft in the area. In this case, the radar plots for the military IFF Mode II are configured to appear as orange, and the encrypted military Mode IV return is configured to display with a unique symbol showing the number four, rendered in cyan.

<u>Controlling Display Layers</u>

For the sake of clarity in illustration, the examples used in this paper have been relatively sterile, in that many elements that are required to perform C2 operations in the real world have been omitted. However, highly colored and figured charts and imagery, color-coded weather maps, routes, airspaces and other boundaries, points and markers of varying types, textual information, etc. are all possibilities for inclusion in modern C2 systems. Given this, interface developers need to ensure that the layers of information that they present can be controlled to optimize the display, and assist operators in maintaining their focus on the most important aspects of the display, which by necessity will vary depending upon mission needs and context. At a minimum, consider having individual layer brightness or transparency controls for maps, lines and areas, points and markers, sensor plots, and track symbology.

In Figure 9, the addition of a chart background element reduces foreground to background contrast to an unacceptable level in (a), rendering track elements difficult to interpret. In (b), the map background has been adjusted for brightness such that it is still useable as a secondary or tertiary reference, but the primary subject – the tracks themselves – remain featured and easily distinguished.



(a) (b)

Figure 9. An example illustrating results of layer brightness adjustment to optimize track presentation. (a) Background chart imagery shown in native brightness reduces contrast and visibility of tactical picture. (b) Map layer individually adjusted for brightness to emphasize track presentation, while still allowing map viewing as a secondary visual reference.

Conclusion

Efficient and effective combat identification is a problem that must be addressed through more than the development of new technologies. Indeed, as the nature of modern warfare evolves to become increasingly dependent upon rapidly changing technology, it becomes more important than ever to adhere to established principles of user-centered design and development. One of the primary ways we can support this effort is to continue to cultivate a deeper understanding of human perception, so that our increasingly complex systems can be optimally developed and configured for maximally efficient human use. Leveraging rules of perception, we can enable improved CID by helping operations personnel quickly gain situational awareness, and by improving the salience of those *differences that make a difference* in the performance of their duties. History has shown that the penalties for not following the rules of human perception can be quite severe; however, the rewards for practically applying the known rules and for discovering new ones will certainly be well worth the effort.

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