

# GeoTime Information Visualization

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## Abstract

Analyzing observations over time and geography is a common task but typically requires multiple, separate tools. The objective of our research has been to develop a method to visualize, and work with, the spatial inter-connectedness of information over time and geography within a single, highly interactive 3-D view. A novel visualization technique for displaying and tracking events, objects and activities within a *combined temporal and geospatial* display has been developed. This technique has been implemented as a demonstratable prototype called GeoTime in order to determine potential utility. Initial evaluations have been with military users. However, we believe the concept is applicable to a variety of government and business analysis tasks.

**CR Categories:** H.5.2 [User Interfaces]: Graphical User Interfaces, I.3.6 [Computer Graphics]: Interaction Techniques.

**Keywords:** 3-D visualization, spatiotemporal, geospatial, interactive visualization, visual data analysis, link analysis.

## 1 Introduction

### 1.1 Information Visualization Benefits

Animated two and three-dimensional computer graphics can be extremely expressive. With the correct approach to the visual design of the layout and the objects, large amounts of information can be quickly and easily comprehended by a human observer. Visualization is an external mental aid that enhances cognitive abilities [Card et al, 1999]. 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 cognition by increasing human mental resources, reducing search times, improving recognition of patterns, increasing inference making, and increasing monitoring scope [Card et al, 1999], [Ware, 2000]. These benefits translate into system and task related performance factors, for individuals and groups, which affect the completion of analysis, decision-making and communication tasks. The time, effort and number of work products required to do these types of tasks is 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) or Visual Links

(www.visualanalytics.com) that display events as a network diagram, or graph, of objects and connections between objects. Several systems exist for tracking highly connected information, most developed for police investigative purposes [Harries, 1999]. Analyst Notebook and CrimeLink, for example, provide tools for organizing and arranging fragments of information into visualizations intended to help the analyst make sense of complex relationships. These tend to be one dimensional representations 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 or other 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 naval command and control systems to show on the 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, which can be problematic when trying to simultaneously display multiple images of adequate size that contain complex data content. One additional technique to mention 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.

### 1.3 Related Work

Recent spatiotemporal research has been progressing in a variety of areas. For example, geographic knowledge discovery methods have been developed using analysis of logs of GPS position data over time. Point clouds and density surfaces in 3-D, with time as the vertical dimension, are used for data exploration. The goal is to develop agent-based computational mechanisms to support time and location based PDA services [Mountain et al, 2003].

Significant work is 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 and 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. Time does not need to be a “hidden dimension”. One technique has been developed [Hewagamage et al., 1998] that uses spiral shaped ribbons as timelines to show isolated sequences of events that have occurred at discrete locations on a geographical map. This technique is limited because it uses spiral timelines exclusively to show the periodic quality of certain types of events, but does not show connectivity between the temporal and spatial information of data objects at multi-locations within the spatial domain. Further, event data objects placed on the solid, wide spirals can suffer from complete occlusion, thereby providing for only a limited number of events and locations viewable with the spiral timelines.

A recent review of geographic dynamics [Yuan, 2003] [Yuan et al, 2002] provides examples of 2-D or 3-D maps with playback and animation controls to discover spatiotemporal behaviors in, for example, the evolution of a weather system, the dispersion of pollutants or the propagation of a disease. Objects move across the surface of the map as they change position or shape in time. One classic example of physical 3-D spatiotemporal dynamics is the National Center for Supercomputing Applications’ study of the evolution of a modeled thunderstorm [Wilhelmson et al, 1990] [Tufte, 1997].

## 2 The GeoTime Visualization Concept

A visualization technique has been developed to improve perception 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.

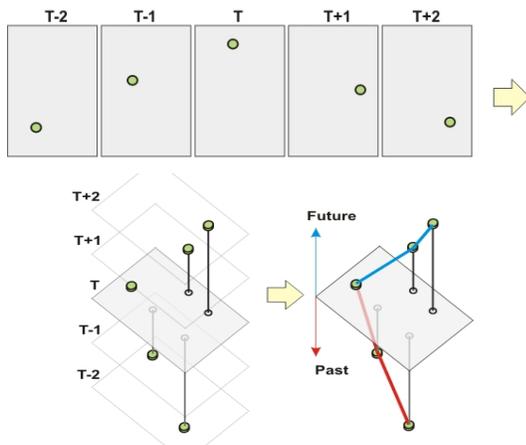


Figure 1: Individual frames of movement are translated into a continuous spatiotemporal representation.

## 2.1 Spatial Time-Tracks

Spatial Time tracks make possible the perception 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.

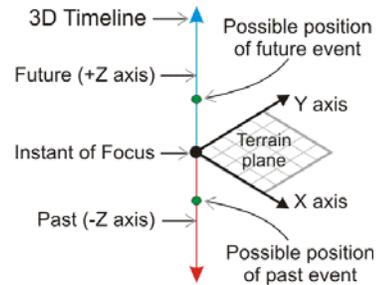


Figure 2: 3-D Timeline configured to display past as down and future as up.

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. Each variation is an increase of saliency of time over geography. 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 normal to the terrain view plane and exist within its coordinate space as shown in Figure 3. This method places more emphasis on the geographical view.

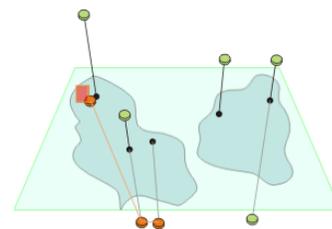


Figure 3: Diagram showing how 3-D Timelines pass through terrain locations. 3-D Timelines are locked in terrain space and are affected by changes in perspective.

### 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. This is shown in Figure 4.

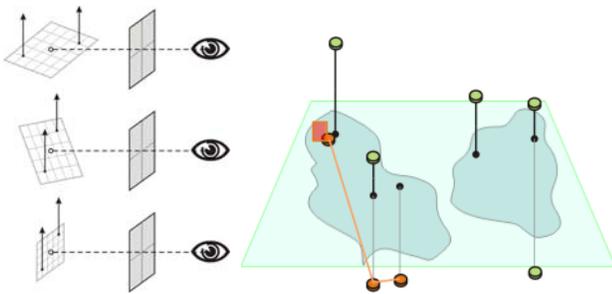


Figure 4: Viewer facing timelines rotate to face the viewpoint no matter how the terrain is rotated in 3-D.

### 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. More emphasis is placed on the time view. The chart grid lines help improve the precision of comparison of event times. 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.

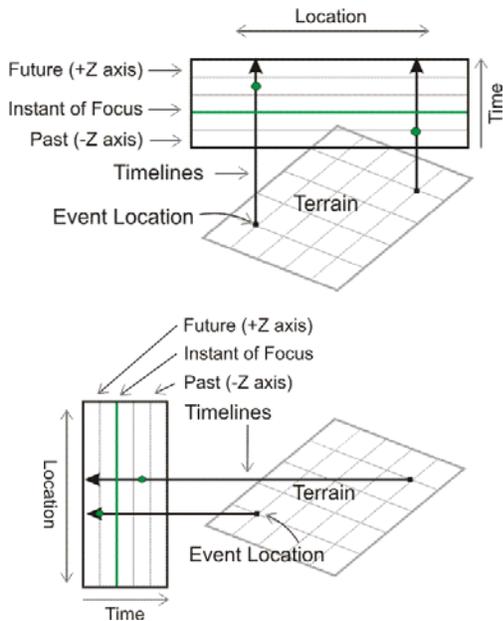


Figure 5: Diagram showing how Time Chart timelines are connected to terrain locations.

## 3 Implementation

GeoTime has been built as a Java application and uses the Oculus.Java class library for rendering and animation. Simple tables of application data are input with a flat file reader or an Excel drag'n drop input wizard. 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 imagery and 3-D digital terrain elevation data, is accessed via an interface to ESRI / CJMTK (Commercial Joint Mapping Toolkit, [www.cjmtk.com](http://www.cjmtk.com)). Screenshots of GeoTime are shown in Figure 6 and 7.

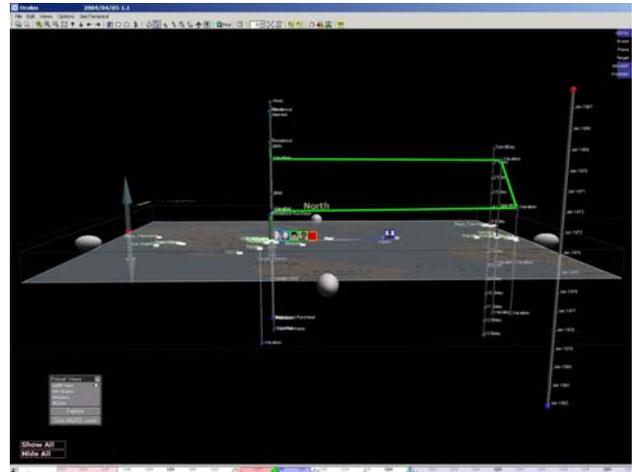


Figure 6: Screenshot of GeoTime with time slider at bottom and moveable time scale at right. The green line traces one entity's movement in time and geography.

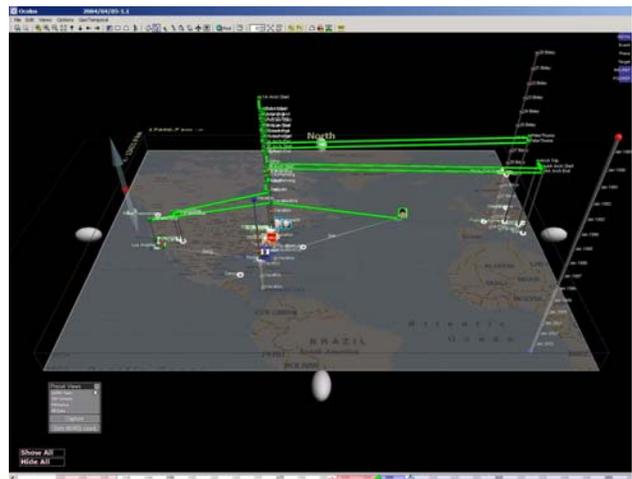


Figure 7: Screenshot of GeoTime with overhead view and time slider advanced forward in time from Figure 6.

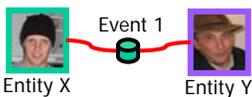
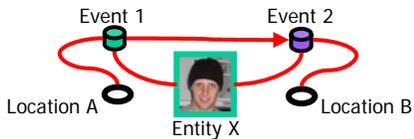
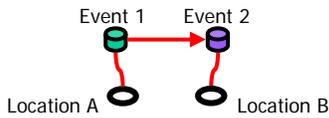
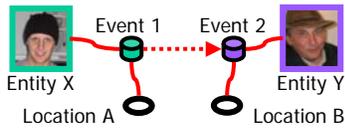
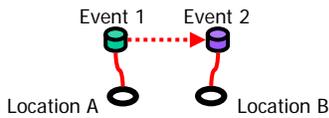
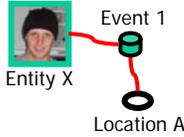
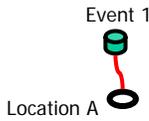
## 4 The GeoTime Information Model

An information model, based loosely on Davidsonian semantics [Davidson, 1980], is used to support the representation of information in GeoTime. The following objects types are employed in GeoTime.

### Entities (*people or things*)

represent any thing related to or involved in an event including people, objects, organizations, equipment, businesses, observers, affiliations etc.

### Group Structure



### Group Type + Sample Application

**Observation Group**  
*(An Incident, news item or observation)*  
 1 Association:  
 •Event 1 occurred at Location A

**Observation with Actor**  
*(Involvement in an incident, observer)*  
 2 Associations:  
 •Event 1 occurred at Location A  
 •Entity X present at Event 1

**Soft Vector Group**  
*(Phone Call, email, money transfer)*  
 3 Associations:  
 •Event 1 occurred at Location A  
 •Event 2 occurred at Location B  
 •Event 1 directed at Event 2

**Vector Group with 1+ Actors**  
*(Phone Call, email, money transfer)*  
 5 Associations: Same as above plus...  
 •Entity X present at Event 1  
 •Entity Y present at Event 2

**Hard Vector Group**  
*(Documented transport such as air or boat travel)*  
 3 Associations:  
 •Event 1 occurred at Location A  
 •Event 2 occurred at Location B  
 •Event 1 moves to Event 2

**Hard Vector Group with 1+ Actors**  
*(Transport of a person or thing)*  
 5 Associations: Same as above plus...  
 •Entity X present at Event 1 (departure)  
 •Entity X present at Event 2 (arrival)

**Actor Relationship**  
*(Familial or employer-employee relationships, organization membership, ownership)*  
 2 Associations:  
 •Entity X member of Event 1  
 •Entity Y member of Event 1

**Observation Relationship**  
*(Indirect involvement)*  
 1 Association:  
 •Entity X member of Event 1

### Representation Schematic

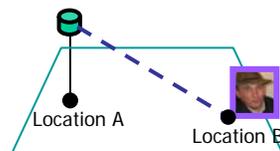
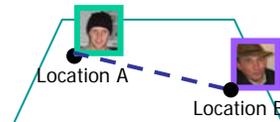
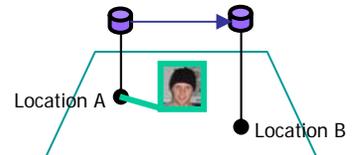
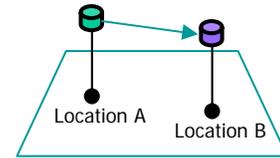
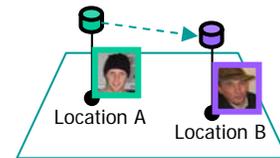
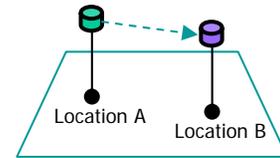
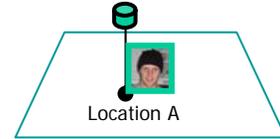
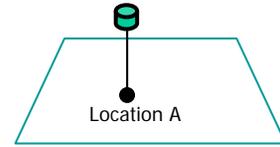


Figure 8 – Example Entity Activity Groups

### Locations (geospatial or conceptual)

represent a place within a spatial context, such as a geospatial map, a node in a diagram such as a flowchart, or even a conceptual place such as “OZ”.

### Events (occurrences or discovered facts)

represent any action that can be described. The following are examples of events:

- Bill was at Toms house at 3 pm
- Tom phoned Bill on Thursday
- A tree fell in the forest at 4:13 am, June 3, 1993
- Tom will move to Spain in the summer of 2004

Events store the times at which the action took place.

These basic information types are combined into groups using Associations. An association is an information object that describes a pairing between two objects. They are the links in Figure 8. For example, in order to show that a particular entity was present when an event occurred, an Association is created to represent that Entity X “was present at” Event A. An association also exists to link Event A to a particular Location. In GeoTime, groups of associated elements have been defined to represent certain classes of occurrences and relationships. These groups have specific visual expressions and interactive behaviors in the display. Example defined groups are described in Figure 8. Extensions, new classes of associations and new types of groups are possible.

A variation of the association type is used to define a subclass of these groups to represent user hypotheses. In other words, groups can be created to represent a guess or hypothesis that an event occurred, that it occurred at a certain location or involved certain entities. Currently, the degree of belief / accuracy / evidence reliability is modeled on a simple 1-2-3 scale and represented graphically with line quality.

## 5 Information Interaction within the Spatiotemporal Workspace

In order for GeoTime to move beyond a visualization concept to a usable prototype, several user interactions within the combined spatiotemporal viewer were necessary. In addition to familiar data interactions 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.

### 5.1 Temporal Navigation

The Time and Range Slider, as shown in Figure 9, is a linear time scale that is visible underneath the visualization representation. This control contains sub controls/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 9: Time slider with variable past + future ranges + handles.

Continuous animation of events over time and geography is provided as the time slider is moved forward and backwards in time. If a vehicle moves from location A at t1 to location B at t2, it is shown moving continuously across the map. The timelines animate up and down at a high frame rate.

### 5.2 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.

### 5.3 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 (see Figure 8) 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. For example, an Entity maybe be involved in events in a dozen locations, and each of those events may involve other Entities, and so on. The association analysis function can be used to display only those locations on the visualization representation that the entity has visited or entities that have been contacted. Two simple association analysis functions have been implemented: Expanding Search and Connection Search.

#### 5.3.1 Expanding Search

As illustrated in Figure 10, 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.

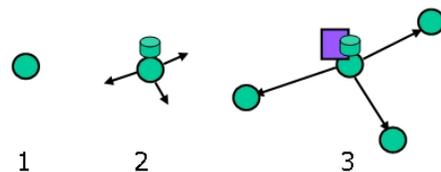


Figure 10: Expanding search.

### 5.3.2 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 11.

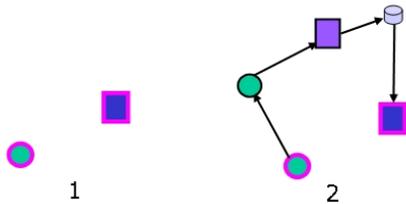


Figure 11: Connection search.

### 5.4 Additional Entity and Event Interactive Visualization

Icons and small images are used to describe entities such as people, organizations and objects. Icons are also used to describe activities. These can be standard 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. An optional “trail”, that traces an entity in time and geography, can be displayed for one or more selected entities.

Some event timelines, for instance cultural or political, do not have a location. Other events have unknown locations. Non-geographic timelines are shown on the side of the map plane.

Mouse over drill down, as shown in Figure 12, allows additional information to be displayed in context.

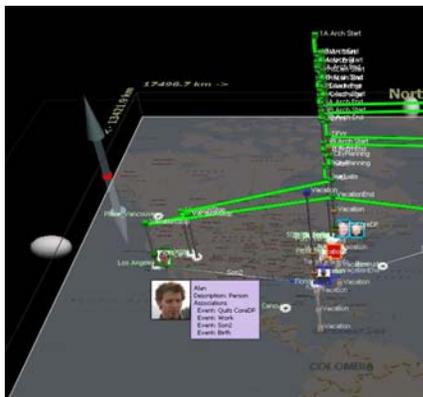


Figure 12: Pointing at an Entity or Activity Drills Down to Additional Information.

Entities and events can be selected and grouped into associations. In this way, a user can organize observations into related stories or story fragments. These groupings can be named with a label and visibility controls allow them to be turned on and off.

### 5.5 Annotations

Ink strokes can be placed on the map by an operator and used to annotate elements of interest with arrows, circles and freeform markings. Some examples are shown in Figure 13. Ink objects are located in geography and time and so appear and disappear as geographic and time contexts are navigated.

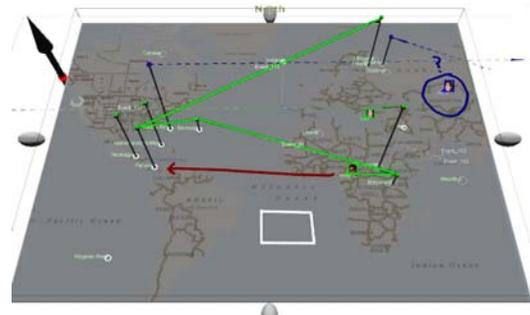


Figure 13: Screenshot of GeoTime with ink annotation.

## 6 Applications of GeoTime

Tracking and analyzing entities and streams of events, has traditionally been the domain of investigators, whether that be police services or military intelligence. In addition, business users also analyze events in time and location to better understand phenomenon such as customer behavior or transportation patterns. GeoTime applications are possible in both reporting and analysis.

### 6.1 Visual History for the “Information Consumer”

The GeoTime display, as shown in Figure 14, can be used to get an instant view of activity at any time/space coordinate. Standard activity reports from other systems can be imported and translated into GeoTime elements. Over the course of weeks or months, hundreds to thousands of events from such automated systems could be stored and reviewed with a system such as GeoTime.

### 6.2 Criminal Analysis by the “Information Producer”

An investigator, such as a police officer, could use GeoTime to review an interactive log of events gathered during the course of long-term investigations. Existing reports and query results are combined with user input data, assertions and hypotheses, as shown in Figure 15. The investigator can replay events and understand relationships between multiple suspects, movements and the events. Patterns of travel, communications and other types of events can be understood. Repetition, regularity, bursts or pauses in activity are easily apparent.

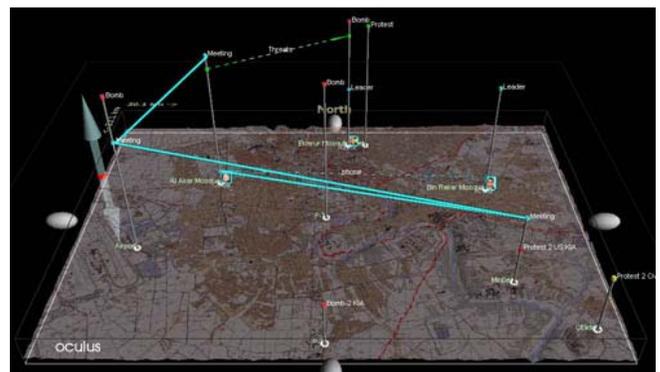


Figure 14: Events and entity trail in time and geography.

## 7 Evaluation and Conclusions

Subjective evaluations and operator trials with four subject matter experts have been conducted. These initial evaluations of GeoTime were run against databases of simulated battlefield events and analyst training scenarios, with many hundreds of events. These informal evaluations show that the following types of information can be quickly revealed and understood.

- What significant events happened in this area in the last X days?
- Who was involved?
- What is the history of this person?
- How are they connected with other people?
- Where are the activity hot spots?
- Has this type of event occurred here or elsewhere in the last Y period of time?
- 

When many hundreds of events are on the screen at once, one key issue that became apparent was the need for seeing through the dense display of objects and labels. New aggregation/de-aggregation and label management techniques can be imagined and investigated to assist with this issue.

Working with hundreds of events seems realistic in military operations. An Army Battalion, the 1 PPCLI, Microsoft Access database used in Afghanistan in 2002 recorded, in three weeks, 500 incidents of who-what-when-where on shootings, bombings, fires, mines, meetings, kidnaps, thefts, assaults, etc. However, subject matter experts discussed situations where understanding less than 100 events was important, as shown in Figure 15, and situations where many thousands of events are involved.

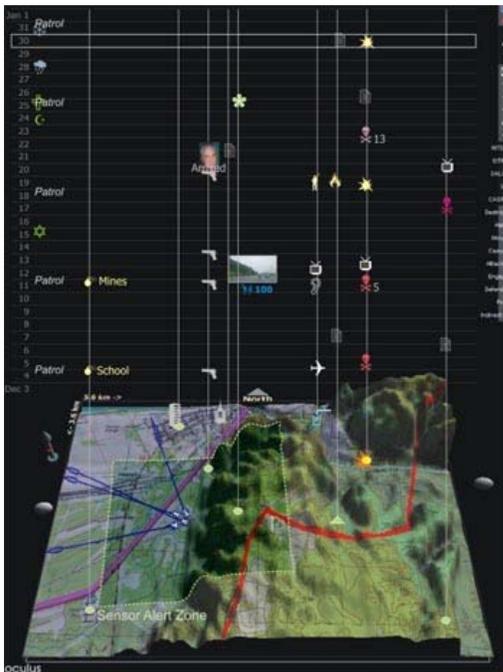


Figure 15: Screenshot of GeoTime prototype in calendar mode showing recent events within a smaller local area.

Additional GeoTime evaluations are planned in the next year, including technology exploration exercises with subject matter experts, as well as more formal task impact and evaluation experiments. A combination of direct observation, user

questionnaires, task metrics and GeoTime instrumentation will be used to help understand specific visualization and interaction strengths and weaknesses. Differences in task performance between GeoTime and existing tools will be compared.

The GeoTime prototype 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. Ongoing research will include further experimentation to assess, explore and develop the full potential of the GeoTime visualization tool.

## 8 Acknowledgement

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