GeoTime Visualization of RFID
Providing Global Visibility of the DoD Supply Chain

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Abstract

The use of Radio Frequency Identification (RFID) technology is expanding rapidly in both commercial and Department of Defense (DoD) supply chains. Many resources within the RFID research and development community have been focused on hardware and firmware components, including active and passive RFID tags, tag readers, and embedded software, yet fewer resources have been focused on exploiting the data collected by tag readers and stored in electronic databases. GeoTime visualization exploits the collection and storage of RFID data, and provides global in-transit visibility of the DoD supply chain down to the last tactical mile.

Background

DoD recognizes the value of expanding their global RFID infrastructure and sees a RFID-capable supply chain as a critical element of defense transformation [Wynne, 2004]. Beginning in January 2005, DoD has mandated the use of RFID for specific product types (packaged operational rations, clothing, individual equipment, tools, personal demand items, and weapons systems repair parts) shipped to specific defense depots (Susquehanna, PA and San Joaquin, CA). In January 2006, DoD mandates will expand to include most product types and most military service and defense depots [DoD, 2004].

Currently, the DoD's Product Manager for Joint Automatic Identification Technology (PM J-AIT) is managing over 1,500 RFID read/write stations in 25 states and 20 countries around the world. These read/write stations will provide supply chain data to five In-Transit Visibility (ITV) servers. The data contained on the ITV servers provides the basis for monitoring the entire DoD supply chain on a near real-time basis. The challenge is to create a visual display of critical data elements that provides military commanders with information such as "Where are my supplies right now?" and "When will those supplies get to my troops?"

1 Introduction

1.1 Information Visualization Benefits

Animated two and three-dimensional computer graphics are extremely expressive. With the correct approach to the visual design of the display and the objects, large amounts of information, such as global RFID data collected by thousands of electronic tag readers, can be quickly and easily comprehended by a human observer. When information is presented visually, efficient innate human capabilities can be used to perceive and process data. Orders of magnitude more information can be seen and understood in a few minutes. Information visualization techniques amplify understanding by increasing human mental resources, reducing search times, improving recognition of patterns, increasing inference making, and increasing monitoring scope [Card, 1999], [Ware, 2000]. These benefits translate into system and task-related performance factors which speed the completion of analysis, decision-making, and communication tasks. The time, effort and number of work products required to do these types of tasks are reduced [Wright and Kapler, 2002].

1.2 Visualization of Events in Time and Geography

Many visualization techniques for analyzing complex event interactions only display information along a single dimension, typically one of time, geography or network connectivity. Each of these types of visualizations is common and well understood. For example, time-focused scheduling charts such as Lifelines [Plaisant et al, 1996] or Microsoft (MS) Project display attributes of events over the single dimension of time. A Geographic Information System (GIS) product, such as MS MapPoint, or ESRI ArcView, shows events in the single dimension of locations on a map. There are also link analysis tools, such as Netmap (www.netmapanalytics.com), Visual Analytics (www.visualanalytics.com), and Analyst Notebook (www.i2inc.com) that display events as a network diagram, or graph of objects and connections between objects. These tend to be one-dimensional displays that show either organizational structures, timelines, communication networks, or locations. In each case, only a thin slice of a multidimensional picture is portrayed.

Some of these systems are capable of using animation to display time. Time is played back, or scrolled, and the related spatial displays change to reflect the state of information at a moment in time, however this technique relies on limited human short term memory to retain temporal changes and patterns. One technique, called "Tracks", is often used in Air Force and Navy command and control systems to show on a map surface the trails of moving entities. Another visualization technique called "small multiples" [Tufte, 1990] uses repeated frames of a condition or chart, each capturing an incremental moment in time, much like looking at sequence of frames from a film laid side by side. Each image must be interpreted separately, and side-by-side comparisons made, to detect differences. This technique is expensive in terms of visual space since an image must be generated for each moment of interest. This can be problematic when trying to simultaneously display multiple images of adequate size that contain complex data. One additional technique is the use of linked views to support multivariate analysis, including time series data analysis in one view, and a map in another view [Becker et al, 1987], [Eick and Wills, 1995]. Interactive linking of data selection across multiple, separate views improves the small multiples technique. However, combining the visualization techniques in a multidimensional display provides a powerful analytical tool capable if showing geospatial, time, and relationship data in a single view [Kapler and Wright, 2004]. GeoTime uses the single view approach, combined with data filtering techniques, to provide global supply chain visibility.

1.3 Related Work

Recent spatiotemporal research has been progressing in a variety of areas. Geographic knowledge discovery methods have been developed using analysis of logs of GPS position data over time, and point density surfaces are being made. The goal of these methods is to develop agent-based computational mechanisms to support location based PDA services [Mountain et al, 2003].

Significant work is being done in health data analysis, where spatiotemporal pattern analysis makes use of multiple maps and statistical graphing. Systems such as GeoVista, make use of map animation, multivariate representations, and interactivity (e.g. highlighting, brushing, filtering and linked selection) to assist in the analysis of geo-referenced time varying multivariate data. However, maps and timelines are separate views [MacEachren et al, 1994, 1995, 1997, 1998, 2003].

Research in the GIS community exploring 3-D visualization of activities in a combined time and geography space is in the early stages. First results include showing paths or track data but without interaction, animation or support of analytical user tasks [Mei-Po Kwan, 2004]. This work is related to a 3-D spatiotemporal concept [Wood, 1992] discussed as a way to allow maps to encode time to the same degree that maps encode space. Time can extend above the map in the third dimension proving time does not need to be a "hidden dimension".

2 GeoTime Visualization Design Concept

The GeoTime visualization technique was developed to improve understanding of movements, events and relationships as they change over time within a spatial context. A combined temporal-spatial space was constructed in which to show interconnecting streams of events over a range of time in a single picture. Events are represented within an X,Y,T coordinate space, in which the X,Y plane shows geographic space and the Z-axis represents time into the future and past (see Figure 1). In addition to providing the spatial context, the ground plane marks the *instant of focus* between before and after; Events along the timeline "occur" when they meet the surface. Events are arrayed in time along *time tracks*, which are located wherever events occur within the spatial plane.

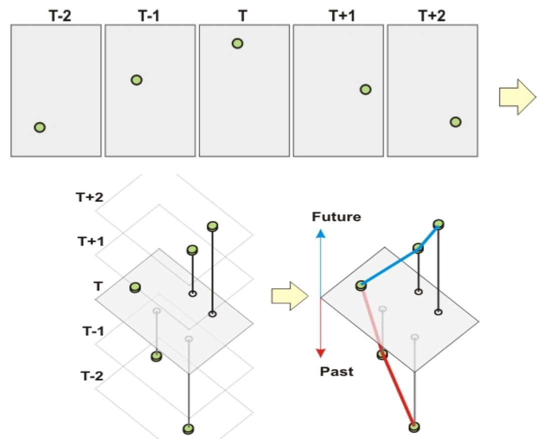

Figure 1: Individual frames of movement are translated into a continuous spatiotemporal representation

2.1 Spatial Time-Tracks

Spatial time-tracks make possible the visualization of *where* and *when*. They are the primary organizing elements that support the display of events in time and space within a single view. Time-tracks represent a stream of time through a particular Location and are represented as a literal line in space. Each unique location of interest will have one spatial timeline that passes through it. Events that occur at that location are arranged along this timeline according to the exact time or range of time at which the event occurred.

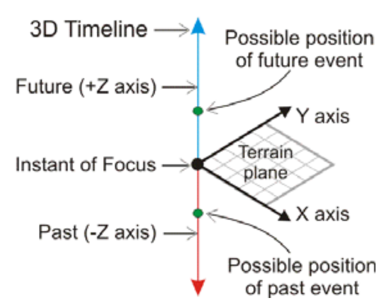

Figure 2: 3-D Timeline configured to display past as down and future as up.

A single spatial view will have as many timelines as necessary to show every event at every location within the current spatial and temporal scope. In order to make comparisons between events and sequences of events between locations, the time range represented by the timelines is synchronized. In other words, the time scale is the same for every timeline.

There are three variations of Spatial Timelines that emphasize spatial and temporal qualities to varying extents. These are 3-D Z axis timelines, 3-D viewer facing timelines and linked time chart timelines. Each variation has a specific orientation and implementation in terms of its visual construction and behavior. The user may choose to enable any of the variations at any time during runtime.

2.2 3-D Z-axis Timelines

3-D Timelines are oriented to the terrain view plane and exist within its coordinate space as shown in Figure 3.

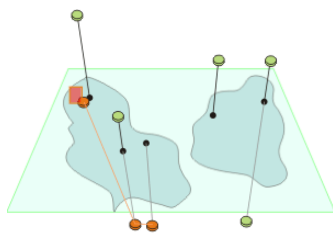

Figure 3: 3-D Timelines pass through terrain locations. 3-D Timelines are locked in terrain space and are affected by changes in perspective.

2.3 3-D Viewer Facing Timelines

3-D Viewer-Facing Timelines are similar to 3-D Timelines except that they rotate about the instant of focus point so that they always remain perpendicular to the viewpoint from which the scene is rendered. As illustrated, in Figure 4.

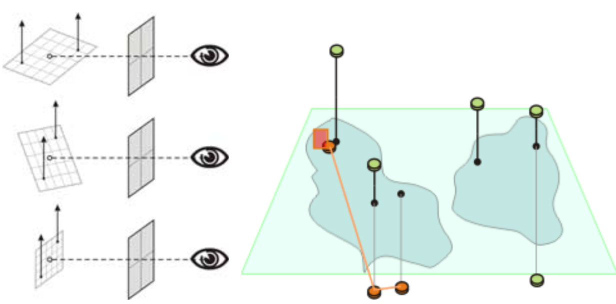

Figure 4: Viewer facing timelines rotate to face the viewpoint no matter how the terrain is rotated in 3-D.

2.4 Linked Time-Chart Timelines

Linked Time-Chart Timelines are timelines that connect a 2-D grid in screen space to locations marked in the 3-D terrain representation. As shown in Figure 5, the timeline grid is rendered in screen space as an overlay in front of the 2-D or 3-D terrain.

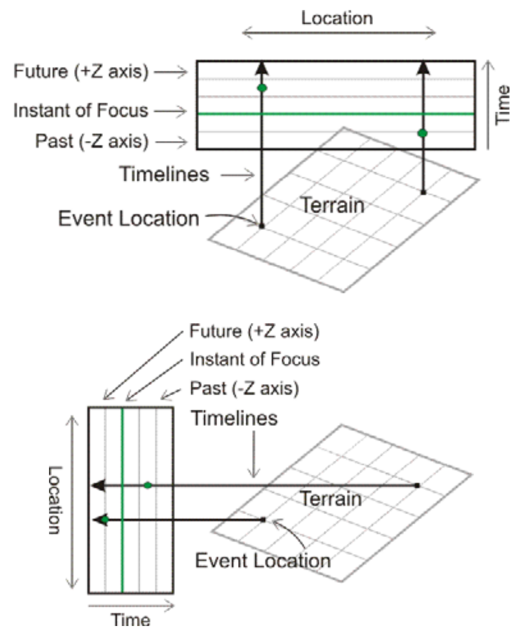

Figure 5: Diagram showing how Time-Chart timelines are connected to terrain locations.

3 GeoTime Implementation

GeoTime has been developed as a Java application and uses the Oculus.Java class library for rendering and animation. Tables of application data are input with a CSV reader, and a Microsoft Access database is used to manage the application data. All three variations of Spatial Timelines have been implemented: 3-D Z Axis Timelines, 3-D Viewer Facing Timelines and Linked Time Chart Timelines. Map data, including 3-D digital terrain elevation data, and event data can be accessed via an interface to ESRI / CJMTK (Commercial Joint Mapping Toolkit, www.cjmtk.com) via ArcSDE. A screenshot of GeoTime is shown in Figure 6.

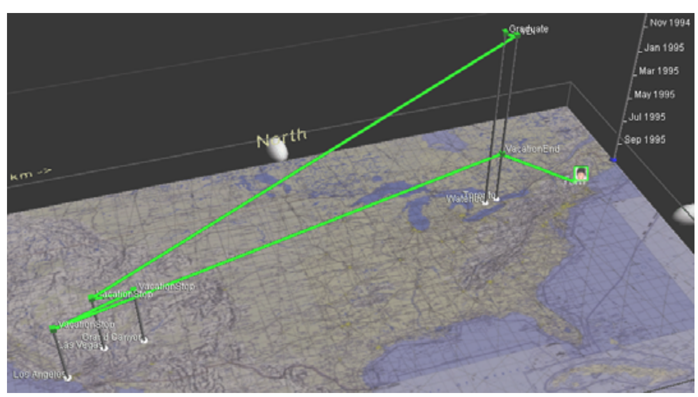

Figure 6: Screenshot of GeoTime with a moveable time scale at the right. The green line traces a shipment of military supplies and its movement over time and geography. As the time slider is moved, a user can see where a shipment of supplies is, where it has been, and where it will be at any given time.

4 Information Interaction

In addition to familiar user interface features such as selection, filtering, hide/show and grouping that operate as commonly expected, the following interactions were specifically developed or customized to work within the GeoTime environment.

4.1 Temporal Navigation

A Time and Range Slider, as shown in Figure 7, is a linear time scale that is visible underneath the visualization representation. This slider contains selectors that allow control of three independent temporal parameters: the Instant of Focus, the Past Range of Time and the Future Range of Time. Past and future ranges can be independently set by the user by clicking and dragging on handles. The time range visible in the time scale of the time slider can be expanded or contracted to show a time span from centuries to seconds. Clicking and dragging on the time slider anywhere except the three selectors will allow the entire time scale to slide to translate in time to a point further in the future or past.

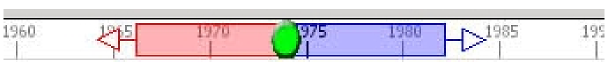

Figure 7: GeoTime slider with variable past and future time ranges and handles.

Continuous animation of events over time and geography is provided as the time slider is moved forward and backwards in time.

4.2 Simultaneous Spatial and Temporal Navigation

Common interactions such as zoom-box selection and saved views are provided. In addition, simultaneous spatial and temporal zooming has been implemented to allow the user to quickly move to a context of interest. In any view, the user may select a subset of events and zoom to them in both time and space using the Fit Time and Fit Space functions. Within the Overlay Calendar views, these actions happen simultaneously by dragging a zoom-box on the time grid itself. The time range and the geographic extents of the selected events are used to set the bounds of the new view.

4.3 Association Analysis

Functions have been developed that take advantage of the association-based connections between events, entities and locations. These functions are used to find groups of connected objects during analysis. Associations connect these basic objects into complex groups representing actual occurrences. These associations can be followed from object to object to reveal connections that are not immediately apparent. Association analysis functions are especially useful in analysis of large data sets where a quick and efficient method to find and/or filter connected groups is desirable. The association analysis function can be used to display only those locations and/or products in the visualization that pertain to critical shipments. For example, "show me all the weapon system repair parts shipped from Defense Distribution Depot, Susquehanna, PA to Baghdad within the past 72 hours". Two association analysis functions have been implemented within GeoTime: Expanding Search and Connection Search.

4.3.1 Expanding Search

As illustrated in Figure 8, the expanding search function allows the user to start with a selected object(s) and then incrementally show objects that are associated with it by increasing degrees of separation. The user selects an object or group of objects of focus and clicks on the Expanding Search button. This causes everything in the visualization representation to disappear except the selected items. The user then increments the search depth and objects connected by the specified depth are made visible in the display. In this way, sets of connected objects are revealed.

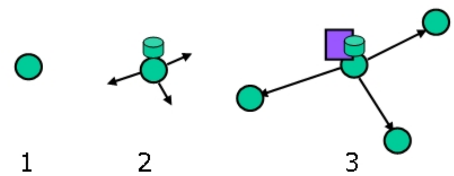

Figure 8: Expanding search.

4.3.2 Connection Search

The Connection Search function allows the user to connect any two objects by their web of associations. The user selects any two objects and clicks on the Connection Search tool. The connection search algorithm scans the extents of the network of associations starting from one of the objects. The search will continue until the second object is found as one of the connected objects or until there are no more connected objects. If a path of associated objects between the target objects exists, all of the objects along that path are displayed and the depth is automatically displayed showing the minimum number of links between the objects. This is illustrated in Figure 9. One application of this technique is displaying the interrelation between a pallet shipped and a pallet never delivered to determine the point of failure.

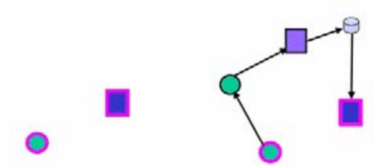

Figure 9: Connection search.

5 Entity and Event Interactive Visualization

Icons and images are used to describe entities such as supply classes, people, organizations and objects. Icons can also be used to describe activities such as item shipped or item delivered. These icons can be standard DoD map icons or tailored icons.

As entities change location in time, their movement is animated from one location to another. Simple linear interpolation is done between individual observations. A trail or track, that traces an entity in time and geography, can be displayed for one or more selected entities. Due to the relative immaturity of RFID tag and reader technology, the assumption can be made that there will be many non-reads and false-reads as objects move throughout the supply chain. In other words, there will be gaps in data. GeoTime "connects-the-dots" and shows reliable tracks of shipments, even with gaps in data.

5.1 Drill-down

Mouse-over drill down, shown in Figure 10, allows additional information, such as text or images, to be displayed in the visualization.

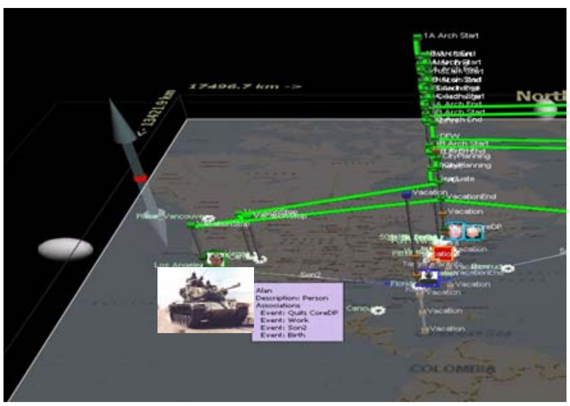

Figure 10: Pointing at an object in the display drills down to additional information.

5.2 Annotations

Ink strokes can be placed on the map and used to annotate elements of interest with arrows, circles and freeform markings. Some examples are shown in Figure 11. Ink objects are located in geography and time and so appear and disappear as geographic and time contexts are navigated.

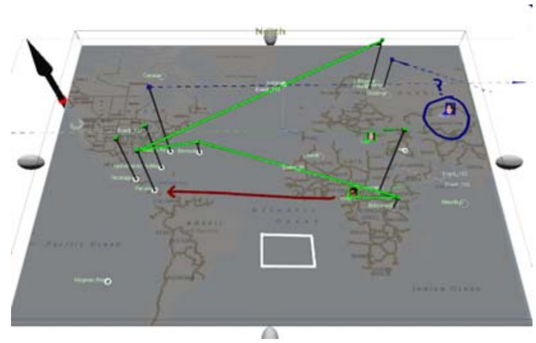

Figure 11: Screenshot of GeoTime with ink annotation.

5.3 3-D Terrain Maps

Tracking objects and events over the terrain in which they travel can be critical for military analysis. GeoTime utilizes both 2D and 3D maps as required. Figure 12 shows an example of a 3D terrain map with shipment tracks and other entity information displayed in a single scene.

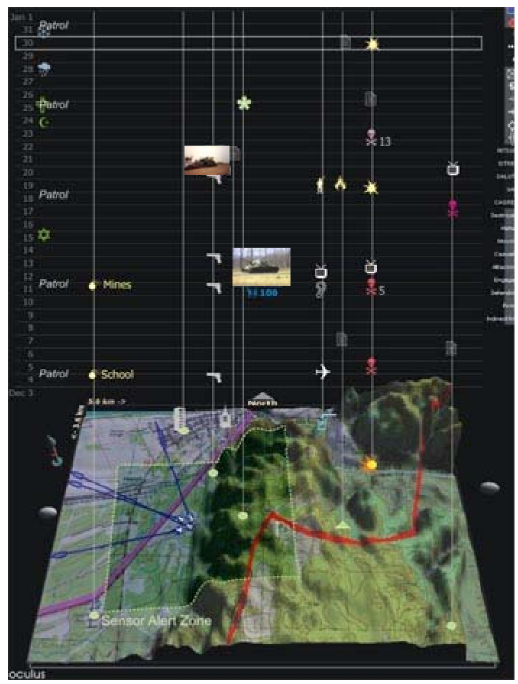

Figure 12: Screenshot of the GeoTime prototype in calendar mode, showing recent events within a localized area.

6 Summary and Conclusions

The GeoTime product demonstrates that a combined spatial and temporal display is possible, and can be an effective technique when applied to analysis of complex past and future events within a geographic context. GeoTime can be used to get an instant view of military shipment status at any time/space coordinate. Standard activity reports from other DoD automated systems can be imported and translated into GeoTime elements. Over the course of time, thousands of tag-reader events can be stored and reviewed within the system. GeoTime visualization exploits the collection and storage of RFID data, and provides global in-transit visibility of the DoD supply chain down to the last tactical mile.

Ongoing development, based on feedback from initial implementations, will further evolve the GeoTime visualization tool and increase the user's ability to see and comprehend the "where, when and what" of RFID and so improve an understanding of the "why".

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