Configurable Spaces:
Temporal Analysis in Diagrammatic Contexts

Thomas Kapler, Ryan Eccles, Robert Harper and William Wright

{tkapler, reccles, rharper, wwright}@oculusinfo.com

Oculus Info Inc.

ABSTRACT

Social network graphs, concept maps, and process charts are examples of diagrammatic representations employed by intelligence analysts to understand complex systems. Unfortunately, these 2D representations currently do not easily convey the flow, sequence, tempo and other important dynamic behaviors within these systems. In this paper we present Configurable Spaces, a novel analytical method for visualizing patterns of activity over time in complex diagrammatically-represented systems. Configurable Spaces extends GeoTime's X, Y, T coordinate workspace space for temporal analysis to any arbitrary diagrammatic work space by replacing a geographic map with a diagram.

This paper traces progress from concept to prototype, and discusses how diagrams can be created, transformed and leveraged for analysis, including generating diagrams from knowledge bases, visualizing temporal concept maps, and the use of linked diagrams for exploring complex, multi-dimensional, sequences of events.

An evaluation of the prototype by the National Institute of Standards and Technology showed intelligence analysts believed they were able to attain an increased level of insight, were able to explore data more efficiently, and that Configurable Spaces would help them work faster.

CR Categories: H.1.2 [User/Machine Systems]: Human Information Processing – Visual Analytics; H.5.2 [Information Interfaces & Presentations]: User Interfaces – Graphical User Interfaces (GUI)

Keywords: human information interaction, visual analytics, graph visualization, geo-temporal analysis, concept maps

1 Introduction

The process of intelligence analysis requires building understanding based on a body of evidence. As an analyst examines data from a multitude of perspectives, they gather evidence to support or refute hypotheses. Visualizations of collected evidence are created to support exploration and explanation of these perspectives; organization charts or process diagrams provide an intuitive snapshot of a situation, based on available evidence. In reality however, organizations or processes are rarely static – they change over time; or our understanding of them changes as additional information is gathered or vetted for accuracy. In this context, these snapshot views are limited because they only show an aggregation of collected evidence. They do not show a continuous time range or provide visibility of raw evidence to help understand underlying temporal dynamics.

For example, while a static social network diagram may summarize the connections between people in an organization, it fails to visually express the rich temporal sequences of interactions that enable an analyst to understand the evolution of the network, along with the flow of information within the network.

In this paper we present Configurable Spaces, a visual analytic method for temporal analysis of evidence within diagrammatic contexts such as processes and social networks. Configurable Spaces is built on a modified version of the GeoTime geo-temporal visualization software. Temporal analysis of events in diagrammatic contexts is accomplished by replacing the geographic spatial dimension of GeoTime with a diagrammatic coordinate system.

In addition, we have explored new ways to create and use diagrams in analysis. For example, diagrams may be generated automatically by transforming information in the GeoTime event knowledge base. Diagrams may also be directly created by the analyst to represent hypotheses and then attached to event data. Multiple diagrams, of multiple perspectives, may then be used as linked views to control and filter a temporal view of events.

The end result is a prototype of a temporally-enabled diagrammatic workspace for intelligence analysis. In coordination with the National Institute of Standards and Technology (NIST), this prototype was evaluated with intelligence analysts.

1.1 GeoTime Unified Geo-Temporal Analysis

Configurable Spaces is built on the GeoTime time-space concept and visualization framework which is designed to improve the perception and understanding of entity movement patterns, events, relationships, and interactions over time within a geospatial context [14].

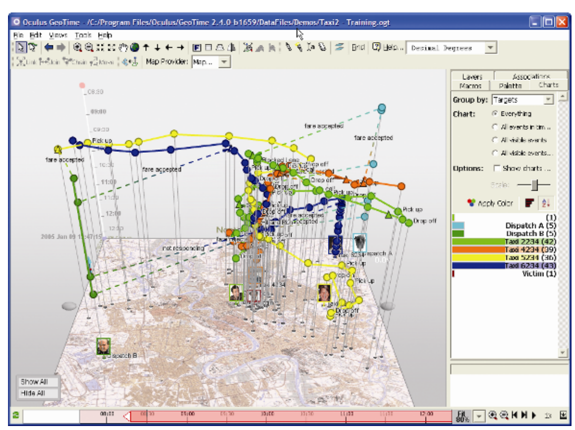

Figure 1: GeoTime system for analysis of events and transactions in time and space. Time is in the vertical dimension.

Events are represented within an X, Y, T coordinate space, in which the X and Y plane represents geographic space, and the Z axis represents time. This method allows activity to be seen across a range of time in a single view.

A slider control allows animated navigation through time. A previous evaluation of GeoTime found that this unified geo-temporal representation increased analysts' understanding of behaviors and relationships [14]. GeoTime has transitioned to being a commercial product and is deployed and used by intelligence analysts.

2 Related Work

A wide variety of tools and techniques currently exist for analyzing various dimensions of intelligence related data in a graphical way. The following tools excel at displaying specific dimensions of a problem space.

For example, Geographic Information System (GIS) tools, such as ESRI ArcView [10] and Microsoft MapPoint [15] display the spatial properties or distributions of data.

Other systems, such as LifeLines [22] and Microsoft Project [17], visualize events over time in a graphical schedule. LifeLines provides overview, zooming, filtering, and detail on demand to unveil relationships between events. Microsoft Project, allows you to track, analyze and control project work, schedules, and finances through the use of interactive charts.

Diagrammatic representation is a rich area for research and discussion, from physiological principles to the use of diagrams for mathematical proofs and argumentation [12]. Analysis tools, such as NetMap [19], Analyst's Notebook [1], CrimeLink [7] and Visual Links [26], display evidence as networks, and provide tools to import data tables and generate visualizations. These tools help to organize fragments of evidence in support of sense making, however, they tend to be limited in their capacity to represent the many dimensions of the evidence over time.

Much research has been done in the area of visualizing change in graphs and social networks, such as PARC's animating Time Trees [4] and [9]. Visualization techniques are limited to the use of animation or temporal snapshots [11] or displaying connected sub-aggregations of a graph over time [3]. These last examples express time by showing multiple time buckets side-by-side (small multiples) or in sequence (animation). Chen [6] has also produced examples of how trends in relationships can be represented with graphs. In some cases, the symbology of the nodes or links is altered to show age of activity, however they cannot visualize a continuous temporal picture of activity.

Other tools such as Tom Sawyer [24] provide layout algorithms for 2D node-link diagrams. Some work has been done on three dimensional graphs [25] and hierarchical three dimensional graphs [21]. These displays do not provide a way to express continuous temporal activity.

A common tool used by analysts for creating and presenting diagrammatic information is Microsoft PowerPoint [16]. It provides the means to rapidly draw any diagram from scratch, but is not data driven, nor does it provide any analytical functions.

Concept maps support the diagramming of ideas and arguments [20]. Mind map software, such as MindManager [18] or nSpace [23] provide tools to create concept maps that are useful in analysis.

Many examples of "linked" visualization methods exist [2] [8] [27] that use multiple charts to enable analysis across several categorical or continuous dimensions. Our work uses this technique to connect secondary diagrammatic views to the main temporal workspace.

3 Cognitive Task Analysis

Prior to the Configurable Spaces investigations, a brief cognitive task analysis (CTA) study was completed including structured interviews with fourteen analysts and examination of work location artifacts. This study yielded examples of how analysts think and work through problems. In the following illustrative interview excerpts, "process" and network diagrams and their application to analysis is described:

- "I use link analysis to establish patterns in communication and travel. Entities may be together, then split apart and then get back together. There is a lot of change."
- "I'm always redrawing link diagrams with new hypotheses and new data."
- "Programs are very organized, multi-dimensional processes or structures with flows. They are large, complex processes that take place over a significant time."
- "I use a diagram to describe a process and organize my thoughts and observations by the process steps in the diagram.
- "Within a social network or process, you determine what is critical. You look for clusters and density. This helps you think of changes in the process."
- "You can compare processes. See where matches occur or not. Partial matches point to things for which to look. Processes can be compared over time e.g. quarter to quarter to see changes."
- "It would be good to have a large digital map, and then be able to draw on it, and annotate it. I'd use date time on the drawing so I could filter by date time."
- "You can show one type of information or the other but not both. Difficult to display a node with all its' characteristics. Icons are useful but you can not display details. Current tools can't hold as much data as I have."

A recently completed ethnographic study of the intelligence community [13] made similar observations during structured interviews:

- "I have a model of the situation in my head. Whenever something new comes in, I see if it fits with the model. If it does, I add it to the model; if it doesn't, I try to figure out why."
- "I'm looking for links and patterns. Once I figure out the pattern, I can figure out where to look next."

In analysis, a process description or network diagram provides a context and a logical framework for reasoning about a subject. It can help explain observations and suggest how elements in the process can be influenced. A diagram provides a template against which to compare evidence, and show where further investigation is required.

Analysts have also indicated a need to visualize problems from multiple perspectives at the same time and enable connections to be made across them. The PMESII dimensions (Political, Military, Economic, Social, Infrastructure, and Information) are an example of a set of perspectives to be considered together during analysis and decision making. Each of these can be represented as a diagrammatic or geospatial visualization.

4 Approach

The objective of Configurable Spaces is to enable temporal analysis within familiar diagrammatic contexts used in analysis. The approach was to modify GeoTime's existing X,Y,T coordinate view of events by replacing the ground plane map with a diagrammatic representation (Figure 2). Our assumption was that this would provide the same ability to see behaviors, tempo, movements and relationships that GeoTime provides in geospatial contexts, but in new problem domains. One would expect to see for example, how a social network evolves by observing interactions between its members over time, follow the restructuring of an organization, or see the history of the flow of a process.

Chen [5] describes the difference between micro and macro perspectives in sense-making: "macroscopic view refers to a representation of global and system-wide patterns, …microscopic refers to a local and detailed view of an individual component or part of an underlying phenomenon." In this sense, our efforts are clearly in the microscopic range. In our experience, significant analytical effort is required at a micro scale when constructing arguments and reports for intelligence problems. This involves comprehending details about fragments of evidence collected over time.

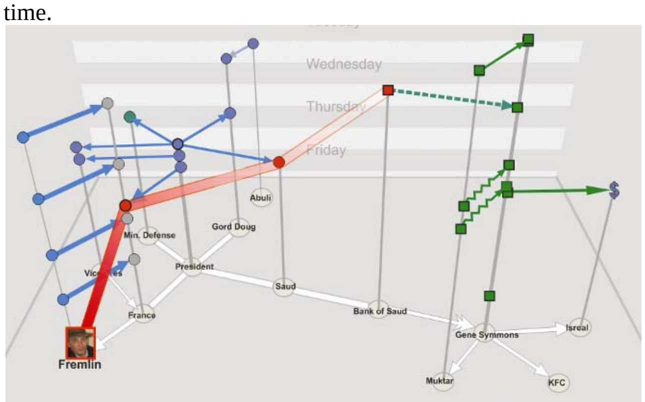

Figure 2: Illustration of a process in an X, Y, T coordinate space. Instances of process events are shown above the labeled process diagram. Time is in the vertical dimension. Repetition of some steps is visible. A persons involvement throughout the process is shown as a trail in red.

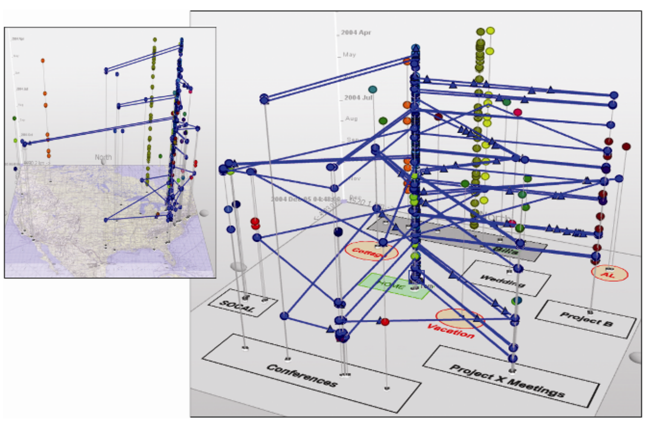

Figure 3: A temporal view of the authors' travel and calls over 8 months, arranged geospatially (left) and by theme (right)

4.1 Initial Explorations

Initial explorations focused on creating temporally-enabled diagrams by rearranging existing spatially-defined datasets according to different criteria. Data sets containing movement and transaction data were rearranged to reflect user preference or priority to provide a view that was de-cluttered and expressive of different aspects of the data.

This essentially de-emphasized the spatial aspects of the data, allowing locations to be organized by the activities that occur there, making it possible to group related events together (Fig 3)

A temporal diagram was also created during the 2006 IEEE VAST [23] contest using an early Configurable Spaces extension to GeoTime and contributed to the submissions's first place showing. The view in Figure 4 was created by repurposing location usage to create a diagram. However in this case, there was no geospatial information to begin with. Phone call event data was imported with unique location values associated with the source or recipient of the call. The analyst then simply arranged these "nodes" using the mouse to create diagrams of the organizations to which they belonged. GeoTime ink sketching tools were used to help de-mark and label the diagrams.

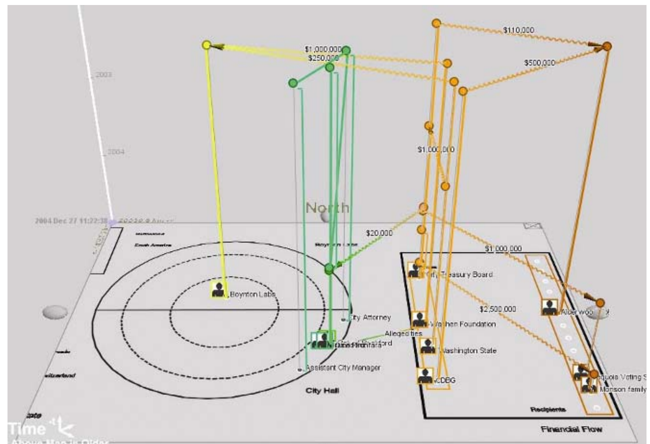

Figure 4: Analysis of phone calls in the 2006 VAST fictitious contest scenario reveals the sequence of communications, financial transactions, and other relationships, including interactions that cross boundaries between commercial, government and personal realms.

4.2 Sources of Diagrams

After these initial exercises, the focus turned to address how to obtain, generate or import diagrams and associated events into GeoTime without analyst effort. Specifically our goal was to display a process in time by displaying the steps of a process as locations and the flow of events through it using transaction events in time, as in figure 5. Considerable effort was put into finding sources of process data that included a diagrammatic representation and captured event data that might be relevant to analysts. Eventually, artificial test data sets were built to better understand what would be required to support the intended display. We eventually realized that the required data was unlikely to be found in a typical analyst's environment. In fact, it began to seem that only a carefully configured and highly instrumented process could provide both a structured diagrammatic view and an event stream that could be linked to it. An RFID tracking system, or a manufacturing process might be able to provide this level of data richness.

Instead, discussions with analysts reinforced that in the intelligence domain, it is more typical that the processes in question are abstract or incomplete, and that they do not have data that can be programmatically correlated to a reference diagram. In other words, intelligence data is messy. What analysts need is a system to help them discover, develop and track complex processes based on incomplete evidence, not a system to help monitor a highly instrumented process. Our focus evolved to supporting two different sources of diagrammatic representations;

Generated Diagrams in which existing spatial or non-spatial data is computationally transformed and laid out to express analytically valuable properties.

User-driven diagrams which the analyst creates to model dimensions of an existing spatial or non-spatial dataset.

4.3 Generated Diagrams

A social network graph is an example of a diagram that is generated algorithmically from a table of to-from event records and a layout algorithm. In the resulting diagram, nodes represent people, and edges represent relationships. A GeoTime knowledge base contains many similar types of relationships that are used to generate a graph. A diagram layout and display system was integrated into the prototype to provide the ability to programmatically generate node-link diagrams based on data in GeoTime. The intent was to use this to form the base diagram over which events are arranged in time. In fact, these diagrams also proved to be useful as linked analytical perspectives.

Diagrams are generated by transforming the GeoTime internal knowledge representation. A GeoTime database consists of data objects representing;

Locations: an x, y coordinate or location name

Entities: tracked objects or people involved in events (also known as "Targets")

Events: a generic occurrence at a certain time or span of time, connected to a single location.

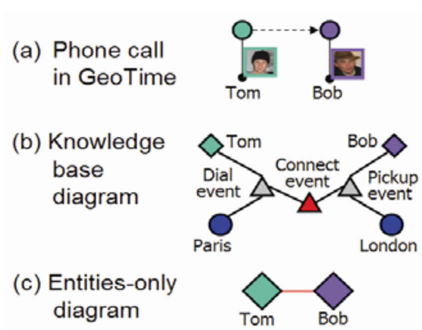

Figure 5: Schematic representation of (a) phone call in GeoTime, (b) knowledge representation diagram equivalent, and (c) entities-only generated view.

These objects are linked together to form semantic structures such as phone calls, relationships or transactions. For example, if Bob phones Tom, the resulting set of data objects and associations in the database are shown in figure 5(b). This structure forms the root graph from which new diagrammatic perspectives can be automatically generated.

4.3.1 Diagram Generation Engine

The configurable diagram engine is predicated on the principle that relationships between elements in a knowledge base can be transformed into diagrams in various ways. The diagram engine rearranges the GeoTime knowledge graph into diagrams by filtering and aggregating the objects and their relationships. For example, the phone call represented in figure 5 is composed of a number of concepts that are linked together through associations. Figure 5(b) is a representation of the actual data objects stored in the internal data representation of GeoTime for a phone call. The diagram engine first parses through the list of objects in the knowledge base to generate a list of graph nodes, and assigns simple symbology and labeling. Another pass through the knowledge base pulls out relationships between the objects selected in the first pass, and instantiates them as edges between nodes. The resulting nodes and edges are then passed into the diagram engine and an 2D graph window is created.

The content that is extracted during these processes can be controlled and filtered. For example, in the phone call example above (figure 5), the first pass extracts the entities ("Tom" and "Bob"). The second pass creates a single edge where a communication event structure ("Dial event", "Connect Event", and Pickup event") connects the entities (figure 5(b)). This results in a diagram shown in figure 5(c). The native GeoTime renderer goes through a similar process to convert its knowledge base to render events in the geo-temporal viewer, as in figure 5(a).

The diagram engine provides UI affordances to filter out certain types of objects (entities or locations) and event types (financial transactions, communications, relationships). It also allows the user to generate diagrams for any subset of events. Thus a high degree of flexibility is possible. For example, in a suitably complete data set, an analyst can create diagrams of financial transactions, phone calls or organizational relationships by adjusting the filter settings, and then apply this to any subset or time range of data.

Alternatively, a very detailed diagram can be created that includes every element and association in the knowledge base. Such a diagram is able to reveal relationships in the data that may otherwise be difficult to detect. The example, Figure 6 shows a diagram based on the GeoTime knowledge base of a complex analytic training scenario. Locations, events and entities are represented as blue circles, triangles, and pink diamonds respectively, and edges represent associations. The space-time view of this dataset is quite complex and challenging to interpret, however when this dataset is processed into a graph via the diagram engine, a clearer organizational picture results. The force directed layout arranges objects in proximity to each other based on how closely they are associated, resulting in a surprising side-effect; the graph layout of the scenario knowledge base reveals regions that strongly correspond to important plots in the scenario.

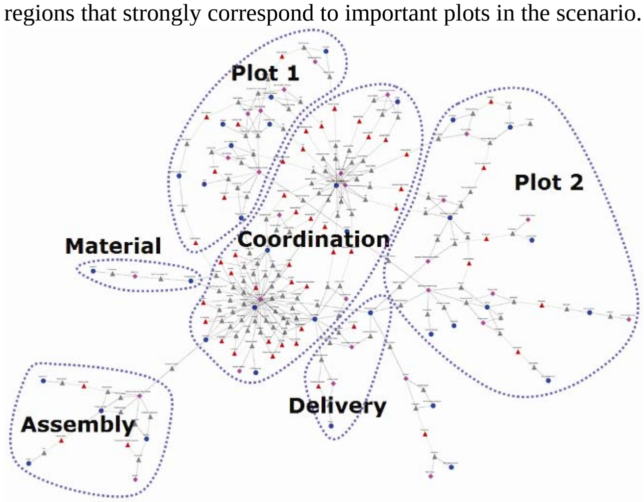

Figure 6: A graph of the GeoTime knowledge base reveals plots in this complex scenario. Plot outlines and labels added by the authors.

This occurs because the people, locations and events within plots are interconnected, thus they form clusters within the force-directed diagram. These plot clusters are then naturally arranged around the larger plot coordinators and meeting locations. The resulting structure is similar to what might be seen in a social network graph between several tightly connected groups nodes. Seeing plots in this way is possible because the graph contains a richer set of objects (locations and events, in addition to just people) and relationships (calls, financial transactions etc).

The original author of this scenario remarked that this diagram revealed the critical aspects of the problem, including his attempts to confuse and add noise. Plots and incidents inserted to distract readers were rendered as separate networks disconnected from the graph in figure 6, and are not shown here.

4.4 User Driven Diagrams as Organizing Devices

We have described generated diagrams that are representations of relationships *internal* to a given data set; that is, they are extracted from within the data itself. Another important class of diagrams are representations that we will describe as *external* to the data. These diagrams describe hypotheses or knowledge that is not intrinsic in the data. For example, an analyst may wish to hypothesize a high-level process to explain an observed activity by sketching it out. Further, it may be beneficial to be able to associate observational data (evidence) with elements of the diagram in order to quickly access or validate that hypothesis.

The Configurable Spaces prototype incorporates tools for interactively creating node-link diagrams from scratch to support this type of workflow. For example, an analyst may choose to create a diagrammatic view of a specific organizational hierarchy as in Figure 7(f). The affordance for creating diagrams is straightforward; a new diagram window is opened and the analyst draws and arranges boxes and links directly in the window. A property of these diagrams is that the nodes are buckets into which Locations, Events and Entities can be dragged-and-dropped from the geo-temporal view. In a sense, the nodes act like folders for organizing information, and the diagram in which they reside becomes a secondary visualization of relationships that the user imposes on the data - a flexible, visual organizing device, like a "mind map" that is tightly linked to geo-temporal and diagrammatic evidence. Linked interactions (described later) allow the user to click on these nodes to highlight evidence in all the other views.

5 Temporal Analysis of Diagrams

The previous sections discussed ways in which non-temporal diagrams can be generated and utilized as supporting views to assist in geo-temporal analysis. The following section describes how these diagrams are leveraged to show temporal activity within processes, concept maps, and network activity.

Temporal analysis of diagrams in Configurable Spaces is achieved by overlaying event data in time above an image generated by the Diagram Engine (section 4.3). Several steps are required to accomplish this. First, a 2D image of the diagram is created, scaled and applied as a map on the ground plane in GeoTime. Then a temporary GeoTime knowledge base of events, entities and locations is generated based on data created for the diagram, and then overlaid above the diagram image. (Note that this data is now two-steps removed from the original source data; references back to the original source data are passed down during each transformation so that linked selection back to the source data can occur.) Finally, the time-space view is updated with the newly generated diagram map image and its corresponding events. The resulting view is a temporal presentation of events in a diagrammatic context (see Figure 8).

All of the interactive analytic capabilities of GeoTime, including temporal and spatial navigation, charting tools, and link analysis can be applied to this view. Typically analysts begin reviewing data in GeoTime by looking at the overall distribution in time and space, and then drilldown through time and space to find points of interest. Then they filter the view to examine individual tracks and relationships in detail. This same workflow is possible in a temporally-enabled diagram. For example, focus can be adjusted to "zoom-in" on certain parts of the network and certain time ranges or hours of the day. Interactions, such as phone calls and other transactions can be played as an animation,

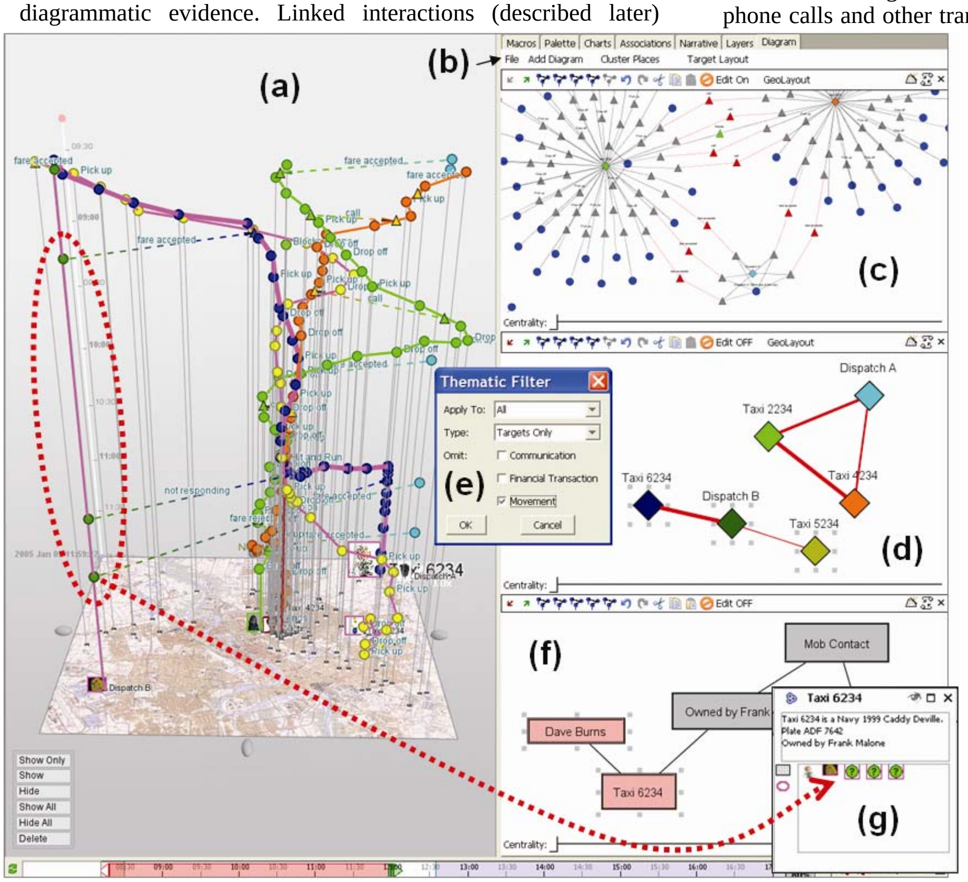

Figure 7: Configurable Spaces Application

(a) Geo-temporal view of events. Selected objects are pink

(b) The Diagram tab with tools for creating, editing and saving multiple diagrams

(c) A generated knowledge base diagram showing entities (diamonds), events (triangles) and locations (circles)

(d) A generated diagram of relationship between entities (i.e. social network). Selected objects have resize handles.

(e) "Thematic Filter" dialog for creating new diagrams. It provides filters for choosing subsets and data types.

(f) A user-driven concept diagram created by the user. Selected nodes are highlighted pink.

(g) Property box for concept diagram nodes. Text can be added and data from other views can be attached by drag and drop.

and charts can be used to filter certain entities or types of events. A single entities' activity over time can be singled out and the chain analysis tool used to display only those events and entities with which they interact.

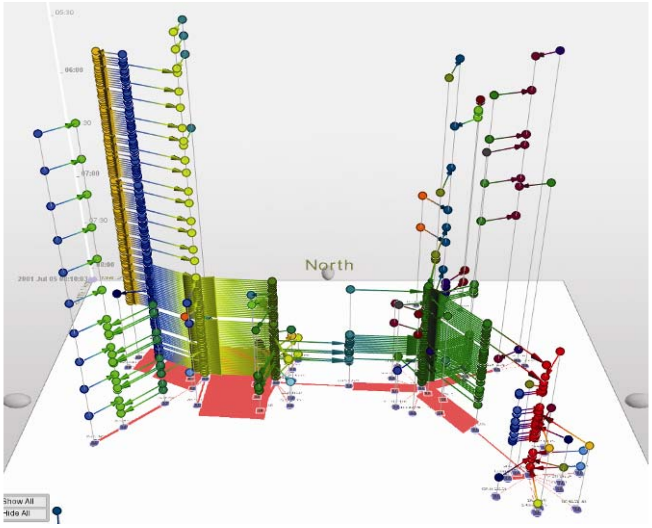

Figure 8: Temporal view of activity in a computer network in GeoTime. Note the summary network image on the groundplane, with constituent network activity as events above in the Z-axis.

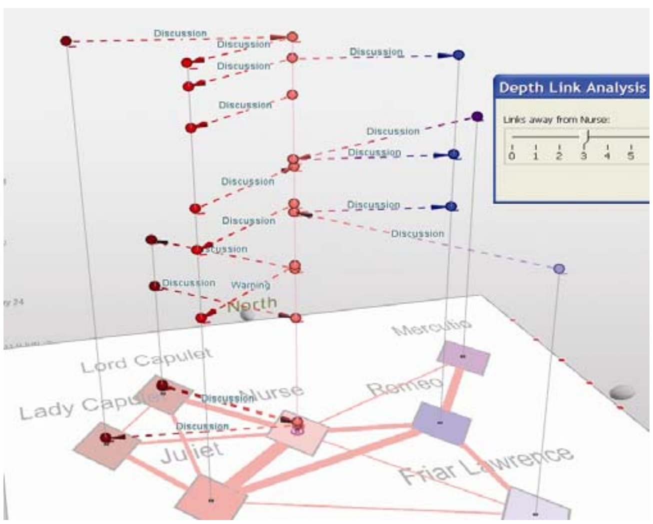

Figure 9: Interaction events between characters in Romeo and Juliet over time, filtered to only show those connected to the Nurse.

In a temporal diagram, the diagram on the ground-plane is static. Early on we considered building a capability to update the base diagram layout to reflect intermediate states of the diagram as filter conditions and time ranges are adjusted by the user. This approach was rejected for two reasons. One, it would require an expensive (i.e. slow) recalculation of the diagram layout on each change, and two, we believe it would cause cognitive confusion to significantly change the consistent spatial layout of the diagram context. In informal tests, it was desirable to have the full data context in view as a substrate over which to display and interpret the details of activity over time.

A full investigation of how to display intermediate diagram states was deferred, but would likely be added as a user option or as an additional 3rd view. Note that in Configurable Spaces, it is still possible to generate intermediate network states for any time range or subset of data by applying the Diagram Engine only to a selected portion of the data.

Temporal analysis of events in a GeoTime diagrammatic context can reveal important behaviors. In the case of a social network diagram or process diagram, the analyst is able to explore the dynamics of a system by visualizing the sequence of individual transactions. Hubs of activity, bottlenecks, recurring events, changes in tempo, outliers, sequence and direction of interaction, direction of flow of information, response time, gaps, response to stimuli and many other patterns can be discerned within a temporal view of events within diagrams. Figure 9 shows the GeoTime's chain analysis tool being used in a temporal diagram to show the sequence of interactions for a single character in a fictional scenario over time. (The link analysis tool allows one to display nodes within an adjustable distance from an object of interest.) Configurable Spaces can scale to support detailed temporal analysis of diagrams on the order of tens of thousands of individual events.

6 MULTIPLE CONCURRENT DIAGRAMS

Early interviews and reviews with analysts indicated a need to visualize problems from many perspectives at the same time. To address this, the diagram workspace was built to support multiple diagrammatic views simultaneously. Each diagram can be created and used independently, and linked selection across all diagrams, views and charts is provided. Selecting entity or event objects in one view also highlights those same objects in the other views. These diagrams are displayed within a scrolling window, or as separate, resizable windows as illustrated in Figure 7.

This multi-diagram capacity allows an analyst to see and connect across several dimensions and views of an intelligence problem space. For example, selecting a step in a user generated process diagram in one window may show that this activity occurs at particular times of the day in a linked time-space view, and that it coincides with communications between key people within an organizational graph.

7 LINKED INTERACTIONS FOR ANALYSIS

Linked interaction between information views is a common visual analysis technique [27]. In Configurable Spaces, linked interactions between the geo-temporal view, generated diagrams, user-driven diagrams and temporally-enabled diagrams are made possible by maintaining references back to the original knowledge base through each transformation. When an event, location or entity is selected in any view, it becomes highlighted everywhere it is referenced. This allows potentially valuable analytical connections to be made across high-level views. For example, in a generated network diagram showing hi-level relationships between entities, clicking an edge between nodes will highlight where and when all the transactions between any two nodes actually occurred in a linked geo-temporal view. Or conversely, entities selected in close proximity in the geo-temporal view could be highlighted in a concept map of an organization. Figure 7 shows linked selection and highlighting across several diagrams and the geo-temporal view.

In addition, a rapid linked-navigation mode was implemented to enable exploration of the geo-temporal view using a diagram. In this mode, when a diagram node is clicked, all the data referenced by, and immediately connected to that node become the focus in the geo-temporal view. This is envisioned as an extremely fast way to explore new datasets across many dimensions at once. This exploratory activity could be further supported by automatically generating pre-filtered diagrams when new data is loaded. Built-in GeoTime charts provide a similar linked-view capability.

8 TECHNICAL ARCHITECTURE

The Configurable Spaces prototype is written in Java and integrated with GeoTime via a dynamic Plug-in system. A commercial graph display and layout toolkit, yWorks [28], is utilized to generate 2D diagram views based on transformed GeoTime knowledge base objects (locations, events, entities and Associations). This also allows a variety of industry standard diagrams and networks to be imported to provide the diagrammatic context for Configurable Spaces.

To generate thematic diagrams, the model transformer handles the knowledge graph trimming to generate diagrams and also performs subsequent translation of diagrams into the GeoTime temporal-diagram view. Within the diagram system, multiple views can exist simultaneously in different windows. The interaction manager tracks context between all the components to support linked selection, navigation and drag-&-drop associations.

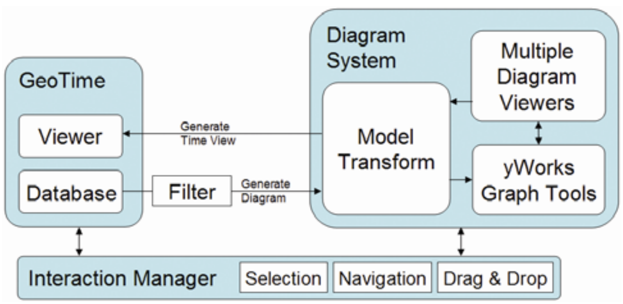

Figure 10: Configurable Spaces technical architecture

9 EVALUATION AND FEEDBACK

In coordination with the National Institute of Standards and Technology (NIST), we conducted a formative evaluation of the Configurable Spaces prototype software. The main purpose was to capture comments and metrics about the *usability* and potential *utility* of Configurable Spaces to enhance the analysis of geo-temporal events over time. The results would then be fed back into the design and development of the system. Our hypothesis was that Configurable Spaces would improve efficiency and effectiveness of analysis when exploring communications and transactions between networks of moving entities. Quantitative metrics of benefit were based on interviews and a questionnaire, and no baseline tool was used as a reference to compare analytic utility.

9.1 Task and Dataset

We developed a set of simple analytic test scenarios. These scenarios were developed to engage the analysts in a challenging problem to exercise the features of the prototype. The scenarios consisted of 25 entities constantly moving within a geospatial region over the course of a few days. Each dataset consisted of 300-400 events, including a total of 40 financial transactions, phone calls and known relationships between the entities. Analysts were asked to identify the key players, networks, and characterize their behaviors.

Three analysts participated in the evaluation. Each analyst rated their own experience: one was an expert with more than 20 years in intelligence analysis, one was intermediate with less than 5 years, and one was a novice. All three rated their computer expertise as “medium”, and none had previously used GeoTime.

9.2 Procedure

The evaluation spanned two days. The first day consisted of training and instruction on both GeoTime and the Configurable Spaces prototype, including interactive sessions and exercises which encouraged analysts to openly explore features of the application. Analysts were trained to generate and manipulate automatic and user-defined diagrams, and to view diagrams in the temporal display. On the second day, the analysts completed the analytic scenarios using the software, and developed a short report in the allotted time. Three expert observers from NIST were present throughout the process. After the evaluation, subjects completed a questionnaire to collect information about demographics and experience. Then, short interviews were conducted to encourage analysts to elaborate on their responses. Some performance measures were based on logged data, including navigation actions (such as pan and zoom), and task completion times. Self-reported measures were collected in the questionnaire.

9.3 Results

Most of the feedback generated by the evaluation was directed towards the usability design of the interface and the system behaviors. Analysts also provided valuable feedback about functionality they felt was missing, such as control over labeling and display in the diagrams, the inability to add annotations to views during analysis, and a lack of report authoring tools. Aside from some expected minor usability glitches and bugs, software logging indicates that analysts were able to successfully use the range of features supported by the prototype.

In terms of workflow, analysts generated diagrams of interactions between entities; essentially sub-graphs of interactions between people. They would then view these as temporal diagrams to show the sequence of interactions over time.

Results from the questionnaire show that analysts were able to successfully identify key entities and which networks entities belonged to. The scenarios and questions were not sophisticated enough to deeply test the analytic potential of seeing larger behaviors and patterns in networks over time. From our perspective, the most important products of the evaluations were the analysts comments about how they felt the tools could help them based on their analytic experience. Analyst comments and survey results from the NIST report indicate that analysts felt the system did enable them to attain an increased level of insight. On a 5 point dual-ended scale of strongly disagree (1) to strongly agree (5), subject said that Configurable Spaces “helps them to explore data more quickly” (average rating 3.7/5), and “elucidate relationships between entities more quickly than with their current tools” (average rating 3.7/5). Additional observations from the NIST report executive summary state:

- “Analysts stated that Configurable Spaces empowered them to identify major players quickly.”
- “Observers noted that Configurable Spaces empowered analysts to quickly uncover the fact that there were two networks.
- Analysts stated that Configurable Spaces will help them to work more quickly.”
- “Analysts stated that Configurable Spaces empowered them to see entities in meaningful clusters to support analytical thinking easily and quickly.”
- “Analysts all felt that, when it is fully operational, the Configurable Spaces functionality will be of great value to them.”

Analysts noted that linked views were helpful for tying events together from different contexts, and selecting objects of interest in the geo-temporal view;

- “It showed the underlying infrastructure to the networks which were not apparent in GeoTime. …I liked the way it could be used as a selection tool for GeoTime data.”
- “It gives you a total operational picture of what they’re doing… You can prioritize targets – ID most active players and anticipate movements”.

This last comment summarizes the objective of this research. Although the results of the evaluation are not compellingly conclusive in terms of measured benefit, such a comment suggests that analysts see significant value in combined spatial, temporal and diagrammatic approaches in their analyses.

10 Conclusions and Future Work

The work described here has explored and prototyped methods for generating, applying, and combining different types of diagrams to support analysis of complex, multi-dimensional sets of events. An innovative visualization method has been developed for temporal analysis of events over diagrammatic contexts. It is flexible and many different types of diagram and network views can be created. A prototype workflow has also been established that supports multiple concurrent, linked diagrammatic perspectives of a situation, so that analysts can simultaneously see and work with processes, organizations, networks, geo-temporal and other dimensions of a problem at the same time.

It is important to note that the linked multi-perspective workspace of Configurable Spaces is made possible because of the existence of the ontological and semantic relationships between the elements in its knowledge base (i.e. locations, entities and events). GeoTime provides a sophisticated data import system which generates the transformable knowledge graph structures necessary to support the range of visualization and interaction possibilities described in this paper. The trade-off for this additional flexibility is, to some extent, scalability. Contrast this with common GIS and network graphing packages that aggregate events to create high-level, low-dimensional graphs or maps of large data sets. These may provide nice summary pictures, but the analyst is often left searching for alternative ways to form a clear picture of a thread of events.

Formative evaluations performed at NIST show that analysts found Configurable Spaces could help to accomplish analysis tasks more efficiently, and with more insight. Additional work is required to test temporally enabled diagrams and multi-perspective workspaces under real conditions in collaboration with analysts. We would like to see analysts build and use Configurable Spaces against temporally-active scenarios that include fused data about organizations, processes and social networks. Ultimately, better data quality and representation is required to support such diagrammatically-rich, high-dimensional event analysis in time. Fusion across data sources into a common knowledge representation seems necessary to support potent new capabilities.

11 Acknowledgements

This study was supported and monitored by the National Geospatial-Intelligence Agency (NGA) under Contract Number HM1582-05-C-0022. The views, opinions, and findings contained in this report are those of the author(s) and should not be construed as an official Department of Defense position, policy, or decision, unless so designated by other official documentation. The authors wish to thank IARPA, NIST, NGA and all IARPA, NIST and NGA staff for their support and encouragement.

References

[1] Analyst's Notebook. Retrieved February 19, 2007, from http://www.visualanalysis.com/products/anb.php

[2] Becker, R., Cleveland, W. and Wilks, A., *Dynamic Graphics For Data Analysis*, Statistical Science, pg 355-395, 1987.

[3] U. Brandes, S. R. Corman, Visual Unrolling of a Network Evolution and the Analysis of Dynamic Discourse, Information Visualization Journal, Palgrave Macmillan, 2003

[4] S.K. Card, Bongwon Suh, B. A. Pendleton, J. Heer, J. W. Bodnar, "Time Tree: Exploring Time Changing Hierarchies", IEEE Symposium on Visual Analytics Science & Technology, 2006, 3-10

[5] Chen, C., Holistic sense making: Conflicting opinions, creative ideas, and collective intelligence. *Library Hi Tech*, **25**(3), 2007

[6] C Chen, Il-Yeol Song, W. Zhu. Trends in conceptual modeling: Citation analysis of the ER conference papers Proc. of ISSI, Madrid, 2007. 189-200.

[7] CrimeLink. Retrieved February 19, 2007, from http://www.crimelink.com/

[8] Eick, S. and G. Wills, *High Interaction Graphics*, European Journal of Operational Research, 81:445-459, 1995.

[9] C. Erten, P. J. Harding, S. G. Kobourov, K. Wampler, G. Yee, Exploring the Computing Literature Using Temporal Graph Visualization, Department of Computer Science University of Arizona

[10] ESRI ArcView. Retrieved February 19, 2007, from http://www.esri.com/software/arcview/

[11] P. A. Gloor, Yan Zhao, TeCFlow – A Temporal Communication Flow Visualizer for Social Network Analysis, ACM CSCW Conference, Chicago, Nov, 2004

[12] Jamnik, M., Automated Diagrammatic Proofs of Arithmetic Arguments, PhD, University of Edinburgh, 1999

[13] Johnston, R., Analytic Culture in the U.S. Intelligence Community, Center for the Study of Intelligence, *Government Printing Office, Pittsburgh, PA.*

[14] Kapler, T. and W. Wright, *GeoTime Information Visualization*, Information Visualization Journal, Palgrave Macmillan, 4,(2), Summer 2005, 136-146.

[15] Microsoft MapPoint. Retrieved February 19, 2007, from http://www.microsoft.com/mappoint/

[16] Microsoft PowerPoint. Retrieved February 19, 2007, from http://office.microsoft.com/en-us/powerpoint

[17] Microsoft Project. Retrieved February 19, 2007, from http://office.microsoft.com/en-us/project/

[18] Mind Manager. Retrieved March 31, 2008 from www.mindjet.com

[19] NetMap Analytics. Retrieved February 19, 2007, from http://www.netmapanalytics.com/

[20] Novak, J.D., Learning, Creating, and Using Knowledge: Concept Maps as Facilitative Tools in Schools and Corporations, Lawrence Erlbaum Associates, (Mahwah), 1998.

[21] Parker, G. G. Franck and C. Ware, *Visualization of Large Nested Graphs in 3D*: Navigation and Interaction, Journal of Visual Lang. Comput. 9(3), 1998.

[22] Plaisant, C., Milash, B., Rose, A., Widoff, S., Shneiderman, B., LifeLines: *Visualizing Personal Histories*. in Proc. of CHI 96, ACM, New York.

[23] P. Proulx, L. Chien, R. Harper, D. Schroh, T. Kapler, D. Jonker and W. Wright, "nSpace and GeoTime: A VAST 2006 Case Study", IEEE Computer Graphics and Applications, Sept/Oct 2007, 46-55

[24] Tom Sawyer. Retrieved March 21, 2007, from www.tomsawyer.com

[25] F. Van Ham, H. van de Wetering, J. van Wijk, *Visualization of State Transition Graphs*, IEEE Information Visualization Conference, 2001, 59-66

[26] Visual Links. Retrieved February 19, 2007, from http://www.visualanalytics.com/

[27] Wang Baldonado, M. Q., Woodruff, A., and Kuchinsky, A., Guidelines for Using Multiple Views in Information Visualization, in Proc. Of CHI 98, ACM, Italy, 110-119.

[28] yWorks. Retrieved March 21, 2007 from www.yworks.com