Spatiotemporal Links

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Abstract

This paper presents spatiotemporal links as an approach to visual query and presentation of spatiotemporal information. In exploratory data analysis, spatiotemporal information mostly is presented as slices and dices, each representing an independent entity, scattered within a multi-dimensional domain. Spatiotemporal links propose a scheme to associate information among entities; it delivers the information of interest, spatial, temporal, or just characteristics, along visual elements that associate the spatial locations of interest. By interactively and iteratively applying spatiotemporal links, it provides a powerful tool to link both spatial and temporal information in visual analytics. We have outlined the concept and operations of spatiotemporal links as an abstract sequence of interaction steps and options through a use-case in the container traffic domain.

Keywords: spatiotemporal analysis; interactive visualization; exploratory data analysis; data exploration.

1 Introduction

This paper describes an approach for data exploration and data understanding of the spatiotemporal links that define traffic and other real-world transaction networks. The approach is being developed in the context of US Department of Homeland Security R&D for US Customs applications. Our focus is on marine container traffic to the US.

Container traffic carries commodities that are produced in some geographical location(s) from port to port until it is delivered to the US, and beyond that to a final destination and distribution point. Professionals of the container industry must continually review and analyze container traffic for pricing, allocation of transportation resources, understanding of import trends, security issues, etc. It is of interest both to characterize transport of individual commodities from and to specific places, and to characterize groups of commodities' aggregated patterns of transport across sets of places. Figure 1, taken directly from (Luo and Grigalunas, 2003), shows a typical visualization of a typical query in this environment.

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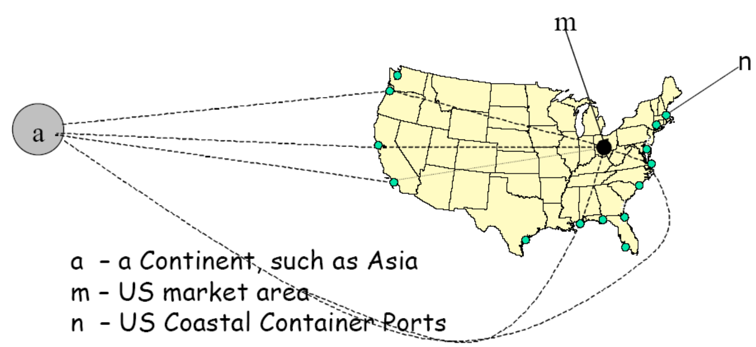
Figure 1: Simplified Depiction for Multimodal Transportation Network



Visualization in this arena is needed in order for analysts to quickly assess the characteristics of trade and the changes in the patterns of trade activity. A typical task might be to determine, for instance, whether scheduled routes are carrying excess unused capacity and should be scaled back.

We present an approach designed to make it easy for analysts to interactively and iteratively specify and examine the transaction history of the trade. The approach we describe allows a user, e.g., a shipping industry analyst, to visually specify a statistical profile of container volume from an arbitrary set of geographical origination points to an arbitrary set of destination points across a set of time intervals of interest. The results are graphically displayed in a way that provides immediate indication of relative volumes among the time intervals of interest. The results are in turn graphically query-able for further statistical breakdown and detail.

Recently the U.S. Department of Homeland Security chartered the National Visualization and Analytics Center at Pacific Northwest National Laboratory to define a five-year research and development agenda for visual analytics to address the most pressing needs in R&D to facilitate advanced analytical insight. The resulting R&D Agenda ("Illumining the Path: The Research and Development Agenda for Visual Analytics", IEEE Press, [Thomas and Cook, 2005]) presents recommendations to advance the state of the art in the major visual analytics research areas. We view the method we describe in this paper as a building block for the wider group of functions that comprise visual analytics. Particularly, in recommendation 4.1 of the R&D agenda, one of the breakthroughs sought includes the "representation of complex space-time relationships within data at multiple levels of resolution." We believe we are contributing to solutions in this area.

In our domain the requirements for Visual Analytics include the fact that spatial and temporal data come together everywhere, that knowledge and pattern discovery for the domain is defined not just spatially but often temporally, that humans perceive and discover such patterns better through information that is presented visually, and that consequently our visual analytics need handle both at the same time. The rest of this paper describes our entry into developing new capabilities for Visual Analytics. The next section briefly discusses the problem of jointly presenting spatial and temporal entities. Section 3 describes the method we are developing. The method is illustrated with a set of examples in Section 4. We provide concluding remarks in Section 5.

2 Quest to present attributes associating both spatial and temporal entities

The ubiquity of spatial data is widely recognized. There is very little that can be expressed without having some spatial referent, or that isn't spatially situated; and nothing that doesn't originate from some source in space. This is true as well for time. Thus, data describing, tracking, or otherwise providing information on our activities may always be associated with spatial and temporal attributes, and very often such associations are explicitly provided.

The temporal dimension often extends spatial attributes. The resultant multiplicative expansion of the information is naturally aggregated, with statistical methods used to understand the relations of the domain. Effective visual analytics would be useful to explore simultaneously spatial and temporal linkages among the attributes.

According to Peuquet (1994), spatiotemporal information involves three components: space (where), objects (what), and time (when). Starting from this model, Andrienko et al (2003) made abundant discussions on existing models and software tools for exploratory spatiotemporal visualization. The visualization of spatiotemporal data generally is carried out by the following techniques: single static map integrated with different temporal objects, multiple static maps each representing one time period, animation map (Campbell and Egbert 1990) rendering the progress along time, and space-time cube (Hagerstrand 1970, Gatalsky et al 2004, Xia 2005). However, as intended by Xia (2005), there should be an additional component: how (characteristics), separated from the component what (object). The work by Buja (1991) can be regarded as an attempt to introduce the association of object's characteristics, or attributes, among space, time, and objects. This leads to multivariable spatiotemporal data; which could be very complicated for space-time cube techniques to display in a concise way. As in (Koussoulakou and Kraak 1992), spatial and temporal domain can have different level of readings: from elementary, to intermediate, and to overall, view. It would be to the analysts' benefit to explore spatiotemporal data, particularly, multivariate data, only at the level needed. This leads to using graph (links or networks) which is more familiar and intuitive to human perception.

We consider the case where we have a binary spatial relation, e.g., origin port and destination port of a shipping line. Let this relation be temporally conditioned, i.e., the relation has an attribute that is independently described by time, e.g., number of voyages per month since the line was established. Visualization is naturally centered around node-link models, where the nodes are locations in a domain coordinate system (e.g., a globe or world map) and arcs are the relations between nodes. Current approaches to visual presentation of such data mostly present the spatial relation at a given time, then redraw the relation at a different time. Such animation can be effective but does not really show space and time simultaneously. Although in (Kapler and Wright 2004), association between locations is utilized, there is no attributes further attached directly on the association links. This limitation led us to explore ways to interactively visualize, and explore, information in space and time simultaneously.

3 An Approach to the Visualization of Spatiotemporal Links

We are attempting to visually present multiple temporal intervals in the same display. Figure 2 illustrates the basic idea of the approach. In this section we describe our approach informally as a set of potential steps a user would take to visually explore a set of spatiotemporal data. In this example we are considering container traffic on sea-going container vessels, but any other kind of point-to-point traffic would work the same way.

Consider a body of transactions or other data elements that occur over time and somehow "originate" from places on the globe:

(1) We allow any two geographical points to be connected (e.g., a "departure port" and an "arrival port")

(2) We support a query of transactions that connect these ports, e.g., "what volume, value, weight, etc of imports were carried from the departure port to the arrival port from start time T0 to end time TN, provided in intervals of deltaT?"

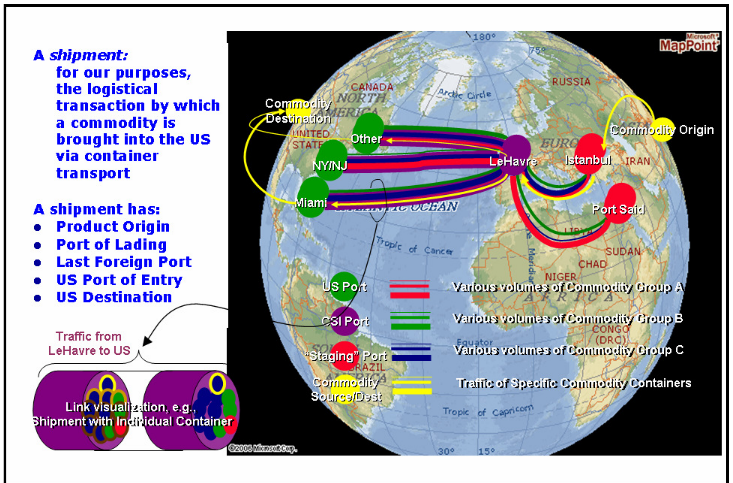


Figure 2: Concept - Visual Analysis of seagoing container shipments

(3) The volume, value, weight, etc is retrieved and indicated by the width of the graphical line segment between the ports, except that this segment is itself segmented into N/deltaT -length subsegments, each of which is drawn with widths proportional to their volume, etc. over the corresponding time interval.

(4) The user may pick any of these subsegments, and a display will come up that shows, for that time interval, the volume, value, weight, etc subdivided and graphically depicted according to the proportion carried by each respective shipper, or the proportion according to the different commodities shipped.

(5) This same visual data exploration procedure may be applied to groups of places on the globe, so that all the ports of China may be treated as the originating "place" to a US port, or Hong Kong to the US West Coast ports (as the destination "place").

(6) Such grouped data exploration/visualization entities may be moved around and placed anywhere in the user's display space, so that the user can treat the display space as a work area, and the visualization entity as a pictorial result to the underlying data. .

(7) Multiple such grouped or ungrouped visual queries/pictorial results may be created and persistently placed in the user's display space, so that some set of queries may be placed next to each other to directly compare, e.g., traffic over the same time from China to the West Coast and China to the East Coast, etc.

Figure 3 illustrates the approach as it existed in its initial prototype form.

The somewhat more formal description below describes the processes of the previous paragraphs as a set of operations over visual structures which, in turn, correspond to queries into a database (or other data source) and the results of those queries:

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Spatial Entities: We are establishing and exploring links between groups of spatial entities. The entities may be presented as locations or shapes on a (potentially extended) map-like display.

Context: The map-like display places the entities in the context of other information in the environment, e.g., of geographic areas.

Visual Cues: Graphical display elements such as texture, stipple, color, shape, size, contour lines and shadings (as in a choropleth map) etc. may be used both for background or to draw attention to parts of the information about the spatial entities themselves.

Links: The spatial entities may be connected by lines that may, themselves, take on forms. For instance, a line connecting a port to another port may have a thickness proportional to the volume of traffic between the ports relative to other ports, and it might be composed of a series of strands of different colors, each coding for a different commodity shipped between the ports. These may in turn have thicknesses representing the proportion of the trade they each represent. Thus the statistical characteristics of the relations between entities may be encoded by visual cues to make them immediately apparent to the human eye.

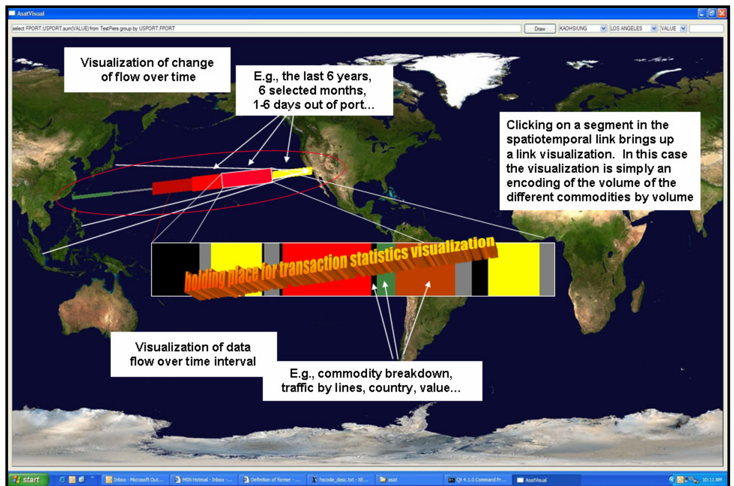

Figure 3: Concept Demonstration - expandable spatiotemporal links

Segments: The links may be broken into segments, each of which represents a subset of the whole set of data elements represented by the link.

SpatioTemporal Links: In our case it is of most interest to break links into segments that represent *time intervals* over the data represented by the link. Thus a link is divided into segments each of which represents all the information in the link, but in (usually contiguous or sequential) individual time periods.

Link Visualization: Each segment may, on demand, pop up with an independent visualization providing more detailed information organized spatially, temporally, or by whatever multi-dimensional, hierarchical category breakdowns, such as (Kemp and Lee 2000), are made available.

The core operations we provide through the visualization are:

Database Actions: a set of interfaces to the domain database for attribute selection and statistics computations. GUI Actions: a set of graphical actions to dynamically manipulate time periods, attributes, categories, places, etc.

Note that some attributes may depend on the selection/manipulation of other attributes, so that some actions are staged to depend on other actions to be set up first.

4 Examples

Below we illustrate some of the capabilities we are building. These are all composed of screen-shots from our running visualization prototype, set into MS PowerPoint, and annotated to direct attention to the intended subject of the individual figure. Figure 4 shows the basic grouping operation. As groups are formed the direct connection to geo-locations is weakened, therefore it's natural to provide the user to place the graphical entity representing the group to be places and moved anywhere. The groups' members – its “anchor points” - are optionally shown.

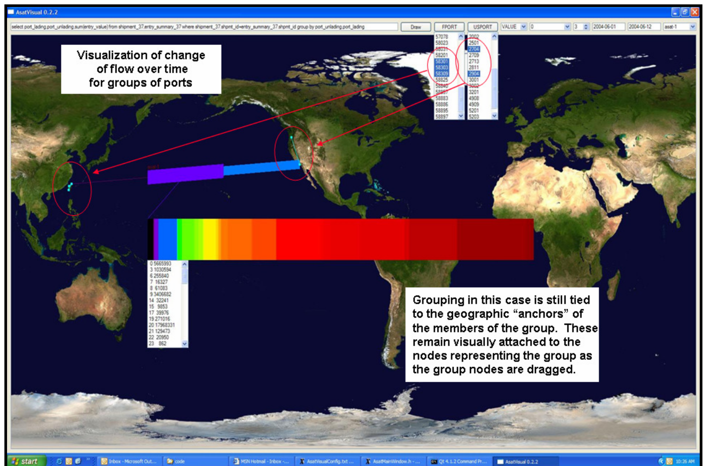

Figure 4: Use of spatiatemporally segmented links on group nodes

Figure 5 shows the visualization prototype displaying two links. These are the same source-destination group of ports but are displaying traffic volume (over the same time periods) for different commodity categories.

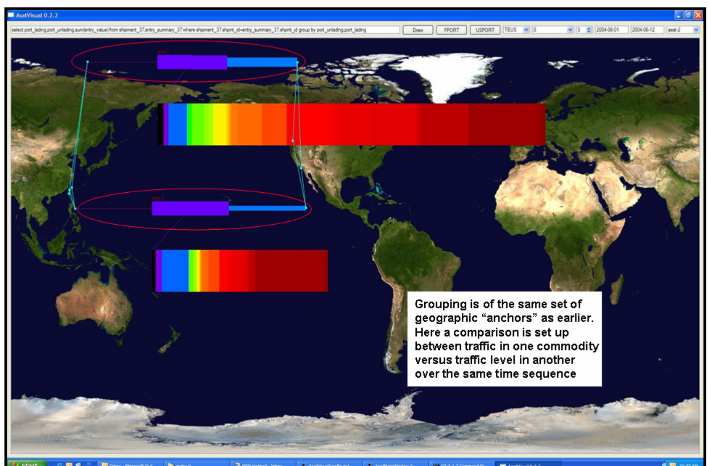

Figure 5: Spatiotemporal links to compare data over same time

Figure 6 also shows the visualization of two links. In this case the links show different source-destination paths over different times but for the same categories of commodities.

We believe the ability to create multiple such visual groups, to store them visually on the display as persistent objects, and to then manipulate them for comparison will facilitate data exploration and analysis in novel ways. Such visual “scratch pad” has not, to the authors' knowledge, been previously made available to the transportation and transaction analyst community.

5 Conclusions

The container traffic domain is an instance of a wide-ranging class of problems whose structure is best described as a hierarchical transition network whose nodes are anchored to geographical or other points in a well-specified spatial coordinate system. The key elements of this wider domain are data items that are described as having both spatial and temporal characteristics. The method we describe is directly applicable to any instance of this larger problem set.

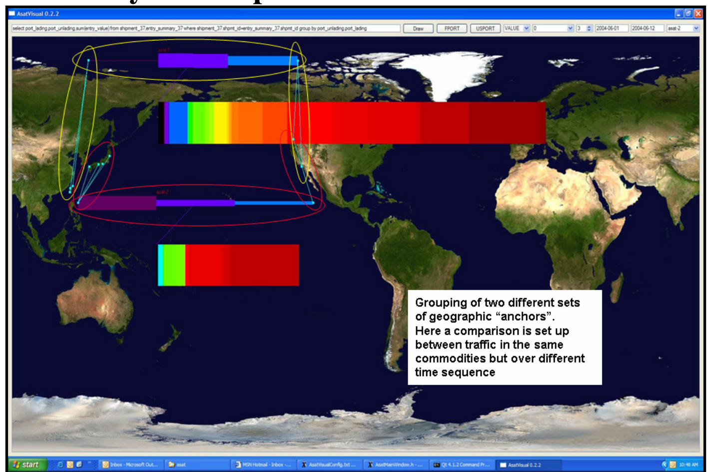

Figure 6: Spatiotemporal links across multiple groups

We have pointed out the need for powerful capabilities to link both spatial and temporal information in visual analytics. We have shown a visual query and presentation method of spatiotemporal links meets the requirements of an important domain of inquiry. We have provided definitions for visual elements that describe the class of domain of which container traffic is an instance. We have provided an abstract sequence of interaction steps and options that outline a subset of use-cases of the method. Finally, we have provided examples based on our implementation of the method.

Future work on spatiotemporal links will extend our implementation to use dynamic choropleth maps, dynamic symbols, and adding animated presentations. The latter will allow the segments to be understood more clearly to be providing convenient views or windows into an extended set of timelines that may be "scrolled" through the display.

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