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Visualization of Self-Reporting Entities for Command and Control

Thomas Kapler and William Wright

Thomas Kapler (POC)
Oculus Info Inc.
52 St Lawrence St, Unit 211
Toronto, ON, Canada
M5A 3N1
voice 416-203-1085
Fax 416-203-0646
tkapler@rogers.com

Abstract

Several innovative visualization techniques have been developed during the DARPA Command Post of the Future (CPOF) program. One assumption of the program is that information will be gathered electronically from the individual platforms of friendly forces. New visualization techniques, combined with this hi-resolution platform-based or *entity-level* data, can be used to generate dramatically improved displays of the battlefield. This paper discusses the visualization methods that have been developed for effective presentation of this information to commanders.

1. Introduction

The Command Post of the Future (CPOF) is a DARPA program that aims to increase the speed, quality and accuracy of command decisions. One CPOF theme has been the development of visualization methods that provide immediate understanding of changing battlefield situations. This paper is a report on the development of a wide range of new techniques utilizing an entity-level approach. It is assumed that in the future, blue forces will be capable of reporting detailed information about themselves at a very granular level. This detailed data and new visualization techniques can be used to create extremely rich, expressive displays of the battlefield. The challenge is to present this data in a relevant and intuitive manner that provides value and advantage without causing information overload.

2. Objectives

Traditional force representation techniques, such as those based on the 2525A symbology (FM 101-5-1) provide a rough overview of what may be a critically complex situation. Information visualization methods [Card, 99] [Ware, 00] [Wright, 97] can provide superior command and control displays. With the correct approach to the visual design of the layout and objects, a human observer can quickly and easily comprehend large amounts of information.

The objective of the work described here is to use visualization to take advantage of the vast amount of information resources that will become available in a self-reporting network-centric force to create a rich shared picture of the battlefield. Multiple sources and types of information are integrated into the same space. The purpose is to improve situation awareness for commanders while saving time.

Design and development methods have proceeded through iterative phases. Collaboration with subject matter experts (SMEs) has been essential to the progress made. Further details of the development methods and experimental evaluations are provided in an earlier paper on CPOF blobology visualization [Wright, Kapler, 02]. This paper will focus on the entity-level representations and tools that have been devised, and the creative methods used to do so.

3. Designing New Representations

To use a representation requires converting data into a viewable form via a mapping or assignment of data to one or more of the form's visual properties. Mappings from data to visual forms need to be easily interpreted by people. A mapping is *expressive* if all and only the data are represented, and a mapping is *effective* if it is faster to interpret, can convey more distinctions, or leads to fewer errors [Card et al, 99]. We would add that a mapping is *relevant* only if some subset of the data pertinent to a decision is shown. We would also say that a mapping is *constructive* if new information is created in the eye of the viewer by the fusion, or co-placement, or artful association of previously separate data elements.
A visual dialogue and visual vocabulary can be inspired by analogies, experimentation, play or artifacts observed within the existing work environment. It is necessary to try different approaches and then evaluate effects. Subtle variations in visual techniques can make critical differences in reading and effectiveness. Careful tuning and testing is necessary. Good information visualization representations capture the essence and nature of objects and relationships efficiently and with power. The objective is to discover natural symbolic connections between properties of the object, and how they are shown. For instance, using a closed boundary to mark the area occupied by a force is intuitive, but showing status with pie chart segments (personnel, ammunition, fuel, weapons) is arbitrary and not intuitive.

Representations need to be meaningful to the viewers. New representations can often be based on forms inspired from an artifact in the existing working environment. Representations need to be efficient and balanced. They should be as simple as possible without losing expressiveness. The "presence" or weight of the representation should be balanced with the importance of the information being conveyed. Representations should also be consistent. Conventions should be set and carefully maintained. For example, use of color, and color associations often follow conventions.

3.1. Data Assumptions

Development of an effective visualization begins with an understanding of the raw data to be displayed. For the CPOF program, there were no reliable existing sources for relevant data so assumptions had to be made. A prioritized list of data requirements (Table 1) was developed with Subject Matter Experts (SMEs - experienced commanders), based on what they would want to know about any entity or group of entities. The list was constrained to measurable properties and categorical facts, eliminating intangibles, such as "intent", "morale" and "cohesion".

Field	***Details***
Designation	String Name (A-1-2)
Location	Lat/Long
Weapons Orientation	Degrees
Movement Orientation	Degrees
Speed	km/h
Echelon/Size	(Battalion, Squad, Soldier, Major, Equipment etc)
Unit affiliation	Parent Unit ID
Status	(engaged, moving, refueling, casualty etc)
Type	(MECH, Sensor, HMG, INF, M1 tank, etc)
Equipment	Itemized list
Range (weapon or sensor)	Meters

Table 1: Entity data fields

The following assumptions were also made...

1. Vehicles, crew served weapons systems and individual soldiers will carry digital frequency tag locators that will constantly update location, orientation and status information to the network.

2. A battalion-sized force was chosen for testing for the following reasons:
   - Large number of entities: ~1200 elements, including organizational nodes such as Teams, and Companies.
   - Dozens of different types of units and entities.
   - Dozens of different object capabilities.
   - 5-6 level hierarchy with 3-8 children at each level.
   - Entities are people, vehicles, crew served weapons, sensors.
   - Can cover a large amount of terrain and have several operations happening simultaneously.

3. Terrain maps providing detail down to individual building massing.
   - USGS 7.5 minute topological maps provided the minimum acceptable amount of detail for planning and interpretation purposes.
   - 30m resolution terrain height data was acquired (although a higher resolution was desired).

3.2. The Entity Representation Concept

Definition: Use the principles of micro/macro design [Tutfte, 83, 90] to express complex or emergent behavior of a large system of diverse elements by displaying their individual attributes simultaneously.

The SME's desired that the display reflect and express their own experience in the battlefield with qualities such as "emptiness", "crowding", "ebb and flow", "surge and wait" etc. In initial design discussions and experiments, displays of an aggregated force (even at the team level) did not provide adequate texture to answer questions about status, cohesion, progress and other characteristics. This type of information is traditionally acquired through time-consuming voice communications to subordinates. Interviews with experienced commanders revealed that a great deal might be inferred from seeing the actual formations of the smallest force elements on the ground (figure 2). An "entity-based" representation could provide the granularity necessary to "tell a story". For example, a loose linear formation moving together may indicate a cohesive force moving quickly through a pass whereas a tightly grouped force oriented in several directions may indicate a unit under heavy fire. Even the location of the commanding officer of a unit with respect to his troops can be indicative of a problem or particular state. Such a display might be able to present sufficient detail to facilitate accurate situation assessments without additional personal communications – resulting in significant potential timesavings for a commander in the field. Creating software to clearly display and manipulate potentially thousands of elements on detailed terrain, each element with dozens of attributes and relationships, became the focus of development.

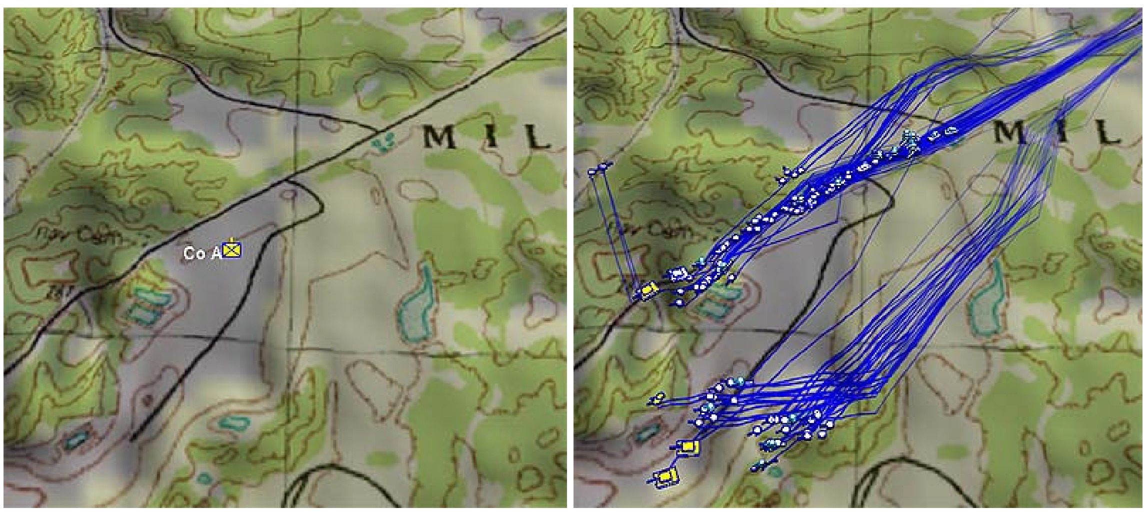

Figure 1: Center of mass vs entity-based.

4. Representing Entities

Entities may be individual people, vehicles, weapons or a unit in the organizational tree such as "Co A" or "1st Platoon". The data attributes for entities are names, values, categories, distances, relationships etc. Most attributes have some natural representation or at least an existing traditional representation. *Weapons Range* for example could be shown as a circle perimeter or as an arrow pointing outwards from the source. Matching attributes with representations was a critical step and relied on both design experience and iterative testing. A principle of using simpler, smaller representations for more common elements and more complex representations for less common elements was applied throughout the design process. As each data attribute was matched with a unique representation (or visual dimension), care was taken to ensure that these representations be visually separate, yet coexist. They must become distinct layers of information about the force. To this end, some simple rules were defined to guide design decisions:

- Yellow is reserved for signifying engagements and fires.

- Pink signifies that an object is selected.
- Each Force has a base color (for example, blue for Friendly, red for Enemy) that is applied more or less exclusively to the visual elements that represent it.

In some cases, a visual element can express several data dimensions simultaneously. The basic visual elements that were developed are described below with explanations of their data mappings.

4.1. Icons

A new symbology was developed to represent entities and their characteristics. SMEs requested that entities be represented physically to facilitate more intuitive interpretation. The icons, as shown in Figure 2, were therefore designed as distilled pictures of the objects they represent. A slight perspective tilt was added to match the default 3D perspective view. They are composed of both an outline and a filled portion, each of which are typically a different color, causing the icons to stand out when displayed small on a noisy background. Simpler representations were used for more common elements; for example, people are represented by circles, whereas vehicle icons are larger and more detailed.

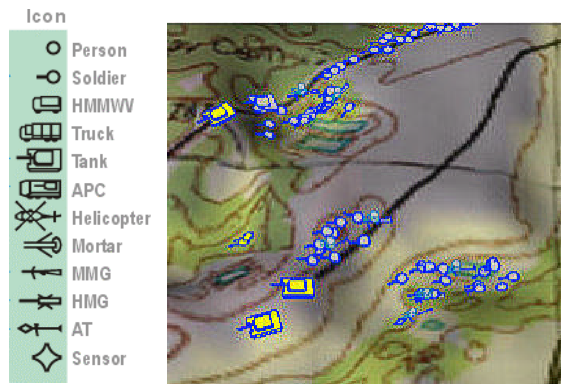

Figure 2: Entity icons in formation with icon legend

Initially, a major concern was the overlapping and crowding of entity icons when viewed from a distance. Icons are variably scaled so that they can be recognized no matter what the zoom level of the terrain. This means that on a large-scale terrain an icon may appear to occupy hundreds of square meters, though in reality it may only represent a single person. Surprisingly crowding was not a concern for SMEs; in fact it was desirable for the representation to express a physical sense of crowding with respect to the area in view. At these scales, SMEs were concerned with the overall picture of open spaces, gaps and concentrations across the battlefield, rather than details about individual entities.

The following are the attributes and states that icons are capable of expressing, and a description of each.

4.1.1. Orientation

The icons are oriented according to data assumed fed from a compass sensor mounted on a vehicle, helmet or weapon. They are meant to give a general sense of the direction of interest or movement. Some entities, such as humans, may change orientation very rapidly depending on the situation, therefore orientation may be more generally relevant for vehicles and crew served weapons than for individual soldiers. A time-based weighted moving average function may reduce the volatility of orientation movement.

4.1.2. *Affiliation*

The outline color of the icons expresses unit or force affiliation. In addition, shades or variations can separate entities within large groups. For example, entities from different platoons can have a different shades or tints of the base force color to separate them from each other.

4.1.3. *Status*

As shown in Figure 3, the icon fill color changes depending on the status of the entity. If the entity is damaged or destroyed or is a casualty, the fill turns bright red or black. If the entity is engaged in combat - either taking or receiving fire - the fill shows yellow.

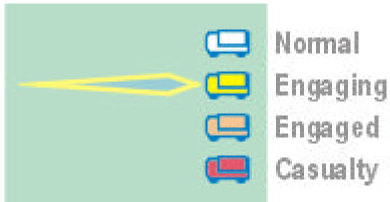

Figure 3: Icon status modes

4.2. *Shoot Spike*

The Shoot Spike expresses weapons capability and status. They are composed of a solid outline and a tinted, transparent fill.

Weapons can be classified as either direct fire (such as rifles or tank guns) or indirect fire (artillery or mortars). Weapon ranges vary greatly with type of weapon, weather conditions, situation, location, target etc, so in most cases weapons' rated range is only a rough indicator of real capability. The ideal situation would be for the weapon itself to transmit information about what it is doing; for example, a tank gun has a targeting system that could transmit the precise location of what it is aiming at. An arrow-type indicator was selected to express weapon capability instead of the alternative, range rings, for 2 reasons.

1) Conservation of visual space.
2) Constructive expression of orientation and intent.

It was determined that range circles would only be an optional view for longer-range indirect-fire platforms.

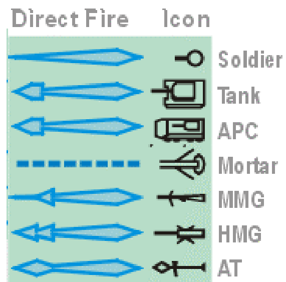

Figure 4: Shoot spike legend

4.2.1. *Weapons Range*

The length of spike shows the rated or target range of the weapon system. In most cases, more powerful weapons have a greater range, thus the length also helps to describe the nature of the weapon.

4.2.2. *Weapon Type*

The arrowhead shape expresses the type of weapon. The variations are based on a mix of traditional symbology and the shape of the munitions.

4.2.3. *Weapon Orientation*

The spikes are oriented based on data assumed gathered by a weapons-mounted compass. Orientation may change very rapidly depending on the situation or the platform. A moving average function would be useful in this case.

4.2.4. Target Tracking

A targeting device attached to the weapon system could allow the spike to point at the exact target location. This data could appear only when the weapon trigger is unlocked.

4.2.5. Combat Power

The shoot spikes can also have variable width. When width is linked to a combat power rating, more emphasis is placed on higher rated systems such as tanks, heavy machine guns (HMGs) and anti-tank weapons (AT). In planning or combat situations, the positioning and location of these assets has high importance, so the emphasis is appropriate.

Figure 5: Shoot spikes in various states

Note that the value of combat power rating as a reliable measure of relative ability is disputed as comparisons may not be accurate. For example, it may be meaningless to compare a tank with a rating of 1.0 to four soldiers each with a rating of 0.25.

4.2.6. Status

The color of the spike is linked to the assigned color of the entity. As shown in Figure 5, the outline color changes to yellow when a weapon is firing in order to emphasize this critical activity.

4.2.7. Terrain Characteristics

Shoot spikes hug the terrain, highlighting the shape of the terrain in the line of fire. The spike length can be modified using a Line-of-Sight algorithm to reflect the impact of terrain obstacles on weapons range.

4.2.8. Indirect Fire Ballistics

The shoot spike can also display the path of a projectile when information is available. Basic required information is the orientation and range of target and the maximum height of the projectile path. The distinctive nature of the path helps to distinguish indirect fires from direct fires.

4.2.9. Selection

When an entity with a shoot spike is selected, the outline color appears pink (default selection color).

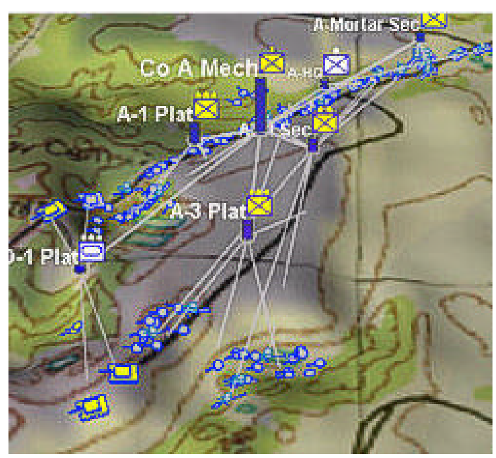

Figure 6: Attrition bars, 2525A symbols and Organization icons enabled for company subordinates.

4.3. Organization Icons

Each unit has an organizational indicator consisting of a light colored line connecting it to the location of its parent unit. Organizational nodes that have no physical component, such as a "Company", are displayed as gray pentagons. Currently, the location of these nodes is based on the center of mass of all subordinate entities that are operational combat elements. Several alternate methods to aggregate properties from the entity level up the org chart are under consideration. Aggregation of certain properties is a topic for subsequent work.

4.4. Attrition Bar

Each unit/entity can display a scalar value by means of a 3D bar with variable height. Currently the bar shows two calculated measures for unit aggregations.

4.4.1. Number of entities:

The relative height of the bar represents the number of entities below that node in the Task Organization.

4.4.2. Attrition Rate:

A portion of the bar is grayed out relative to the number of entities that have been attrited. Attrition rates are also displayed in the task org view next to unit name if the rates are greater than 0%.

4.5. 2525A Symbol

2525A symbology is the traditional means of describing properties of units in military organizations. They apply to aggregations and express the size and function of a unit in an efficient manner. The symbol layer can be turned on or off for any unit or entity, though they only appear for relevant organizational nodes. These symbols are implemented as overlay –based graphic objects. They are connected to a point in the terrain but they appear to float and are oriented towards the viewer, distinguishing them from entities that sit in the 3D terrain space. They are composed of an outline and a fill. The color assignment rules are identical to those of the icons.

4.6. Movement Vectors

As shown in Figure 7, the movement vector describes the current movement characteristics of an entity. It is an arrow-like element distinct from the shoot spike by color and opacity. It shows several dimensions of movement.

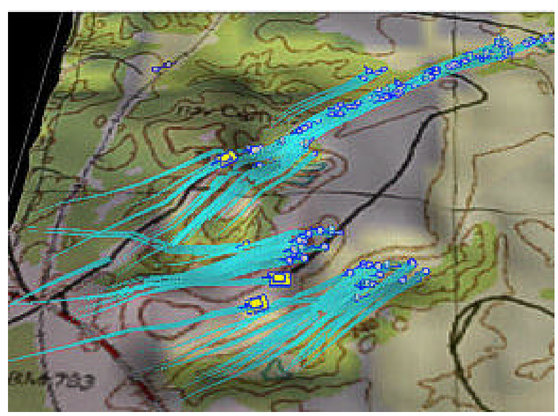

Figure 7: Movement Vectors show projected entity movement

4.6.1. Direction

The movement vector points in the current direction of movement, or when viewing historical data, points at a future known location of the entity.

4.6.2. Speed

The length of the vector is proportional to speed, and shows the distance that will be traveled in a user-set time period.

4.6.3. Potential Destination

This arrow naturally marks the potential movement distance over a set period of time, based on the current known orientation and speed of the entity. The user can vary the time period to make approximate future predictions of where the unit will be in that time.

4.6.4. Actual Destination

When reviewing historical data, the arrow points at the known location of the entity for the time period.

4.6.5. Terrain Characteristics

The arrow hugs the terrain, emphasizing the shape of the terrain in the direction of travel.

4.7. Movement Trails

Thin blue lines connect each entity to its recently reported locations as shown in Figure 8. The lines fade relative to the age of the update. Information can be inferred from observing these trails such as intent, speed, formation and tactics, however interpretation depends on the experience and skill of the observer. In informal trials, these tracks have helped to answer questions such as "How did I get here?" and "How well was the plan executed?"

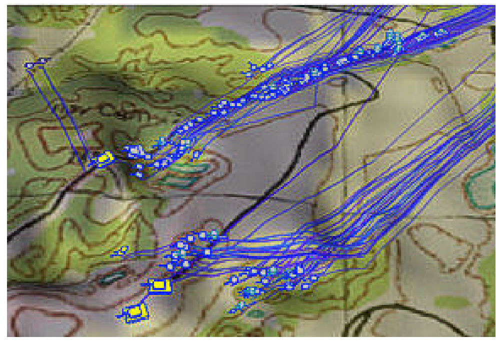

Figure 8: Movement Trails show where units have been.

4.7.1. Sensor Paths

Movement trails for sensors mark the area actually targeted by the sensor, creating a record of what has been covered by the sensor. The path changes width dynamically to reflect varying sensor parameters, such as zoom level.

4.8. Indirect Fire Range Ring

Each entity may show an indirect fire range if it is suitably classified. Two measures are expressed as illustrated in Figure 9.

Figure 9: Indirect fire range and orientation

4.8.1. Weapons Range

A simple ring with a dashed line indicates the rated range of the weapon.

4.8.2. Orientation/Source

A line connects the ring to the source entity and simultaneously indicates the current target or orientation of the weapon.

4.9. Sensor Range Circle

Each sensor entity may show its sensing area based on a simple range distance. A two-color densely dashed circle with a bright transparent fill marks the range of potential sensitivity. An example is shown in Figure 10.

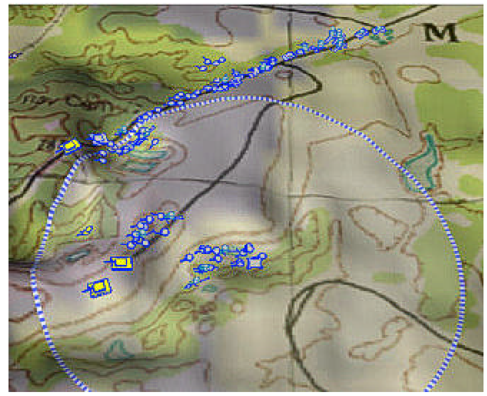

Figure 10: Sensor Range indicator

5. Information Layer Controls

Not all attributes need to be displayed all the time. What attributes are displayed varies with the situation and the user. Rapid, flexible and easy to use methods are required to tailor the display. A layer-based interface was developed that permitted each entity (or group of entities) to have any combination of visual attributes turned on or off. This is shown in Figure 11.

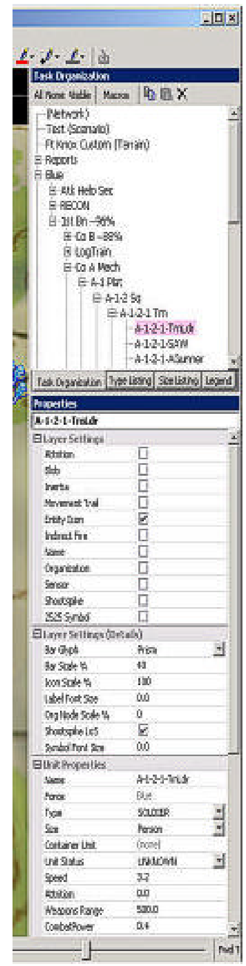

Figure 11: Layer settings with Object Tree

Regular, informal tests were run in which commanders were presented with new versions of the software and a battlefield scenario that was new to them. These tests were meant to reveal weaknesses in the workflow and patterns of use.

Initially, the SMEs attempted to create relatively complex views of the battlefield in which different types of entities had different attributes turned on or off. The workflow was simple: select units (either in terrain or tree) and then turn layers on and off as required. However, this seemingly simple task became a significant impediment to usability. The users spent so much time finding, selecting and adjusting the layer options that they lost sight of the task at hand. A set of shortcuts was developed to answer common task-related questions, based on observations (examples are shown in Figure 12). The shortcuts activate conditional attribute/unit display combinations across all entities with a single click. They were especially effective for building situation awareness from a cold start. In subsequent tests, they were used almost exclusively, evolving into a kind of second-order set of information layers.

5.1. Shortcut Layer Workflow

The following sequence is a typical overview of how the shortcuts were used in order to gain situation awareness from a cold start: When commanders were first presented with new scenarios, they typically began analysis by activating the “Entity Icons” shortcut in order to get a sense of massing in the terrain. They then chose the “High-Level Org” to see the hierarchical groupings and command structure. The “Activity + Status” was then used to identify critical activities emphasizing casualties, engagements and direction of fires. “Movement Trails” generally followed to expresses the history of moves and by inference, intent. Other shortcuts were utilized when looking deeper into particular situations or during planning activities.

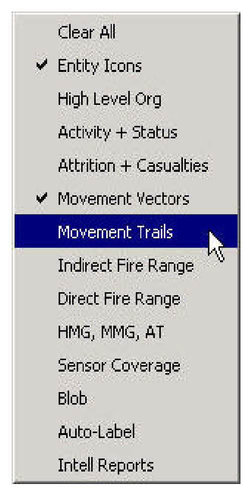

Figure 12: Macro Options

The sequential selection of layers is an interactive, cognitive process that provides access to details while keeping the big picture in focus.

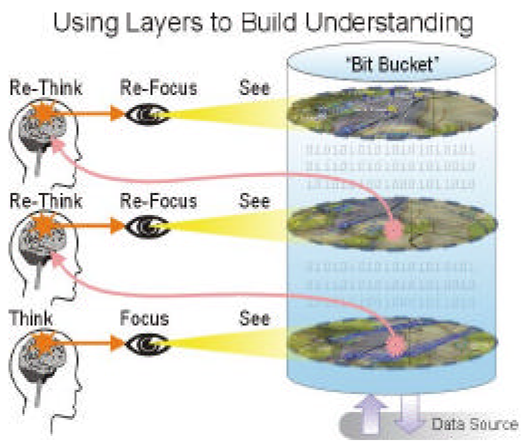

Figure 13: Diagram describing the layer-based workflow

6. Task Organization View

Commanders require a traditional Task Organization chart to orient themselves to the forces available and command structures. An object tree viewer was merged into the display beside the terrain view (Figure 14), and integrated as a secondary interface for interacting with tactical information. This viewer contains the force Task Organization hierarchy down to the entity level. Additional nodes were added for scenario meta-data, terrain display properties, intelligence reports, and opposing force units. The Task Organization is dynamic and reorganizes over time as units are reassigned. It can also display extra information, such as attrition rates.

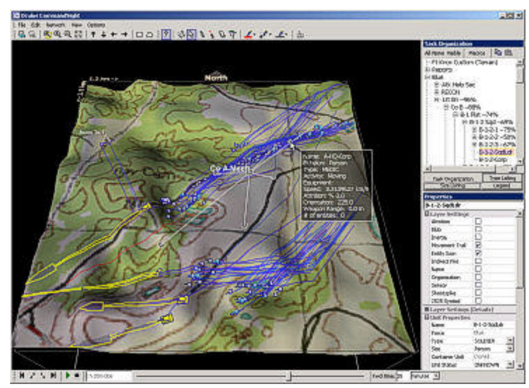

Figure 14: The application window showing the terrain, task organization and the object properties viewer/editor.

7. Battlefield Terrain Display

The SMEs considered a 3D terrain viewer an essential tool for the accurate interpretation of a situation. As the base upon which entities are displayed, the terrain viewer is a critical component of the visualization. Its development presented additional challenges in user interface design, however this work will be the focus of a future paper.

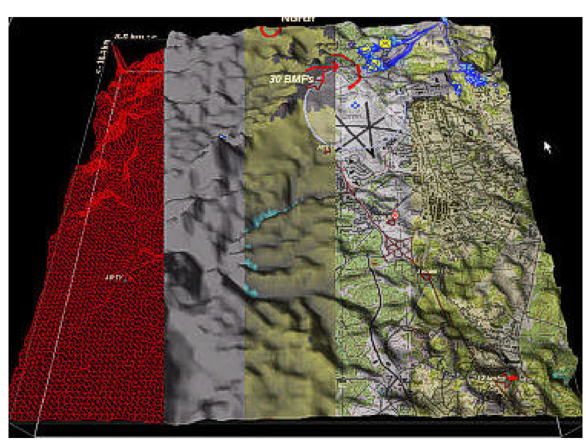

Figure 15: Composite image of terrain information layers

To summarize, the battlefield is displayed in three dimensions with entities placed on the terrain. Topographic layers and analytics can be added with varying intensity, allowing commanders to customize the view to reveal properties such as lines of sight, key terrain and avenues of attack. It also allows increased terrain detail for close-up views.

Several techniques were developed to simplify navigation and improve performance:

- Simplified constrained navigation controls
  - Rotation handles
  - Single-click Pan and zoom
- Animated transitions between view changes
- Very high resolution terrain texture maps based on 1:24000 7.5' USGS topographic maps
- Contour tone enhancement overlays
- Shading enhancement overlays
- Variable vertical exaggeration

8. Conclusions

The right visual artifacts have profound effects on people's abilities to assimilate information, to reason with it, to understand it, and to create new knowledge. For commanders, the benefits and their consequences are significant:

- Increased speed of comprehension;
- Improved quality of command decisions.
- Increased tempo of operations.
- Improved command decision-making by less experienced commanders and/or under circumstances of great fatigue.
- Use of smaller more mobile command structures.
- Increased capability for concurrent planning and execution.
- Less communications and guesswork required to assess a given situation.

To achieve these objectives, new visualization representations have been developed to enable commanders to perceive the significant aspects of battlefield information to support decision-making.

Informal testing and feedback from SMEs indicate that it is possible to create an interface to display thousands of entities on a terrain for commanders to use under severe time constraints without causing information overload. The resulting entity-based representations provide the granularity necessary to express a situation in enough detail that commanders may not require direct communication with subordinates to make assessments. With this enhanced perception and pattern recognition, a commander may estimate the properties of a situation more accurately and with less training then traditional methods.

When properly designed, an entity-based visualization is capable of effectively exploiting information resources to provide significant advantage to commanders. In designing the visualization, there was sufficient visual bandwidth to display the critical information dimensions, resulting in a rich and expressive picture. Tools and rules are required manage this picture and to display information only when needed and relevant.

To develop an effective, relevant display based on entity-level data requires careful design the involvement of SME's. In fact, without SME participation
have been considered due to incorrect assumptions about the usefulness of such granular data. The

through testing.

9. Acknowledgements

During the course of the CPOF program, the authors have had the privilege of working with a

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Good information visualizations ease cognitive burdens and make explicit the inherent structures

create a good visualization without a deep collaboration with knowledgeable practitioners.

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