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Perceptual Based Visualization Techniques for Improving Ground Situation Picture Understanding

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Name of Authors/Co-Authors(s)
Foo Meng NG[1], & Hian Beng LEE[2]

Point of Contact
Foo Meng NG
Name of Organization
DSO National Laboratories

Complete Address

1 Human Factors Laboratory
Defence Medical and Environmental Research Institute
DSO National Laboratories
27 Medical Drive, #11-00
DSO Kent Ridge Building
Singapore 117510

2 Advanced Analysis and Fusion Laboratory
Information Division
DSO National Laboratories
20 Science Park Drive
Singapore 118230

Telephone /Fax
Tel: 65-64857179
Fax: 65-64857172

E-mail Address
ngfoomeng@dso.org.sg

Abstract

Military commanders require timely and accurate awareness of the ground situation in their respective areas of responsibility. With increasing use of sensors from multiple spectra in the battlefield, large volumes of information will have to be processed in a complex way. Constraints in human working memory make people inherently poor at eliminating duplicates, resolving conflicts and correlating large continuous streams of data across time and space. Data fusion decision support systems have been developed to process large amounts of raw data and present the fused situation picture. This reduces the cognitive load on the human and facilitates subsequent decision-making. Although humans are inherently poor at analyzing large volumes of information, representing and organizing ground situation information according to principles in visual perception (in particular inter-relationships between elements) will enhance the ability of commanders to perceive and understand the situation.

This paper presents 3 novel visualization prototypes developed for representing higher order cognitive information required by commanders for ground situation assessment. The glance-able visualizations developed include density techniques for representing enemy troop concentration, Blob, 3D-links and totem pole de-cluttering techniques for presenting disposition and composition of adversaries. The visualization techniques were designed and developed based on established visual perception principles: pre-attentive features and Gestalt pattern recognition. The paper also discusses an interactive functionality afforded by the blob and 3D-links visualizations for enabling commanders to explore alternate interpretations of the ground situation picture based on the results of the fusion engine.

Last but not least, the paper presents a Space-Time browser for facilitating the reasoning of time and space for the purpose of assessing the intention of the adversary.

1 Introduction

In the modern battlefield today, information is increasingly playing more important roles. The commanders have to process large volume of information and they are unable keep track of so many entities and events mentally. Furthermore, the number of sensors and reports is set to increase in the future, and the reports will come from a wide range of spectra. Constraints in human working memory make people inherently poor at eliminating duplicates, resolving conflicts and correlating large continuous streams of data across time and space. Data fusion decision support systems have been developed to process large amounts of raw data and present the fused situation picture. Through tracking of targets and track-track fusion, the attributes of the targets can be enriched using complementary combination and attribute refinement. The targets can be aggregated to form unit for a concise picture. This reduces the cognitive load on the human and facilitates subsequent decision-making.

To associate data with different attributes (from different sources), targets are tracked in groups and multiple trackers are designed so that data could be processed by the respective trackers. Time and space reasoning is used in associating the reports taking possible uncertainty in the target types into consideration. Tracks from these trackers are then correlated to form an integrated picture. Targets are then aggregated into unit using fuzzy rule engine which can be trained through supervised learning.

Even though much work has been done to improve data fusion algorithms, relatively less effort has been afforded to improve the visual presentation of the fused data. Information representation methods used to-date have remained largely unchanged; a case in point is the persistent use of rectangular symbology inspired from linear formations and an era of massed formations. Commanders are still required to spend time to mentally form higher order cognitive information such as movement, disposition, composition and other factors based on the symbology to make connections and correlations for the purpose of discerning the intention of the adversary.

Although humans are inherently poor at analyzing large volumes of information, representing and organizing higher order ground situation information according to principles in visual perception (in particular inter-relationships between elements) will enhance the ability of commanders to perceive and understand the situation.

2 Visual Perception

Perceptual theories suggest how the human visual system perceives structures and groups of information from the scene, it is possible to design information visualization techniques for amplifying human cognition. The mapping of data to perceptual based visual representations will reduce search times, improve pattern matching, trend identification, recognizing gaps and error discovery. Table 1 describes significant system and task related performance benefits afforded by perceptual based visual representations for operators.

Table 1: Some Human Performance Benefits Afforded by Perceptually Designed Visual Representations. (Kapler & Wright 2002)

PERFORMANCE FACTOR	DESCRIPTION
Display Density	More objects and attributes are shown on the screen.
Economy of Interaction	Fewer selections, commands, controls are required.
Number of Displays/Screens	Fewer displays and/or screens are required.
Speed	Tasks are completed in less time.
Accuracy	Tasks are completed with fewer errors.
Completeness	Tasks are completed based on more information.
Training	Less training is required.

The following sub sections will briefly outline pre-attentive vision processing and gestalt principles of organization that can be considered for designing information visualization for representing higher order cognitive information required in C2 environments.

2.1 Pre-attentive Features

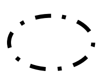
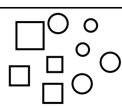
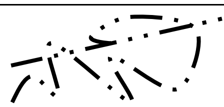
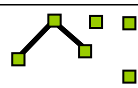
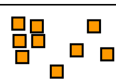
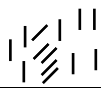
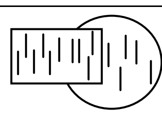
Research in vision and psychology has discovered that the human low level visual system rapidly processes information in parallel to extract basic visual features of objects in a scene. These are simple shapes and colors that “pop out” from their surroundings. The theoretical mechanism underlying the pop-out phenomenon is called pre-attentive processing as it occurs prior to conscious attention. The visual features that are pre-attentively processed can be organized into a number of categories based on form, color, motion, and spatial position. A survey of these features can be found in (Healey & Enns 1999). These pre-attentive features have been applied to create multi-dimensional visual representations to support visual cognitive tasks such as target detection, boundary detection, region tracking and counting and estimation at a single glance in less then 200 milliseconds (Healy at el 1995). Experimental studies have also found that the pre-attentive features be applied in a static environment as well as a dynamic environment where the datasets are constantly changing.

2.2 Gestalt Principles of Pattern Perception

Gestalt psychologists were intrigued by the way the human mind perceives wholeness out of incomplete elements (Behrens 1984, Muller, K & Sano, D 1995). The Gestaltists proposed a theory of pattern perception that relies on the overall form and is not predictable by considering the sum of its components. Factors that impact on the perception of form and impact on how parts are grouped into structural forms are captured in what are called the "Gestalt Principles of Organization”. There are in general 9 Gestalt laws as shown in Table 2.

Gestalt principles can be applied as abstract information visualization design guidelines for showing relationships. The principles can be used to describe how information should be organized or grouped so that critical structures and relationships can be easily perceived. By mapping the information structures to easily perceived patterns, it is easier to interpret the relationships as well as the structures of the information. The information structures will also be easily interpreted when they are mapped to readily perceived patterns.

Table 2: Gestalt principles

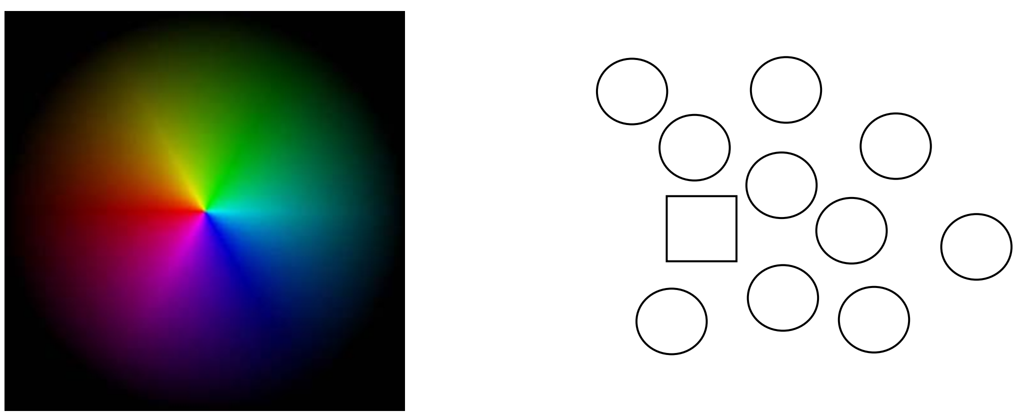
Law of Simplicity		Every object is perceived in a way that the resulting structure is as simple as possible.
Law of Closure		Tendency to close gaps and complete unfinished objects.
Law of Similarity		Elements which look similar (example, size, colour, orientation, velocity and shape) are perceptually grouped together as a object
Law of Good Continuity		Elements that are smooth and continuous are perceptually grouped together than ones that contain abrupt changes in direction
Law of Connectedness		Elements that are physically connected are perceptually grouped together as a object
Law of Proximity		Elements that are close together are perceptually grouped together as a object
Law of Common Fate/Common orientation		Elements with the same moving direction or orientation are perceptually grouped together as a object
Law of Balance/Symmetry	<< >>	Elements in symmetrical alignment are perceptually grouped as a object
Law of Common Region		Elements tend to be group if they are located within a common region. The closed contour tends to be perceived as the boundary of the object.

3 Design and Development of Perceptual Visualization Techniques

Prior to actual design and development, a brief cognitive task analysis (CTA) was conducted to understand the higher order cognitive information needs required by commanders. This was conducted with personnel from G2 Army as well as developers of the experimental ground situation fusion system. The elicited information was then compared to data types used in an experimental fusion engine. This was to shortlist suitable data types found in the fusion engine that can be exploited for supporting the design and development of perceptual visualizations for presenting higher order cognitive information.

Troop concentration, estimated footprint and composition were identified as suitable for subsequent visualization development for inferring adversary intention.

The design effort drew inspirations from suitable theories of perception, namely pre-attentive processing, Gestalt laws of organization and forms inspired from artifacts found in the environment. Callaghan (1989; 1990) has found that pre-attentive features such as form, hue and intensity have no interferences with one another (when used together) and are prioritized by the human visual system as illustrated in Figure 1.



Hue and intensity color circle   Shape/form

Figure 1 – Pre-attentive features such as hue, intensity and form when combined does not interfere with one another in the human visual system.

Two density based visualization techniques that exploit the hierarchy of features principle (form, hue and intensity) have been designed and developed to represent adversary troop concentration levels as shown in Figure 2 and 3.

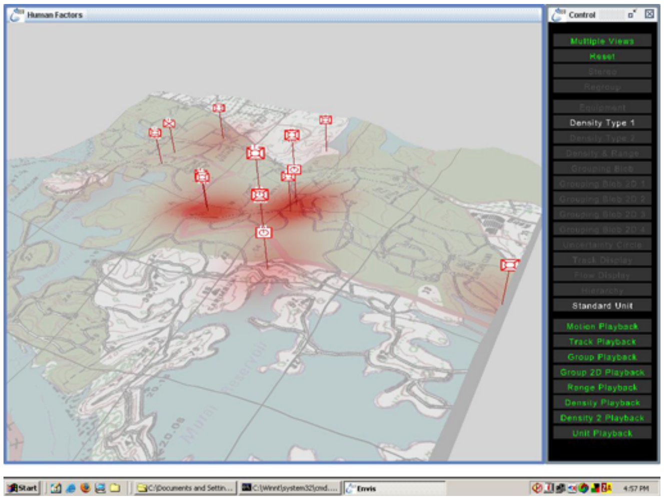


Figure 2 – A density based visualization technique using the intensity of hue to rapidly present adversary troop deployment.

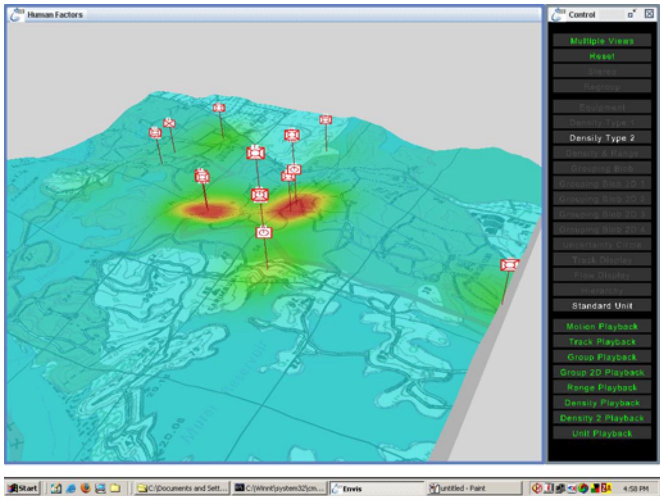


Figure 3 – A wider spectrum of hue to better depict key concentration spread of adversary troop deployment.

The higher the intensity of the color scale, the greater the concentration levels of heavy equipment, thus allowing commanders to rapidly see enemy troop concentrations at any instance in time and provide an extra channel to plausibly infer the tactics taken by the adversary.

One possible scenario is that the build up of forces depicts the location as a holding area, thus signifying an imminent attack. Another possible situation is that the enemy has entrenched itself and is defending the area suggesting possible high value facilities located in the vicinity. From the above polar scenarios, it is easy to see that intensity and color, though useful in determining troop concentrations, may be insufficient to determine the enemy's intentions. Time series information will help in this aspect and will be discussed in detail later in section 4.

Applying the Gestalt Law of Common Region we developed the blob based visualization technique using close contours for showing footprints and set relationships/groupings among chaotic array of discrete entities. The Law of Common Region states that elements will be perceived as grouped together if they are located within an enclosed contour/region.

The blob visualization technique enables commanders to rapidly visualize regions that demarcate each unit, and also enables them to easily comprehend the organizational relationships between aggregated units and each unit's equipment manifest, based on the output of the fusion engine shown in Figure 4 and 5.

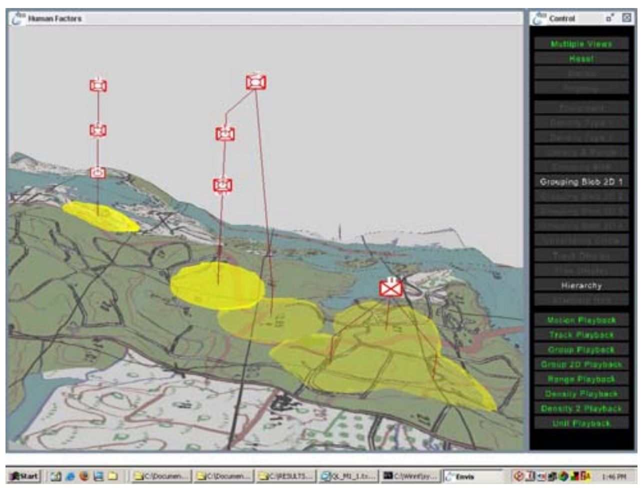


Figure 4 - Blob visualizations for representing aggregated units and estimated footprint in the battlefield.

The visualization of the estimated footprint of enemy forces also facilitates the identification of possible safe corridors for maneuvering friendly forces as well as loop holes in the enemies' defenses.

The Law of Connectedness indicates that objects that are linked together by lines are perceived as having a relationship between them. Inspired by this gestalt principle, our 3D-links visual presentation technique (red lines as shown in Figure 4 and 5) was created to group or show relationships between entities that are either apparent or implicit in the battlefield. The 3D-links visualization further reinforces the blob visualization, in perceiving relationships between units and subordinate equipment as interpreted by the fusion engine.

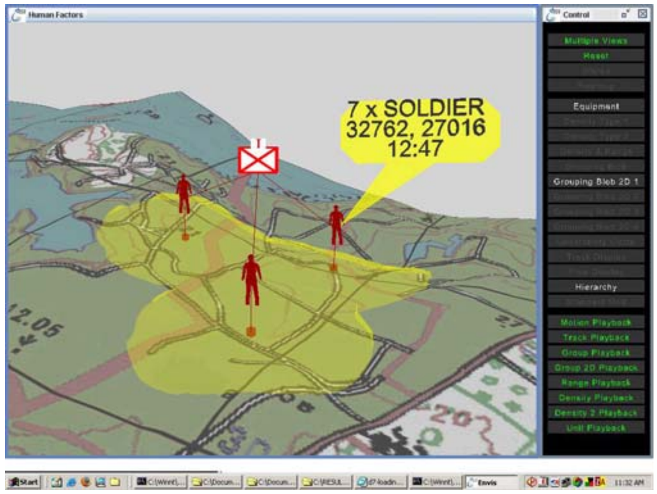
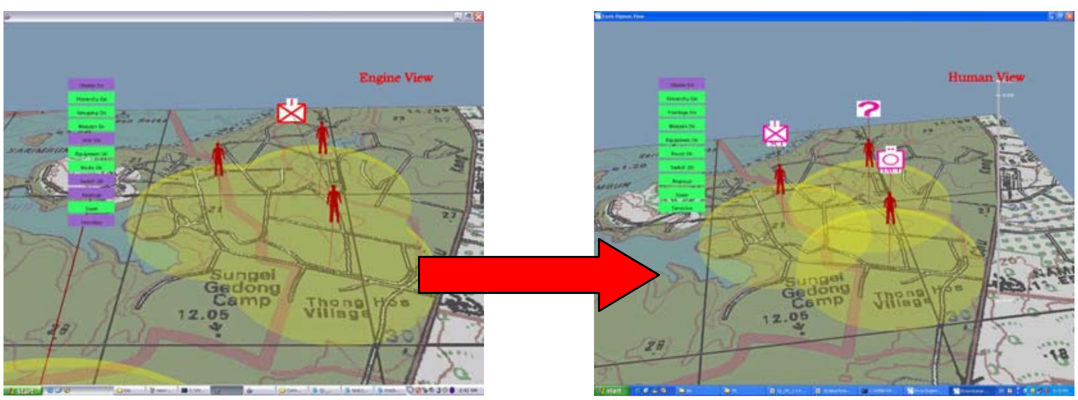


Figure 5 – An aggregated infantry company showing a drill down detail view of each equipment location at different parts of the aggregated region.

With the presented 3D-links information commanders are able to use their experience to interactively splice or merge the units or equipment to test out alternate interpretations of the ground situation picture by interacting with the advanced visualizations as illustrated in Figure 6.



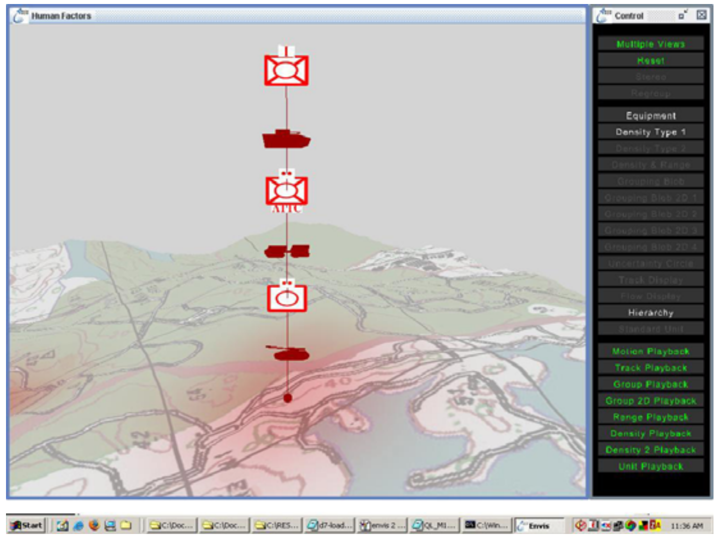
Interpretation of ground situation picture by fusion engine.

Commanders' interpretation of the ground situation picture.

Figure 6 – Commanders' interpretation of the ground situation picture after refining the fused picture.

As units amass at particular locations, it becomes more difficult for commanders to rapidly cognize the various units or equipment on the ground. To de-clutter the display we have implement a totem pole de-cluttering technique whereby units and equipment are stacked up one above another as shown in Figure 7. This technique alleviates the visual clutter problem and allows commanders to quickly discern the various clustered units at a glance.

A totem pole



Totem pole metaphor for de-cluttering ground situation picture

Figure 7 – The application of totem pole metaphor for de-cluttering the ground situation picture.

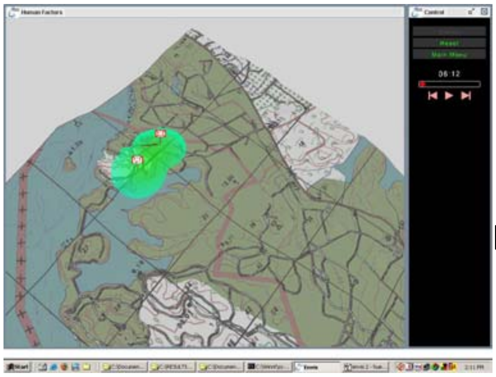
4 Reasoning about Time and Space

At present, commanders are required to plough through and study numerous situation maps in an attempt to piece together and perceive the movements, events and relationships of enemy units over terrain as they change over time. This process is time consuming, exerts a high cognitive load on commanders and most importantly delays decision-making which may result in enemy forces surprising and out maneuvering friendly forces.

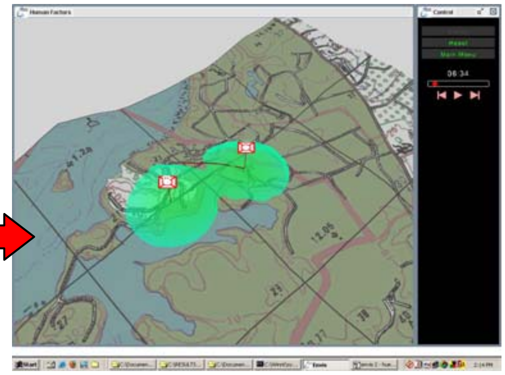
In order to assist and improve the efficiency and effectiveness of inferring adversarial intentions, an interactive 3D Time-Space browser was developed. The interactive browser allowed a dynamic animation of units' movements and relationships as they change over time over terrain. The tool facilitates the played back of time, as well as the associated spatial, density and blob visualizations changes to reflect the state of information at any instance in time. Such a facility enables commanders to better reason about time and space so as to elucidate information such as the pattern, speed and direction of adversary movement, troop deployment changes and most importantly infer on the intention of enemy forces.

As an example, Figure 8a shows two units that are of the same combat group massing at a particular location. Subsequently, the time series data shows the two units splitting and moving away from each other (see Figure 8b). As time progresses, the 2 units are now completely separate (see Figure 8c), with no intersecting blob boundaries. Figure 8d shows new units appearing and these new units appeared to have moved and congregated over time (see Figure 8e and Figure 8f). This can be seen from the increasing hue and density of the blob colors. Figure 8g finally shows the units dispersing from the amassed location, as can be seen from the lightening of hue and density, possibly indicating execution of a mission.

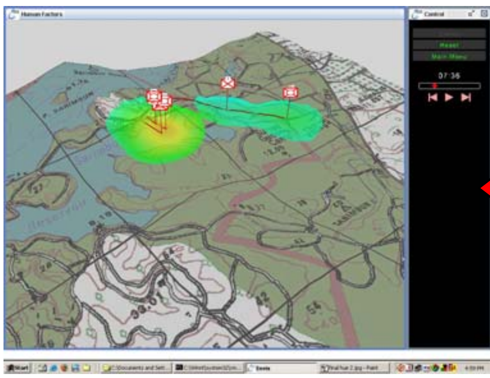
A possible interpretation by a commander could be that the enemy unit is moving off for a mission in the locality of friendly forces. This signals a need for pre-emptive action to be taken, e.g. to prepare an artillery strike or to continue monitoring the movements of the unit to further understand their intentions.



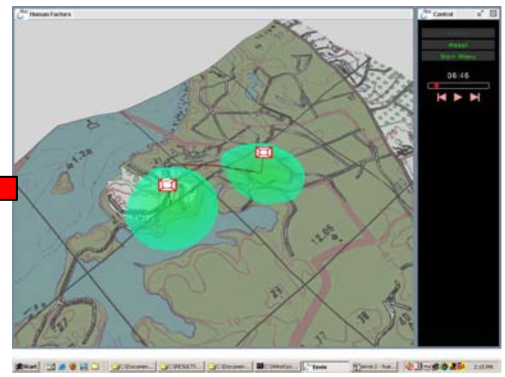
(8a) – Unit 1 and 2 massing at a particular location.



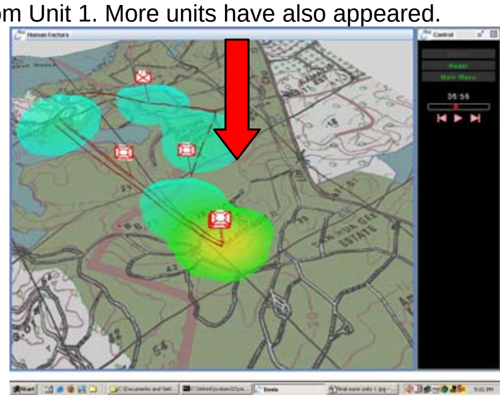
(8b) – Over time Unit 2 moved further away from Unit 1.



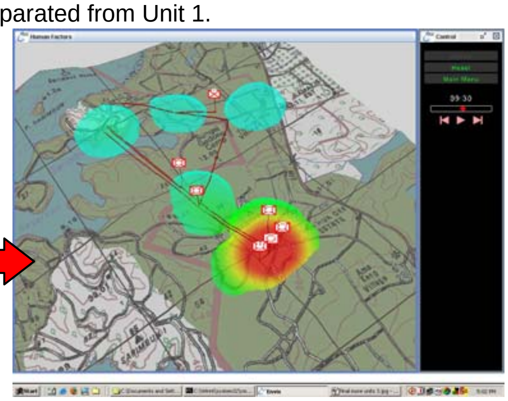
(8d) – At 0730 hrs Unit 2 has completely separated from Unit 1. More units have also appeared.



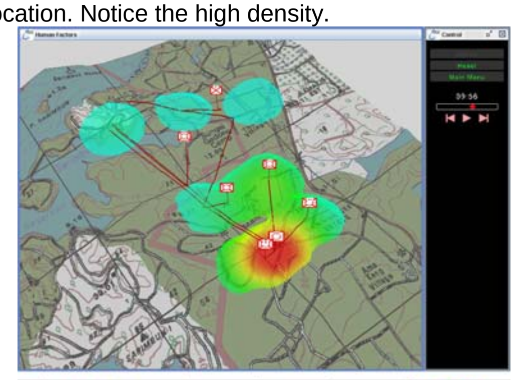
(8c) – As more time passed, Unit 2 has completed separated from Unit 1.



(8e) – Units appearing to traverse towards a particular location.



(8f) – Over time, units are amassing at a particular location. Notice the high density.



(8g) – Units dispersing off, possible heading off for a mission. Notice the reduction in hue and density.

Figure 8 – Time frames showing the progression of movement.

5 Conclusion

This paper has presented a suite of customizable advanced interactive visualization techniques namely: density, blob, 3D-links, totem pole de-cluttering and an interactive 3D Time-Space browser for augmenting commanders' assessment of the ground situation picture. Pre-attentive features and Gestalt pattern recognition principles of human visual perception were key aspects considered in the design and development of the glance-able visualizations.

Pre-attentive features such as intensity, hue and saturation, allow for rapid searching and boundary detection used by the low level human visual system and afforded commanders the ability to determine enemy troop deployment at a frame of time. The Gestalt principles of common regions and connectedness enable rapid recognition of patterns (i.e. possible adversary intentions) and alleviate visual clutter, thus helping commanders to rapidly understand adversary organizational relationships and estimated footprint.

Work will have to be carried out to incorporate the perceptual visualizations and interaction tools into experimental C2 systems. Experimentations will then be conducted to ascertain the effectiveness of the visualizations and tools and quantify if they do indeed improve ground situation assessment.

6 Future Work

The preliminary prototype has illustrated the possibility of representing higher order cognitive information visually for the purpose of amplifying higher order cognitive processes (i.e. situation awareness and assessment). The interactivity (Fig 6) afforded and the time and space reasoning tool have also provided commanders the avenue to bring to bear their experience to explore alternate interpretations and better assess the intention of the adversary.
In order to achieve and develop truly glance-able information visualizations and interactive tools tailored for supporting and augmenting commanders' situation assessment, reasoning and decision-making processes, more research and development work will be required in the following areas.

1) There will be a need to develop a comprehensive set of established and scientific based design principles and guidelines for designing information visualizations based on state-of-the-art knowledge in graphic design, cognition and visual perception science.

2) New interactive visualizations techniques will have to be developed to support higher-level information problem-solving. Such tools will be required to enable operators to compare and categorize data, extract and re-combining data, creating and testing hypotheses and the annotating data for the purpose of evaluating evidence, challenging assumptions

overcoming biases finding alternative as well as reducing cognitive overload.

3) More comprehensive spatial-temporal visualization techniques will have to be developed to enable operators to easily reason about time and space.

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Disclaimer

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