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Increasing Situational Awareness by Combining Realistic and Non-Realistic Rendering Techniques

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# Increasing Situational Awareness by Combining Realistic and Non-Realistic Rendering Techniques

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Figure 1 a, b, c: 3 types of vehicle models: realistic, non-realistic and symbolic

## ABSTRACT

Advances in computer graphics hardware have led to astounding increases in visual realism for 3D environments. Although this improved visual realism can lead to a better sense of immersion and a more faithful reproduction of the natural world, it does not necessarily promote increased awareness of an evolving situation. Although some requirements overlap with other applications such as off-the-shelf games, military Command and Control systems (including stability operations and homeland defense missions) have unique requirements. In particular, the overriding goal is to provide timely data effectively, independent of how visually pleasing it may be. The primary objective is to convert the abundance of information into concise knowledge. This paper proposes a method of combining realistic and non-realistic displays to increase display effectiveness, and hence improve situational awareness.

**CG Keywords:** I.3.6 [Computer Graphics]: Methodology and Techniques – Interaction Techniques; J.7.0 [Computer Applications]: Computers in Other Systems – Command and Control; I.3.7 [Computer Graphics]: Three-Dimensional Graphics and Realism – Virtual Reality;

**Additional Keywords:** information visualization, HCI (Human-Computer Interface), Military training systems, situational awareness.

## 1. INTRODUCTION

There are many visualization techniques, but in order to be useful they must work together in a consistent, unified fashion. A realistic view provides a more natural interface for viewing geographical data and provides the optimal domain for spatial reasoning. However, non-realistic display techniques may enable a viewer to more quickly assess an overall situation. Our goal is to combine the best of both visualization techniques, along with other types of data displays, to enhance understanding of the data. This paper discusses military display systems with respect to the requirements, visualization techniques, and most importantly, their interaction in a commercially successful product.

An effective information station helps the user to make better decisions, in a timely fashion. Much of Command & Control, Communications, Computers and Intelligence (C4I) deals with making decisions in the face of uncertain or inadequate data. One of the more important aspects of making those decisions is situational awareness – the ability to comprehend the people, places, history and current events that will affect the battle space. Reducing uncertainty (also referred to as the "fog of war" or "friction"), so that better decisions can be made is the goal of situational awareness.

“There are four sources of ‘fog’ commanders and staffs must overcome to achieve accurate situational understanding:

- Inadequate or poor-quality information.
- Misinterpretation of information.
- Conflicting information or choices.
- Too much information.” [1]

"When commanders' situational understanding is better than their enemy's, they have a significant but temporary advantage." [2]

An information station that can be used to simulate and train military operations has several components. These may include a 2D display, a 3D display, text and hierarchical lists, etc. This paper focuses on the 3D display and to a minor extent, its interaction with the other types of displays.

In the following sections we discuss the requirements of a military training system, categorize the non-realistic data we visualize, discuss specific types of data where a non-realistic version is more effective than a realistic version and how the assorted visualizations interact in a complex system. We conclude with a discussion of related products.

## 2. REQUIREMENTS

Our list of requirements is based on feedback from fielded systems with previous versions of this and other products, customers (both foreign and domestic) who purchase the base toolkits in order to build their own systems, and employees with military experience. Some of the fielded system locations include: Fort Leavenworth Command and General Staff College; Fort Lee (logistics course); USMA (West Point); U.S. National Guard 35 Field Training Group; Illinois National Guard; USME Expeditionary Warfare School in Quantico, VA.

Military training systems have many similarities to commercial games, in particular those with a military flare like America's Army, Full Spectrum Warrior or Close Combat. Dynamically changing data forces the user (player) to make time critical decisions. The scenario (game) progresses, even without active user input, so that lack of an active decision is still an action.

However, there are a substantial number of important differences, the most important of which is the primary goal -- not to entertain, but to train. According to Alberts, Garstka and Stein, "Providing battlespace awareness ... with requisite accuracy and timeliness requires that data and information from multiple sources be ... presented in ways that facilitate rapid and accurate inferences." [3] Realistic displays are not bad, but do not necessarily lead to improved situational awareness. This is counter-intuitive, as most people prefer the most realistic displays, even though their performance might be worse [4].

A series of research experiments by people like Smallman, St. John and Cowen have shown 2D is better for some tasks, while 3D is better for others [4]. Nagata showed that increasing the depth cues in 3D displays increases localization [5].

Similarly, many advocate the use of non-realistic visualizations to improve various aspects performance in 3D environments. By blending the most useful aspects of 2D and 3D, realistic and non-realistic displays, we can create a product that takes advantage of the best of each. To reiterate, realism is not more important than accurate assessment of data.

Some of the more substantial differences between a shrink-wrapped game and a tactical training system are the range and sophistication of users; when and why data is developed; playing time evaluation metrics, and the upgrade path of the application.

Users at different levels of command and/or in different roles must work together. The data must be synchronized, but differ according to individual needs. The training system must be flexible enough to support, not only different roles, but the ability

to dynamically switch between them as users switch roles to cover someone who is no longer able to fulfill that role, or to allow commanders to view what their staff officers are seeing.

Unlike games, there is no progression through levels where users learn interaction techniques; all techniques could potentially be used at any point in time. (Not a different technique per "level"). Nor are the users necessarily familiar with similar products. This makes the training system interfaces harder to learn. As compensation, the user base accepts that some user training is necessary, unlike games installed by isolated individuals on their home machines.

Generation of the source data (scenarios) is substantially different than games. Scenario generators (instructors) generate the data to meet particular training objectives, *after* the training system is developed. Based on the results from one training exercise, a new scenario can be created to meet the next training objectives. This is in contrast to games, where the game designers have control over the input data, and the data is created before the game is shipped.

Since the data is based on a realistic scenario, as opposed to what would make the game most interesting to play, too much data is more common than too little data. Consequently, de-cluttering the data is an important task -- tying directly back to the goal of reducing the fog of war.

Training scenarios are typically long endeavors. There are many phases preceding the battle such as planning and deployment. Various brigade/battalion training scenarios run at Fort Leavenworth took between 1 and 4 hours from start to finish [6]. These scenarios were predominantly using 2D displays, but we anticipate similar time commitments with 3D displays

In order to provide effective feedback, different evaluation metrics are required than those provided by first person shooting games. Detailed after action reviews require detailed data histories of vehicle movements, interactions, status changes etc., as well as the ability to display and discuss these concepts within a group. We address this issue by using a separate product which records the data for subsequent analysis and replay, and providing "instructor mode" view controls so that one machine can control the views of others. This recorded data can be replayed similarly to a VCR, with override capabilities for point of view.

## 3. APPROACH

In order to aid the user in the important goal of understanding the data, we implemented a series of non-realistic techniques that augment the realistic virtual display. This could be considered "augmented virtuality" or "exaggerated reality". First we will discuss the non-realistic techniques, and then their interaction with the realistic techniques.

The non-realistic techniques can be categorized as follows:

- **Visualization of non-visual data.** Additional information is given a visual representation.
- **Alternative visualization.** A non-realistic visualization technique is used in place of a realistic depiction.
- **Data reduction.** Data that would normally be displayed in a realistic view is removed from view or de-emphasized so that the focus is on the relevant information. This is also referred to as "de-cluttering".

### 3.1 Visualization of Non-Visual Data

Some types of data are invisible, so no realistic depiction is even possible, such as the volume swept out by a radar sensor. Pictures show the *relationship* between objects (“is this entity within the coverage of that sensor?” “What areas of the battlefield have no coverage?” etc.) Translucent sensor volumes highlight the area being sensed, but do not obscure other data. User controlled color settings can be used to distinguish between various types of sensor coverage if desired. This is important, as sensors differ in frequency and accuracy, i.e. the types of things they can “see”. Visualization of this type of data concisely shows how the data is changing, as the sensor moves relative to the both the terrain and other entities.

Several criteria are used to select which non-visual data to depict, and how to depict it. The data must be relevant to the user, help the user with his/her task, and most importantly, have a spatial representation. An example of non-visual data without a spatial organization is the force hierarchy. In this case, a list box is a better representation.

Some data is important to visualize because its spatial location changes rapidly over time. This includes threat domes (the area surrounding an entity for which its weapons are effective, communication lines (which can rapidly change due to relative changes in location, terrain interference, or weather interference; biological, chemical, and nuclear clouds (which can be color coded to indicate type of hazard), drop down lines with altitude labels for planes which indicate height above terrain and the precise XY location (which may not be obvious in a perspective view), movement or trajectory history for vehicles and missiles (which help in prediction of future location and analysis during after action reviews), inter-visibility lines etc.

Other data does not change location, but is important for planning and decision-making. Tactical graphics such as planned routes, waypoints, areas of impassible terrain and minefields are all examples of non-visual data that are represented visually.

Once we determine what data should be represented, it must be decided which are the important aspects to represent, how to represent them and for how long.

History movement is conceptually simple, and hence a good example. The “what” is easy – where did the vehicles come from. How to represent this has many options. A series of ghost vehicle images shows clearly where the vehicle used to be, but due to their size, clutter the display. A single line drawn at the center point of the vehicle will show the past location, but not the vehicles orientation (more important for submarines and planes than tanks). But a “ribbon” will show both. Since there are many vehicles, color-coding the history trail by force affiliation reduces confusion.

The last consideration for deciding on the visual representation of non-visual data is how long it should be displayed. Vehicle trajectory histories show the movement of any vehicle, and can be turned on or off though a dialog. This balances information availability and screen clutter. There are two options for the length of the history trail: distance or time. Each has its own advantages. With time, the user configures the relevant time period -- say N minutes. The history trail shows where the vehicle was during the last N minutes. Since different types of vehicles (such as planes and tanks), move at such substantially

different speeds, the length of the trail is an indicator of velocity (faster vehicles have longer trails). Using distance, uniformly spaced locations are saved. All vehicle trails are the same length, so no velocity information is available. There is potentially less screen clutter with distance based history trails than time based. Given the same number of data samples, the distance-based approach will give finer granularity for abrupt changes in orientation and direction, such as loops.



Figure 2 "Ribbons" show the location and orientation history.

### 3.2 Alternative Visualization

According to Booch et. al, “A rendering is an abstraction that favors, preserves, or even emphasizes some qualities while sacrificing, suppressing, or omitting other characteristics that are not the focus of attention.”[7] Raskar and Cohen compare photo-realistic to non-photo-realistic rendering and state that “a simplified diagram is often preferred when an image is required to delineate and explain” [8]. Alternative visualizations are used when a realistic depiction is possible but is less helpful to the task at hand than a non-realistic or rendered version.

Of the graphical models used in a military training system, those used to represent vehicles are the most pervasive, so we spend the most time talking about the visualization of these, followed briefly by an overview of a few of the other objects for which we support alternative visualizations.

#### 3.2.1 Vehicles

Dynamic vehicle model swapping supports realistic, non-realistic, and symbolic models; shown respectively in Figure 1 (a, b, c). Each model category offers distinct tradeoffs in the task of vehicle identification.

For all vehicle model categories, shape identifies whether the entity is a land, air or sea vehicle, and the models come in various levels of detail. The first category, realistic models, is quite standard in 3D environments and need not be discussed in detail here.

The second category, non-photo-realistic vehicle models, is reminiscent of cartoon images. Color is used to emphasize the force affiliation (friendly, enemy, neutral or unknown). The shape provides a coarse categorization of vehicle type (land, air or sea). These models lose the realistic rendering that would, for example, allow one to distinguish the exact type of aircraft. Due to their simplified form, the non-realistic models have fewer polygons, and are faster to render, which means that scenarios with larger numbers of entities can be supported without loss of performance.

The third vehicle model category, symbolic billboards, is the least realistic, but provides stylized information. A configuration file maps the vehicle type to any graphic desired. In our application, we use standard military symbology 2525A/B. Like the non-realistic models, color indicates force affiliation. The symbol markings allow the knowledgeable user to recognize the exact vehicle type.

Each of these three techniques offers different trade-offs. No one approach is best all of the time. By allowing the user to dynamically switch vehicle models, we support the “most effective view at the right time”.

Realistic models, non-realistic models, and symbolic models show progressively less realism and progressively faster performance. Compared to other things, such as terrain models, the cost of vehicle models is small, but with large complex systems, sometimes every little bit helps.

As with realistic models, the symbolic billboards show the exact vehicle type, but need a smaller amount of screen real estate to do so. Realistic models in the distance are not detailed enough to identify. Although the user can increase the scale at which the non-realistic models are rendered based on a slider, it is not always feasible. For example, when the view is further away, and a large number of vehicles are in sight, increasing the model scale causes the vehicle images to overlap. In this situation, symbolic billboards are superior to either of the other model categories.

This is consistent with experimental results by Smallman et al. who state, “Abstract symbols can be made arbitrarily distinct”. Non-realistic models are superior to symbols for “conveying category (air or sea) and heading information”. [4]

Another advantage of symbols is aggregation (discussed in more detail later). Aggregation is the process of representing a set of vehicles as a single entity. A simple marking on the top of the symbol distinguishes a single tank from a platoon of tanks or even a battalion.

Billboards do have some drawbacks. They are rotated so that they always face the point of view. Consequently, the orientation of the vehicle is lost. The other disadvantage is the total lack of realism, which can reduce the sense of immersion and hence enjoyment.

So, to summarize, a realistic view should be used when vehicle details are 1) both needed and possible to distinguish given the model scale and/or 2) the emotional factors of a realistic immersive display are required. A non-realistic model provides quick identification of force affiliation and orientation and better performance, but not identification of the exact vehicle type. Symbolic billboards have no visual or emotional appeal, but are very descriptive (except for orientation) even in crowded scenes, and have the best performance.

### 3.2.2 Other Alternative Representations

Terrain can be represented realistically using detailed terrain database models and satellite imagery, but other representations have their uses. Two techniques emphasize the contours of the land: shading based on elevation and exaggerating the terrain. (See the color plate for examples). Elevation shading is easier to see than a realistic view. Terrain exaggeration is not realistic, but makes it easier to see if a helicopter is higher or lower than a particular mountain peak – important for placing communication

equipment. A third non-realistic technique is draping a terrain model with political and road maps. This helps with planning and logistics operations.

Although not as realistic as a perspective view, using an orthographic view to determine whether something is left or right of another is easier. It also prevents distant objects from “disappearing” from view.

We provide an “exaggerated reality” mode, which is a composite. The terrain and non-realistic vehicle models are drawn with perspective, but the vehicles are automatically scaled. The near and far vehicles are drawn so that they use the same amount of screen real estate. This provides the benefits of a perspective display, without the disadvantage of far away vehicles disappearing from awareness.

There are several techniques for drawing shadows. Gooch et al. discuss three modes: “a shadow with a hard umbra and hard penumbra, a single hard shadow, and a soft shadow” [7]. In non-realistic mode, we exclusively use the hard shadow since it provides clearer identification of the vehicle shape, and consequently the vehicle type. Unlike Gooch et al., we locate the shadow directly “under” the vehicle, independent of the light source, and provide an altitude line from the center point of the vehicle model to the center point of the shadow. (Hence the term “drop-shadow”). The main purpose of the drop shadow is to provide information about the XY location of the air vehicle, which may not be obvious in a perspective view, and an additional cue as to the vehicle type. Clearly these must be easy to toggle on and off, as they have the potential to add too much clutter to the screen, the same reason that only the air-borne vehicles are given drop shadows.

## 3.3 Data Reduction

Data can be reduced in two ways: by eliminating it completely, or by compressing it into a more compact format. The following sections will describe one instance of each.

### 3.3.1 Data Elimination

Stone et al. introduced filters that can be used to reduce some data so that the important information stands out, or to show additional data when needed [9]. For example, when non-realistic vehicle models are shown, we automatically hide vehicle effects such as smoke, fire, dust trails, vapor trails etc. This allows the focus to be on the vehicle itself. Another example, which we have implemented in 2D but not yet in 3D, is hiding dead enemy units. This emphasizes the enemy units that are still a threat. An example of showing additional information is displaying sensor volumes. This is important to the information officer, but would just add unnecessary clutter to the display of the logistics officer.

Our filters can be global (apply to the entire screen), or local (apply to portion of the screen, and change between these. Filters can be easily toggled on or off. Like Stone et al.’s work, their effects are cumulative.

Overlays are a simplification of filters for a particular purpose. Tactical graphics are symbols which users place on a battle space map to assist in various stages of a military operation. These are grouped on a series of overlays. Overlays correspond to traditional acetate sheets overlaying a terrain map, upon which one can draw. Any symbol can be placed on an overlay layer. Through the overlay manager, overlays can be dynamically

created, toggled on or off, or even reordered. Unlike acetate sheets, overlays can be shared with other networked colleagues.

Other techniques to reduce the data visualized are user controlled switches to turn off almost anything visualized, dialogs that can be closed and retrieved at will, and temporary displays of data. For example, semi-transparent information dialogs will pop up when the cursor rolls over an entity, and then disappear as the cursor moves away. This provides immediate information, without cluttering the display with dialogs for every entity. List boxes provide the same information, but organized by hierarchy, not spatial location. In addition, multiple entities can have their associated data displayed simultaneously.

### 3.3.2 Data Consolidation

Another important difference between realistic and non-realistic views is the level of detail. Training systems are not just first person games, with individual entities such as tanks represented as realistically as possible. Often, due to the size and level of the simulation, vehicles must be aggregated into larger military groupings. Military commanders are often interested locally in units within two levels of their own level, and in units at their level in adjoining areas of interest [10].

For example, a brigade commander is primarily interested in companies and above. A representative battalion might have between two and three hundred tanks as well as other assorted ground and air vehicles. Due to the scale of the terrain viewed, it is not possible to depict the vehicles to scale. If they were correctly scaled, they would not be visible. If scaled larger than is realistic, then we have problems with vehicles overlapping when they come into close proximity (for example a battle or when traveling as a convoy). Consequently, visually representing a group of vehicles is an important issue for training systems.

We have addressed this problem through two techniques: user controlled dynamic scaling and aggregation. A user can control the scale at which vehicles are drawn through a simple slider. We examined the possibility of automatic scaling based on a combination of terrain scale and entity overlap, but found that user controlled scaling was better since only the user knew what portion of the screen was of interest at a given moment. There are also individual differences in user preference, and a slider to control the scale is also better in this regard.

The second technique to deal with vehicle scale is aggregation level. The aggregation level (level of detail) applies independently to both the simulation and to the display. Again, this refers back to the emphasis on accurate data assessment rather than realism. Vehicles can be aggregated, or combined into a higher-level representation. For example, three individual tanks can be combined into a squad; three squads make a section; three sections a platoon etc. Aggregation levels can be set a priori or dynamically.

Dynamic aggregation is one option when the displayed graphical models overlap. For example, if the models are scaled larger than real life (for visibility reasons), then when a subset comes into close proximity, they overlap. We provide three options:

- Combine only those vehicles of the exact same type.
- Combine overlapping entities with identical Platform/Domain/Force (e.g. a tank and truck can be combined into a single, more general 'land' visual)

- Combine overlapping entities with identical Platform/Force (e.g. a tank and airplane can be combined into a single, more general 'vehicles' visual)

## 3.4 Technique Interaction

Individual 3D display techniques are not useful to an application unless they are easy to use. They must work both with other 3D display techniques, and with other types of data representations.

### 3.4.1 Point of View

It is important that the users can easily and dynamically choose the view that is most informative. The user can easily toggle between realistic and non-realistic modes; and between perspective and orthogonal views. The standard 3D controls for setting the view frustum are available. These settings are all independent, so each combination is possible.

We allow the user to save as many customized views, as he/she wants. These views consist of the point of view, and the terrain extents. We provide the two most common views in the saved-views menu: top-down (2D) view, and a 45-degree view. Both of these views are initialized based on the extents of the terrain.

We also provide cross tool control mechanisms to allow the users to control the 3D application's viewpoint from a separate 2D application. Our 2D product provides additional features to aid situational awareness. Many of these features would not be suitable to anything except a top down 2D view. Embedding them in the 3D product would clutter and confuse the 3D interface. Likewise, the 3D views provide information missing from the 2D views. Sometimes however, only one view is needed for particular types of tasks. Consequently, these remain separate products. However, this leads to the requirement for cross-tool control.

There are a few key requirements for cross tool control. First, the 2D and 3D products must work together, whether they are running on the same machine or not. Not just technically, but with an easy to use and understand interface. Second, a single 2D application must be able to control multiple 3D applications views.

On the 2D display, a pair of binoculars icon represents each controlled 3D view. The 3D view can be attached to individual vehicles or sets of them. This means the view moves as the relevant vehicle(s) do. A line between the binocular icon and the vehicle icon represents the relative offset and eye point (which need not be looking directly at the associated vehicles). There is substantial flexibility in manipulating the 3D view, but we will not go into the details here.

The 3D controller icons appear in the hierarchical list view of entities. This allows the user to quickly find the controllers, even when the main 2D view is focused on a subset of the terrain which does not contain the controllers.

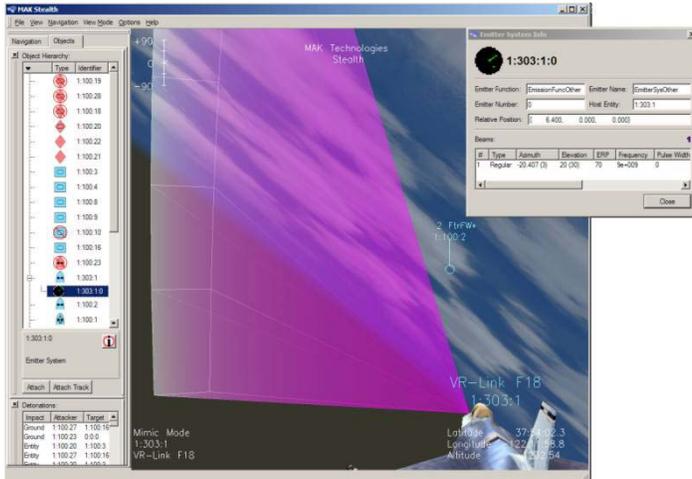
### 3.4.2 Other Data Representations

Sometimes a spatial view is not the best information format, whether it is realistic or non-realistic. For some types of data, both the spatial and non-spatial data representation offer things the other cannot, and processes for using both concurrently must be developed.

Vehicle representation is one such type of data. Clearly the best depiction of a vehicle's position relative to other vehicles and the

terrain features is spatial. But to represent the vehicles organizational structure, a hierarchical list-view is best. The user needs to be able to locate a particular vehicle in one representation from the other etc.

Another example of this type of data is the sensors that can be attached to vehicles. Placing them in the organizational hierarchy as subcomponents of their vehicle allow the user to “attach” to them, and monitor their details through information dialogs.



**Figure 3** An F16 (having ID 1:303:1) is emitting a sensor. Its sensor has one beam whose azimuth sweep extends 3 degrees and whose elevation sweep extends 20 degrees. The sensor's attributes are described both visually (through the pink volume emanating from the nose of the jet) and textually (through the information dialog to the right).

### 3.4.3 Reducing Confusion

There are many things that are best represented as lines. But too many lines create confusion, not understanding. For example, history trails, fire and detonate lines, communication links, lines of sight, roads, routes, tactical graphics etc. Clearly the ability to hide lines by category is required. One can also use different types of lines: different colors, dashed/solid, fine line / ribbon / tubes, arrows on the ends etc. Since different users are interested in different subsets of data, we allow users to easily change the default configuration for each data category.

## 4. RELATED PRODUCTS

When we look at related work, we are primarily interested in other situational awareness (SA) products that are of commercial quality and available as retail products, i.e. commercial off-the-shelf products or COTS products. Our 3D visualization product is called the MÄK StealthXR<sup>tm</sup>.

Analytical Graphics makes Satellite Toolkit (STK)[11]. There are three major differences between STK and the StealthXR: underlying data transport mechanism, scope, and cost. STK does not support HLA or DIS (the network protocols used for many military applications). STK focuses on an earth view, showing cones of coverage as opposed to closer coverage suited to battlefield vision at the level of planes and tanks. It is also seven times as expensive as the StealthXR

eNGENUITY makes VAPS[12]. These animated instrumentation components deal with instrumentation, not visualization. For example, data input from outside stimulus is used to control the needle display on a graphical cockpit-dial. These instruments are primarily oriented at helicopter and aircraft applications. It is primarily a code generator rather than extensible toolkit or part of a tactical training system.

DiSTI (distributed simulation technology, inc.) makes GL Studio [13]. GL Studio synthesizes photographs, 3D models and behavior logic to create photo-realistic 3D interactive real-time Reusable Simulation Objects. Like VAPS, these are primarily animated instrumentation.

## 5. RESULTS AND FUTURE WORK

MÄK's StealthXR visualization product was demonstrated and has received positive feedback from many tradeshows and military research conferences, including: Simulation Interoperability Workshop (SIW) 2004, International Training Education Conference (ITEC) 2004, C4I Summit 2004 and Transformation and Operations (TOPS) in Cyberspace 2004

The Air Force contract under which this work has been done is still not finished. Despite this, the StealthXR<sup>TM</sup> toolkit (which encompasses the work described in this paper) has two customers. It has been successfully used as a base toolkit by OpNet to create a communications visualization tool called 3D<sup>TM</sup>. OpNet in turn has generated sales from their new product. Our second customer, ITT, has used the toolkit to visualize hazardous clouds which are driven by data they created using sophisticated particle based mathematical models.

This paper describes a commercial product, whose on-going development and maintenance will continue for many years. Many of our plans are based on preliminary customer feedback and trade show demonstrations, but will change with additional feedback. The future work plans are too lengthy to list here, so I'll just mention a few of the major categories.

**User studies.** Many of the implemented features were created with feedback from knowledgeable about military needs. However, objective productivity measures, obtained through subject experiments would provide invaluable feedback.

**Performance.** For example, convert the symbolic billboard models to fonts blitted onto a billboard. We do this in our 2D product, and previous performance testing showed that true type fonts were up to an order of magnitude faster than comparable bitmaps. Also, improved outline techniques for the non-realistic vehicles models. Currently this is based on work by Gooch et al. [8], Lake et al. [14] and Buchanan and Sousa [15], but our implementation could be more general.

**Better data filtering.** For example, only enemy units within striking distance, show only munitions (missiles, torpedoes, bombs), only vehicles within a certain distance of a point, or between particular latitude/longitude lines.

**Automated data displays.** Spawning sub-windows based on activity (pop up a window focused on an area under attack)

**Knowledge voids.** One of the most extreme examples of "inadequate information" is no information at all, or a knowledge void. By simply and easily identifying regions of the battle space where we do not have any data, commanders can make more

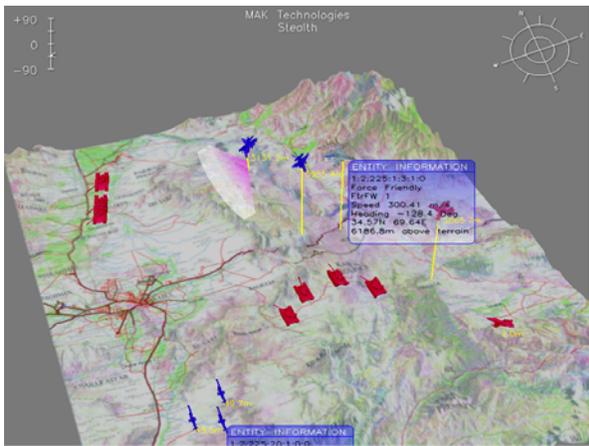
informed decisions about where to place sensors or send information gathering sorties.

## 6. ACKNOWLEDGEMENTS

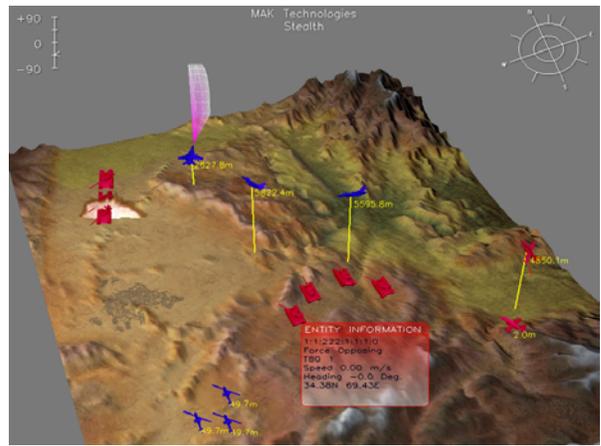
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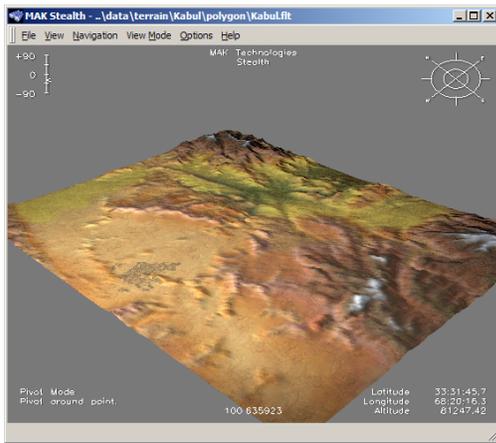
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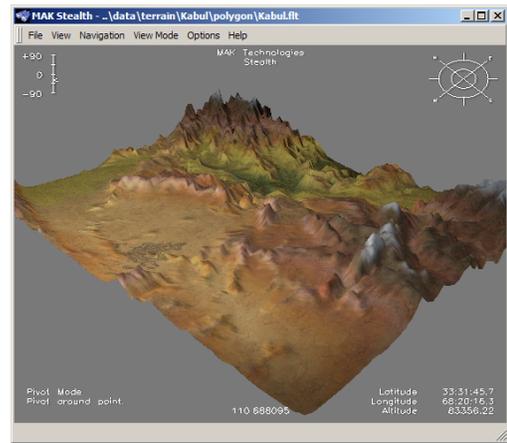
**Color Plate 1: Raster map draped over terrain, non-realistic models.**



**Color Plate 2: Terrain shading, drop lines, red (OPFOR) information dialog, and sensor volume.**



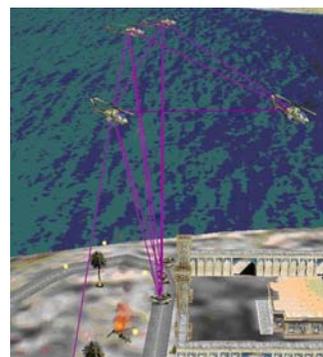
**Color Plate 3: Correctly scaled terrain.**



**Color Plate 4: Same terrain -- exaggerated scaling.**



**Color Plate 5: Visualization of non-visual data like Nuclear, Biological, or Chemical clouds**



**Color Plate 6: Visualization of communication lines.**