Cross-dimensional Visual Queries for Interactive+Animated Analysis of Movement

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Visual analysis tools are increasingly taking advantage of coordinated multiple view approaches to provide analysts with flexible interactive querying across multiple data dimensions. While the foundation for interaction in the vast majority of visual tool designs continues to be the essential analytic utility offered by Shneiderman's *Visual Information Seeking Mantra* of "overview first, zoom and filter, then details-on-demand" [1], recent tools like XmdvTool [2], Spotfire [3], Polaris/Tableau/ShowMe [4], and Jigsaw [5] have begun to offer richer analytic utility through ongoing interactive choice of which multiple dimensions to overview, filter, and detail. Multidimensional analysis in these tools, however, revolves around visual abstractions designed for nominal, categorical, or quantitative data values. Spatial and temporal dimensions are treated as quantitative and effectively independent. Even with flexible choice of any such dimensions, loose interactive coupling between them severely limits the potential utility of visual analysis for the study of spatiotemporal phenomena.

We describe here some of our current efforts to develop multidimensional query techniques for visual analysis of spatiotemporal information. Our focus here is primarily on the development of interactive multidimensional filtering and highlighting techniques for visual identification and exploration of complex motion patterns, with an eye toward supporting analysis of individual and group movement behaviors. To do this, we are exploring how to adapt and extend our cross-dimensional filtering techniques, originally developed for visual analysis of historic hotel visits, to point-based data sets that describe the locations of a set of individuals over a range of instances in time.

This development effort began as a collaboration with Patrick Laube during his three-month visiting position at the GeoVISTA Center at Penn State in fall 2006. We added his relative motion pattern (REMO) algorithms [6] as new data transformation modules to the Improvise library [7], then iteratively built a sequence of coordinated multiple view interfaces using the Improvise live design interface. The resulting interactive visual tool exhibits substantial analytic utility during armchair analysis of two representative data sets — caribou herd migration and carrier pigeon homing — sufficient to justify continued interest in further development of multidimensional visual query techniques for such purposes.

Figure 1 shows an application of the tool to visualization of radio collar tracking data for caribou herd migration. Various coordinated plots display bivariate relationships between both the measured data points in time and space and the derived values for azimuth, sinuosity, and speed calculated at those points by the REMO algorithms. The main "map" view (at center) displays individual motion in space using the direction and size of arrows to represent azimuth and speed. The visualization supports selection-based filtering (brushing) on individual caribou and range-based filtering on all of the measure and calculated quantitative data dimensions. Stretching and

dragging a span of time limits the analysis to radio collar measurements in that span. Arbitrary selection of individuals (shown as miniature time series at center left) allows isolation and analysis of potential groups of individuals displaying similar movement behaviors in the form of overlapping motion characteristics. Dragging and stretching translucent selector boxes in various views filters the main view to show subranges of time, speed, azimuth (direction), and sinuosity (ratio of total path length to straight-line distance, or "curviness"), thus allowing the user to focus in on specific kinds of motion patterns. Interaction triggers all relevant view queries immediately, allowing the analyst to manually animate over one or two dimensions, such as by dragging the time selector (the rubberband in the view in the upper right) to scrub a temporal window of individual caribou locations.

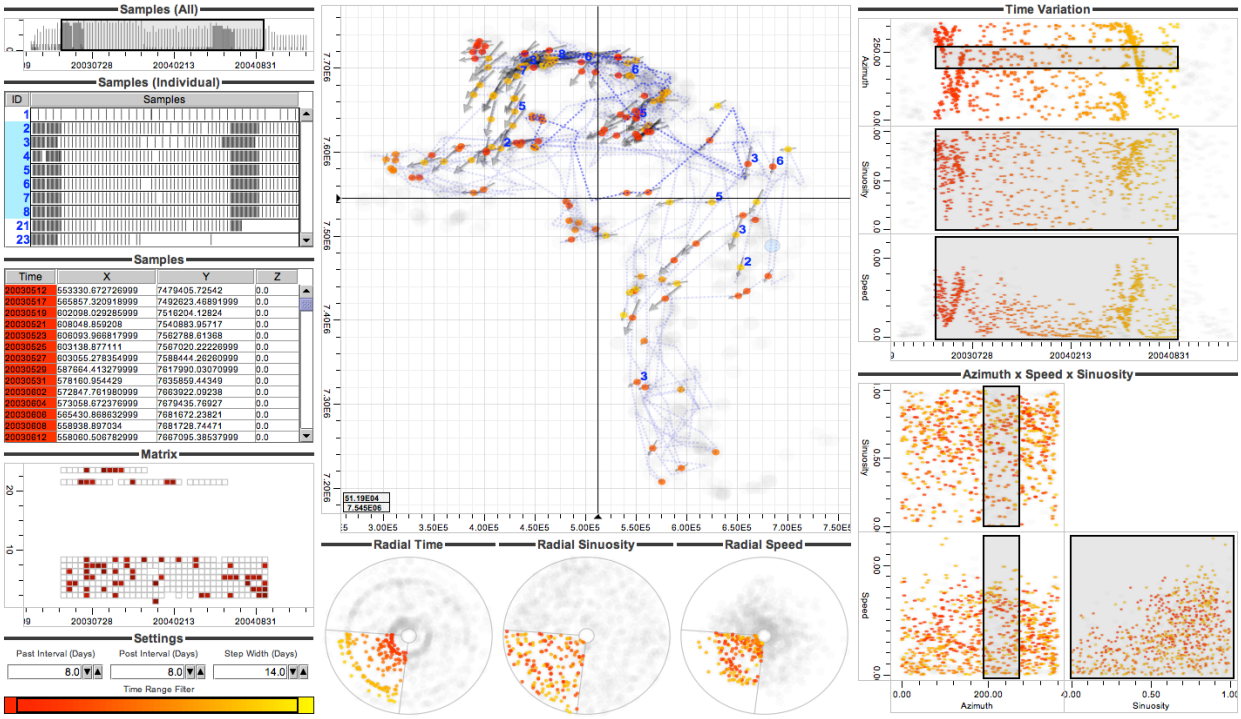

Figure 1. Visualization of radio collar tracking data for caribou herd migration. Selecting southwesterly points then scrubbing over time reveals a divergence of two groups of animals in late spring 2003.

In this visualization, the several peripheral views constitute a multi-dimensional overview that the analyst can use for zooming and filtering the space-time-individual points visible in the central map "detail" view. Filtering is based on a conjunctive combination of range filters (for each raw and derived point dimension) plus set containment in the brushed group of individuals. The peripheral views are also filtered on each others' range selections as well as the spatial extent of the map itself, meaning that the visualization overall embodies Shneiderman's mantra in a (nearly) symmetric and multidimensional manner; in a sense, every view is a detail view that can be zoomed and filtered through interaction in all other views taken together. We were quite surprised to discover that the conjunctive nature of this overview+detail mesh of views actually reduces analytic utility by forcing successive drill-down interactions and their reverses to apply to all dimensions simultaneously.

We have been able to extend the visual design and underlying cross-dimensional queries to build a new visual tool in Improvise that supports fine-grained scrutiny of individual and group movement in terms of any combination of space, time, speed, azimuth, and sinuosity. We did this by adapting the views and queries from the cross-filtered views technique [8] for use in visual analysis of movement, resulting in a "cross-highlighted views" technique that reveals the characteristics of fine-grain movement patterns in the context of overall movement traces. Cross-dimensional querying decouples data dimensions for purposes of displaying detail, meaning that the analyst can change the dimensional filters applied to each view in order to explore motion patterns and pose complex questions about movement behaviors. The analyst effectively determines their own evolving context for multidimensional reasoning by controlling both which dimensions and which values in those dimensions are queried and displayed.

Figure 2 shows an application of cross-dimensional querying to a simulated evacuation of a health clinic. The interface enables cross-highlighted analysis of the movements of people (yellow circles) not only in space and time but also as a function of motion behaviors suggested by the speed, direction, and curviness of paths. Subsets of individuals, regions of space, and subranges of time and derived motion parameters can all be selected in various views, then used to highlight the movement traces displayed in a chosen subset of other views. In this case, the analyst is looking at how people who end up motionless in a particular area of the building (the gourd-shaped area of yellow and dark gray in the building map at top center) move just after a critical event. Although this example demonstrates range-based selection in the temporal and derived motion dimension, the design could be modified to support region-based selection as is used for spatial selection in the building map view.

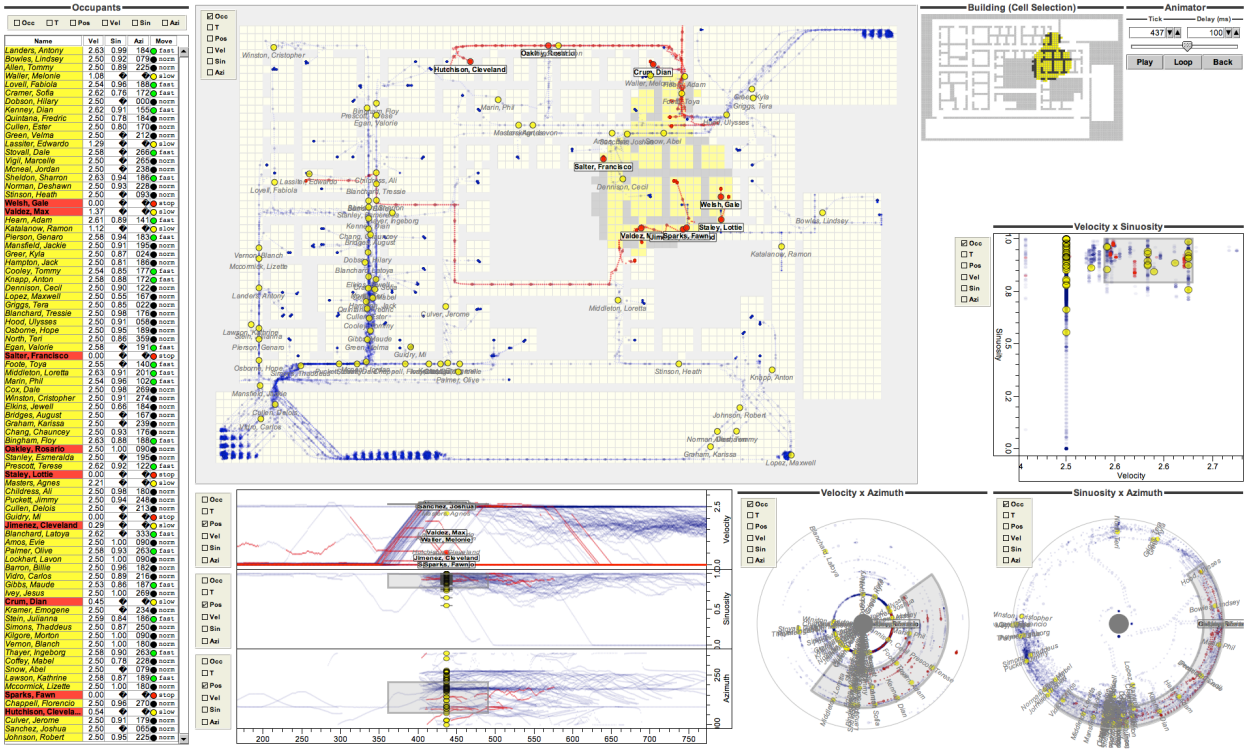

Figure 2. Cross-dimensionally highlighted visualization of a simulated evacuation from a health clinic.

Time is a critical factor in the analysis of group movement behavior in scenarios like this one. We implemented a new, variable-speed, looping, forward/backward animator to the Improvise view/control library, then added one to the visualization to allow even scrubbing over time within the scenario. Because the automator widget is an asynchronous control like other Improvise views, the analyst can interact anywhere in the visualization (albeit often with difficulty) while animation is active, such as to brush a set of individuals in the map while they are moving. Our idea here is that animation across multiple views simultaneously may allow the analyst to choose a abstract multidimensional data subspace and then sit back to watch it evolve from multiple "camera angles". Performance is a critical factor for the effectiveness of such an approach; the current in-memory database inside Improvise allows interactive+animated cross-dimensional querying performance for upwards of 100000 data records. (The data set in this example has 60000 records, with ~80 individuals over ~800 time steps.)

The evacuation visualization shown here is in its third version after roughly 30 hours of expert interactive design. By reusing the views and underlying queries statements (written in the Improvise query language), we expect that applications of cross-dimensional highlighting to other spatial analysis applications could be designed and implemented on a similar timescale.

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