NaturalMotion: Exploring Gesture Controls for Visualizing Time-Evolving Graphs

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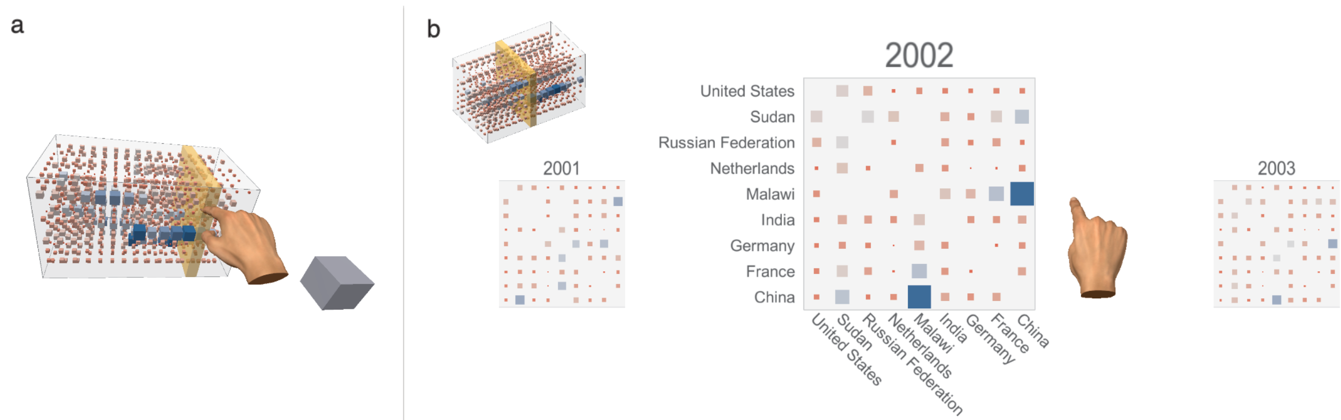

Figure 1: Screenshots of the NaturalMotion prototype being used to visualize a synthetic dataset of annual trade volumes among nations. The color mapping shown is weight-based, i.e., larger trading volumes in a given year are represented by larger blue cubes, while smaller trading volumes are smaller and colored red. **a**: selecting a slice in the overview cube. The rotation of the small cube in the bottom right is linked to that of the larger one, allowing the data visualization to be rotated without being blocked from view. **b**: viewing a slice in the *single slice* view.

Abstract

We are investigating new ways for people to explore time-evolving graph data represented as the recently-introduced Matrix Cube, through natural gestures in a 3D environment. In the cube, one axis is time, and the other two axes comprise an adjacency matrix of a graph. We want to understand how recent advances in virtual reality technologies may help the user more naturally explore the dimensionality and richness of this 3D visualization, enabling them to more effectively gain insights into relationships and anomalies in the data. We use a Leap Motion controller to capture the user's hand gestures that manipulate the cube into its many possible projections. We prototyped this synergy of data visualization and virtual reality on a time-evolving graph of annual trading volumes among major countries from 1995 through 2010. Please see the accompanying video for a demo of our prototype.[1]

Index Terms: H.5.1 [Information Interfaces and Presentation]: Multimedia Information Systems—Artificial, augmented, and virtual realities;

1 Introduction

The ubiquity of time-evolving graph data in many different fields, from financial transaction data to social networks, presents great opportunity for novel visualization tools for such data. Recently the Matrix Cube [1] was introduced as an effective means of visualizing these graphs, constructed with visualizations of 2D adjacency matrices from different times packed face to face sequentially along a time axis. The same authors also introduced Cubix [1], a system to manipulate the Matrix Cube using a standard computer mouse, and demonstrated the unique insights that researchers in diverse fields were able to extract from their data with the tool.

Recent research suggests that for certain 3D manipulation tasks, interaction techniques using six degree of freedom (6-DOF) input devices could significantly outperform a system using a traditional keyboard and mouse [5]. Inspired by these findings, we want to better understand how recent advances in virtual reality technologies may help users more naturally explore the dimensionality and richness of 3D visualizations like Matrix Cube.

While 3D visualizations may add great value in terms of *expressiveness*, they do not negate the value of 2D projections in balancing the oft-encountered tradeoff in expressiveness and effectiveness to make accurate inferences while visualizing high-dimensional data [2, 4]. In fact, 2D visualizations have been shown to be more efficient for accurately making specific inferences on 3D data, in some circumstances [3]. For this reason, 2D projections available in Cubix were made available, albeit through new interaction techniques, in the design of *NaturalMotion* [1].

Thus, our *NaturalMotion* approach seeks to leverage users' hand gestures in 3D space, as detected by a 6-DOF input device, in order to manipulate the Matrix Cube in ways that may have more direct physical analogs to everyday experience. Through gestures such as rolling, swiping, poking, and pinching, users are able to manipulate the cube through a variety of views, competitive in richness with the views available in Cubix. By using these natural hand gestures and superimposing a realistic view of the user's hand into the simulated 3D environment, NaturalMotion bridges data visualization and virtual reality (VR). We hope our research will help generate

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new knowledge as to whether such tools like NaturalMotion may benefit domain users for different applications, from scientists understanding complex relationships in biological networks to analysts extracting business intelligence from social network data.

In the remainder of this paper, we will first summarize our current investigation and the design and development of our NaturalMotion prototype that supports hand gestures in 3D space for interacting with time-evolving graphs. Then, we describe our research plan for extending our work and evaluating our tools and ideas.

2 NaturalMotion Interface Design

NaturalMotion consists of a dynamically rendered graphical view of a Matrix Cube as it is manipulated into different views, with input provided by a Leap Motion Controller (`http://www.leapmotion.com`). Figure 1 shows NaturalMotion being used to explore a synthetic dataset of annual trade volumes among nations from 1995 through 2010. In the figure, heavier graph edges are represented by proportionally larger cubes.

The Leap Motion device is used for tracking the orientation and position of the user's hand. A realistic depiction of the user's hand in its current orientation is rendered in the same graphical environment as the cube. Within this environment, hand gestures perform different functions depending on the position and movements of the hand, as well as the state of the cube. The rendered hand gives the user real-time visual feedback as to which volume the user's hand is occupying in the virtual 3D space. Potential manipulation operations are detailed below.

2.1 Manipulation Operations

Several essential manipulation operations of the Matrix Cube were chosen to be implemented in this prototype: rotating, scaling, color-mapping, and slice views. Different hand gesture schemes were designed to perform each of these operations and to transition between the different projection views of the cube. Please see the accompanying video for a demo of our prototype.

Rotating Rotating the Matrix Cube allows the user to examine how a graph's edges, visualized as smaller cubes of sizes proportional to their weights, change over time at a macroscopic level. The rotation of a small cube in the bottom right and the rotation of the large cube are linked (see Figure 1a), as both cubes rotate about their respective centers. Using the smaller cube ensures that the user's hand does not block the visualization from view during the rotation.

Scaling Scaling is performed when the tip of the user's left index finger and thumb are in contact with the larger cube. A pinching motion of the two fingers is used to alter the scale of the cube, with an expansion of the distance between the fingers increasing the scale, and a contraction having the opposite effect.

Color-Mapping Though the cube is initialized to a simple monotone color-mapping, a horizontal swipe of the hand in either direction cycles through the different color-mappings: monotone, time-based, and weight-based. The time-based mapping helps the user keep track of the orientation of the time axis. The weight-based color mapping (as shown in Figure 1) emphasizes relative weight differences between nearby edges, making the topology of edges within the core of the cube more apparent relative to the more superficial topology near the faces.

Slicing Sometimes, a user may want to focus on a particular time step, and to visualize that slice's adjacency matrix in the *single slice view* (see Figure 1b). To select a slice, the user dips the tip of her (virtual) index finger into the body of the cube into the desired slice, which is highlighted to signify that it has been tentatively selected, as in Figure 1b. Removing her finger from the cube cancels the selection. To finalize the selection of a slice and transition to the *single slice view*, the user makes a downward tapping motion inside the cube with the same finger, transitioning the cube to the *single slice view*.

Single slice view In the single slice view, a slice is centered on the screen with the slices immediately preceding and following it on its left and right, respectively. An orthographic projection of the overview cube is shown in the top left of the view, with the currently selected slice highlighted to indicate context of the slice within the overall time series. This view may be suitable for investigating more instantaneous changes in the topology of the temporal graph. To navigate to another slice within this view, the user may swipe left or right to advance to the next or previous slice, respectively. The user may scroll rapidly through the slices in a forward or backward direction with a circular motion of the index finger in a clockwise or counterclockwise direction, respectively. In order to investigate more long term changes, the user may transition to the *multi-slice view*, described below, by making an upward swiping motion with a hand. A downward swiping motion hides the *single slice view*, pulling the overview cube back down to its original state.

Multi-slice view In order to investigate more long-term time-dependent changes in the graph topology , the *multi-slice view* compares several consecutive time slices aligned by their axes for consistent comparison. Similar to navigation within the *single slice view*, a horizontal swipe of the hand to the left or right advances the view to the next or previous set of slices, respectively. An upward swipe of the hand returns to the *single slice view*, and a downward swipe of the hand hides the *multi-slice view* and pulls the overview cube back down to its original position.

3 Conclusions and On-going Work

We presented our NaturalMotion prototype and ongoing investigation for new ways for people to explore time-evolving graph data. We want to better understand how recent advances in virtual reality technologies may help users more naturally explore graph data.

We are working to develop additional gestural interaction techniques to complete feature parity with Cubix [1]. And we are planning and designing a user study to evaluate the usability and effectiveness of these interaction techniques. For example, we want to understand if the gestures are natural to perform and easy to recall.

Currently, the NaturalMotion prototype can smoothly render a time-evolving sparse graph with approximately 2500 total time-based edges on a laptop computer in real time. We will test the prototype with larger graphs in order to better understand how the visualization and interaction techniques may work in different conditions. We are also starting to investigate the effectiveness of rendering the visualization in a more immersive stereoscopic display, such as the Oculus Rift (`http://www.oculus.com`).

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