Engineering Design Graphics Journal (EDGJ)
Fall 2013, Vol. 77, No. 3
http://www.edgj.org

ISSN: 1949-9167

A Graphics Design Framework to Visualize Multi-dimensional Economic Datasets

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Abstract

This study implements a prototype graphics visualization framework to visualize multidimensional data. This graphics design framework serves as a 'visual analytical database' for visualization and simulation of economic models. One of the primary goals of any kind of visualization is to extract useful information from colossal volumes of data and more importantly, communicate the extracted information. Using a multidimensional framework not only significantly enhances the ability to view multiple variables, but also brings together diverse data formats on one canvas. Economists cope with huge multi-dimensional data sets on a day-to-day basis. Various graphic and tabulation methods have been used for methodically representing and analyzing such colossal data. However, not much effort has been directed towards applying desktop Virtual Reality (dVR) based technologies to visualize such multidimensional economic data sets. Such procedures enable data visualization without compromising the richness of preserving multiple dimensions relevant to the analytic questions in consideration. We demonstrate the possibility of such an application to a widely used time-series bilateral multi-sector trade dataset. Usefulness of this framework and application is shown using several analytical and numerical examples.

Introduction

Virtual reality based visualization empowers the decision makers to view and comprehend even hidden or ineffable information. The 3D virtual scenes besides enabling navigation also provide a sense of immersion whereby the planners can position themselves within the scenes and perform exploratory data analysis. One prominent advantage of using visualization models is that even a bird's eye view can provide enormous details to the observer. For instance, visualization enables identifying patterns and outliers from huge data sets. The ability to view a scene from innumerable perspectives is an essential functionality to capture the links between the various dimensions of a virtual scene. Scene characteristics that are otherwise incomprehensible become evident when using such advanced 3D visualizations. Hence, this study intends to exploit the immense power of desktop Virtual Reality (dVR) based visualization to economic data sets. Today's world economy is more inter-linked than it was decades ago. Policies framed and implemented by one country influence those of the neighboring as well as far-off nations. The main source of such linkages is the global trade of goods and services. Economists often use tables, graphs and less

ISSN: 1949-9167

frequently, GIS maps to visualize the global trade for inferring policy recommendations and business strategies. Although such visual representations are widely comprehended by professional economists, these may not be so much appreciated by other, perhaps more important, stakeholders such as policy-makers, engineers and scientists.

One reason for this lack of comprehensibility is that these involve huge datasets of numbers, with a host of underlying mathematical formulae and statistical relationships. For example, let us consider an illustration showing that USA exports x% of its aircraft exports to EU. This illustration in conventional graph formats may further go on to explain that this x%, is indeed y% of total EU aircraft imports. The aforementioned statistical information can be rather confusing to the non-specialists. However, informed decision-making involves dissemination of information to and input from diverse audience, including non-domain personnel. The purpose of visual representation of data varies across individuals and policy/strategy questions at stake. For example, one may be interested in the aggregate picture of global trade, i.e., about the biggest exporters and importers, overall patterns and outliers. For this, one does not need hundreds of graphs/tables with details showing the shares of different countries in the trade of different commodities, but just one map highlighting the biggest exporters/importers in distinct colors. However, one who is interested in the policies governing the lack of automobiles trade between two countries would need a lot of details, such as automobile policies in these two countries, distances, political relationships, etc. Thus, the level of detail varies across the disciplines and is motivated by purpose of visualization of data. The framework explained in the study helps both spatial and temporal visualization.

Economic datasets involve diverse data formats (or modes) including spreadsheets, documents, graph sheets, pie charts, and various graphic as well as video formats. This study aims at demonstrating a novel tool of multi-dimensional multi-modal visual analytic framework to visualize the aspects in global trade between pairs of countries and the factors influencing it, particularly, the policies and distance between countries. While doing so, interactions between the drivers are also factored in. This is accomplished by enabling us to view, explore, and analyze the data in multiple modes and dimensions. Another functionality that may be helpful is the ability to visualize 'what-if' scenarios. This refers to visualizing the outcome by manipulating a set of parameters (variables). This enhances our understanding of the correlation among various data variables. For example, one could readily visualize the structural change in bilateral trade flows by imposing the share of agriculture in bilateral trade between 2 nations in 1995 on the corresponding bilateral trade flow in 2007 to see what would have been this flow if the 1995 structure were to remain unchanged in 2007.

Rather than the final product resulting from the visualization, it is the actual process of trying to visualize the datasets that leads to finding the correlation among the various pieces of data. One of the primary goals of any kind of visualization is to extract useful information from colossal volumes of data and more importantly, communicate the

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extracted information. Chandramouli and Bertoline (2013) employed a multidimensional framework to stimulate interest in technological and engineering literacy. The efficiency gains from such a cognitive exercise are enormous and may result in faster, easier, effective, and informed decision-making. This paper describes the development and implementation of a multidimensional visualization (MDV) framework that serves as a 'visual analytical database' for visualization of economic statistics. As an illustration, we use the time-series bilateral trade statistics (Gehlhar, 2008) derived from GTAP (Global Trade Analysis Project) Data Base (Narayanan, Aguiar and McDougall, 2012). This data involves a high differentiation by years, sectors/products and countries (exporters and importers). Using visualization for this kind of data can be extremely beneficial to draw meaningful inferences from raw data.

Literature Review

The need for visualization and its effectiveness in solving practical problems has been emphasized in numerous works by authors from diverse fields. In their works on visualization, Tufte (1990), emphasize the importance and usefulness of visualized data. Recently, 3D visualization of information has turned out to be an essential tool in demographic, medical, land-use, infrastructure, meteorological, hydrological, and several other environmental applications. Modern sophisticated data acquirement technologies have made it possible to acquire complex data which were primarily much more difficult to procure; nevertheless, to extract useful information from this sea of data volumes is an overwhelming chore. With increasing data accessibility and the development of a plethora of tools for visualization, there is a mounting need to sensibly and efficiently model data and phenomena eventually. Visualization practices not only enable the user to obtain an insight into the data being analyzed, but also facilitate effective presentation of the results of the analytical process (Koppers, 1998, McGaughey, R.J. 1998). Visualization enables combining diverse datasets to present an integrated view of the data.

For issues involving design and decision-making within the realm of financial and economic applications, 3D visualization serves as an immensely valuable means for exploring data. Visual representations are comparatively easier to comprehend and employ, than their analogous tabular or written versions. In the context of modern research, there is a need to visualize complex, multifaceted data in its 3D form in multifarious fields such as demographical studies/research, health-care, voter-information, civil engineering, hydrology, disaster management, oil exploration, mining, and so on. This research extends this notion to data analysis and decision making involving huge data-sets pertaining to economics. It is important that all stakeholders participate in the economic policy-making process with the level of rigor that has so far been the forte of economists alone, since the issues considered herein affect people from all walks of life.

Bertoline, Wiebe, Hartman, & Ross (2009) state that 'once you know the language of graphics communication, it will influence the way you think and the way you approach

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problems'. This is especially relevant for the multi-dimensional data considered here. For instance, if we are interested in viewing the trends in export shares of agricultural products in total exports from a country to a group of countries using this data on a global map, several steps are needed: aggregating the commodities into a single agricultural product group, aggregating the group of countries of interest, computing export shares for different years and then matching this data to a global map. This needs considerable data processing and programming if we use popular statistical packages such as R, STATA and SAS. On the other hand specialized software like GEMPACK (Harrison and Pearson, 1996) provide tailor-made solutions such as aggregation packages that simplify the process of adding up across sectors and regions and features to look at different types of shares, with a maximum of two dimensions at a time. But, this also involves additional processing load and time, since four dimensions are involved here: commodities, years, exporters and importers, which also need to be mapped to a global map. There is also a steep learning curve involved in gaining expertise, even at a simple user-level, for these tools.

Over time, we are used to visualizing particular information in a specific way, and this biases and often times, inhibits our ability to perceive information in different ways. For instance, line curves, bar charts and pie graphs pop into one's mind when speaking of time-series multi-commodity multi-country exports data. Though these have efficiently served needs of the respective communities over time, alternative forms of representation shown in this paper may be optimal and may better facilitate information extraction. This is especially true in today's scenario when stake-holders are from numerous disciplines such as environment, energy, engineering, and agriculture. These stakeholders are concerned about understanding the global trade patterns for almost all issues related to policy and business. For example, scientists are interested in models to analyze global trade structure for predicting economic costs of global warming and its implications for poverty (Hussein *et. al.* 2013), agriculture (Diffenbaugh *et. al.* 2012) and land use (Baldos and Hertel*,* 2013). Even if we find a table large enough to spread out all the charts and tables required for a multidisciplinary project or a screen large enough to project different data formats and components, trying to correlate among such diverse data sets is an onerous task.

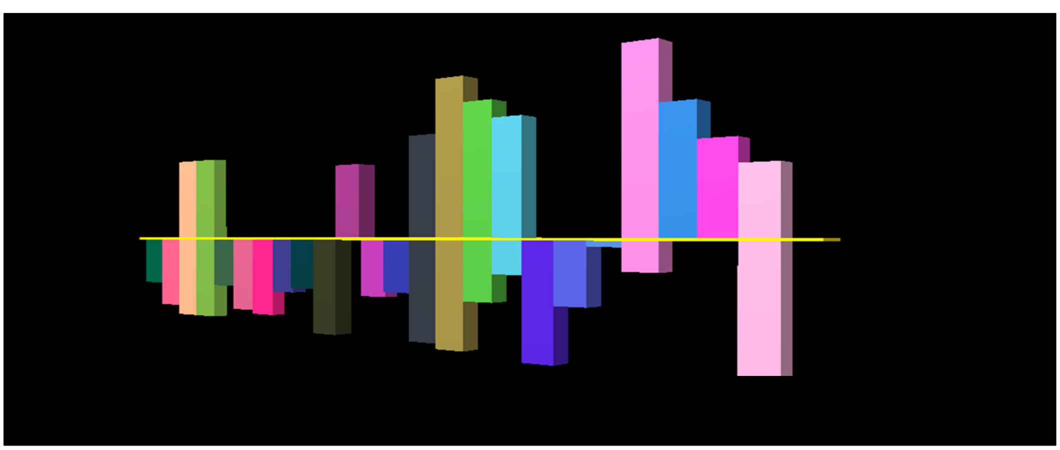

Figure 1. Alternative Representation to Accommodate Additional Dimension.

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Figure 1 illustrates an example that not only uses the conventional x, y, z representation, but also uses the –ve Y in combination with colors for additional dimensions. Understanding complicated data is inevitable to analyzing simulation results from large-scale economic policy models. While different programs provide methods to visualize data and the results, none of them may be suited for all occasions and all software. Britz, Perez and Narayanan (2012) discuss the specificity of the visualization tools provided by the standard economic modeling software packages: the need for one tool that can be used in conjunction with all of them arises mainly because each of them has unique advantages which are desirable in the context of other software packages as well. Hence, this paper uses a multi-dimensional framework that uses ‘geometry and graphics’ as tools to facilitate information extraction from global trade patterns. The framework uses the ‘geometry’ of objects and subsequently employs ‘graphics’ as the medium to serve as an interface to the ‘visual-analytical database’. One primary drawback with a vast majority of visualization systems used in understanding trade patterns is that information is in a pre-determined fashion, which may or may not be understood by researchers from different disciplines. A good visualization platform should be flexible enough to allow the user (audience or the information receiver) to interact with the information.

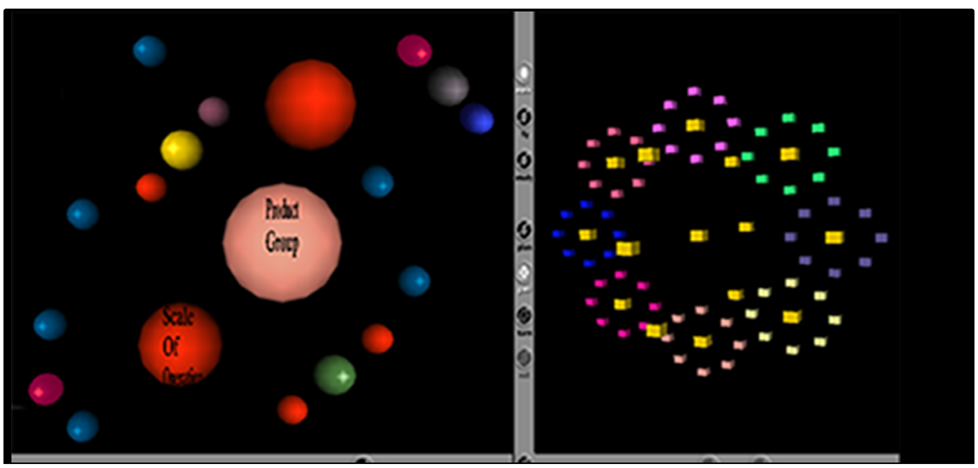

Figure 2. Interactive Virtual Worlds Representing Multidimensional Economic Datasets.

Figure 2 represents alternative visual representations of multidimensional datasets within an interactive framework. As mentioned earlier, this study presents a multidimensional visualization framework as a gateway to a database that can be analyzed, and hence the name ‘visual-analytical database’. The MDV (Multidimensional Visualization) framework can be considered as the front-end and the time-series global trade database as the back-end with all the different forms of information.

Methodology: Desktop Virtual Reality based Visualization

Virtual Reality is a tool for 3D data visualization that helps visualizing and interacting with data. Much of the 3D visualization in today’s applications is done in a virtual space

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that is often described as 'virtual worlds'. The reason they are called virtual worlds is that they are not actually 3D worlds in real space, but they are digital or cyber worlds that have their own coordinate systems and define a 3D virtual coordinate space within which applications can be built. The users can navigate within these virtual worlds, move objects, rotate or scale them, and transform them in multiple ways. These virtual worlds aid user interaction with 3D objects and provide a sense of immersion. In our own example, we have four dimensions: commodity, exporter, importer and year, so we can easily visualize this data looking at three dimensions at a time. The users should be able to view the complete dataset at the same time, by holding one dimension constant. If we hold year constant (say, at 2007, for example), the user will be able to navigate through exports of various commodities from various source countries to various destination countries. Many different transformations may be envisaged at this stage. Some of them could even be used to examine economic hypotheses and debates. For example, the existence of trade creation versus trade diversion may be examined for each commodity over the years, by scaling or normalizing the bilateral trade flows over the aggregate imports by each country, thereby obtaining a measure of 'relative' performance of bilateral exports of different source countries. Over the years, let us say that the exports from country A to country B decrease relative to aggregate imports by country B, for a commodity G. On the other hand, let us assume that the exports from country C to country B increase, relative to aggregate imports by country B. From this, it may be inferred that trade has been diverted from country A to country C, as far as the import market for commodity G in country B is concerned. Such deep insights may be obtained from the multidimensional visual data representations proposed in this study.

Virtual world objects are described as shapes with geometry and appearance. All features can be modeled as shapes which can be grouped together and transformed (translated or rotated) within the coordinate system within which they are built. The geometry field is used to describe the geometric properties of the object and the appearance field is used to describe how the object looks. A significant number of VR models were developed using the customizable nodes, called PROTOS (short for Prototypes). PROTOS represent reusable scene objects and these can be referenced from within the file and externally (EXTERNPROTO, short for External Prototypes). The PROTO library created as part of this study can serve as an extremely useful addition that can be extended into several other applications as well. The framework also provides functionalities to dynamically change graphical attributes such as diffuseColor /specularColor/ transparency (Visual Attributes) to generate various appearances of the same object and also dynamically manipulate the size of the object. This can be used to display and correlate attributes and attribute relationships. When the user manipulates the size without scaling up or down that of all objects, the system takes it as a real change in that trade flow and uniformly adjusts all other trade flows to accommodate this change and retain the system balance. For instance, in other words, increasing the size of US-Brazil trade in aircrafts would entail increasing its real value at the cost of aircraft trade between US and other partner countries. The default allocation is equi-proportional to the initial trade flow, but this can be modified by the user by

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providing a set of mini-model rules. Some important functionalities of a virtual world include:

- The ability to move about in the 3D space: with commodities, exporters and importers as three dimensions in this context, for each year
- Walk through the dVR (desktop Virtual Reality) Application: in the context of trade data, one may walk through different commodities, exporters, importers and years.
- Locate and navigate to particular points of view (POV): For instance, one can locate a particular commodity and navigate to viewing the trade between different exporters and partners across time.
- Select a particular path and display a video sequence along: this feature will be useful to illustrate various movements in trade across the years, for example.
- Provide different levels of detail (LOD): People interested in greater commodity details at global level may choose a suitable LOD, while other interested in a particular exporter or importer at aggregate commodity levels may also choose such an LOD.

The 'intelligent' objects that can 'sense' user actions are programmed along the notion of 'Event Driven Programing'. The basic concept behind this notion is that the objects react to the user's action. Users can interact with objects in the dVR in several ways including selection, selection and dragging, hover, and transforming. The last word transforming refers to performing transformations (on geometric objects) such as translation, rotation, and scaling. The following diagram illustrates this notion of event-driven programming (Figure 3).

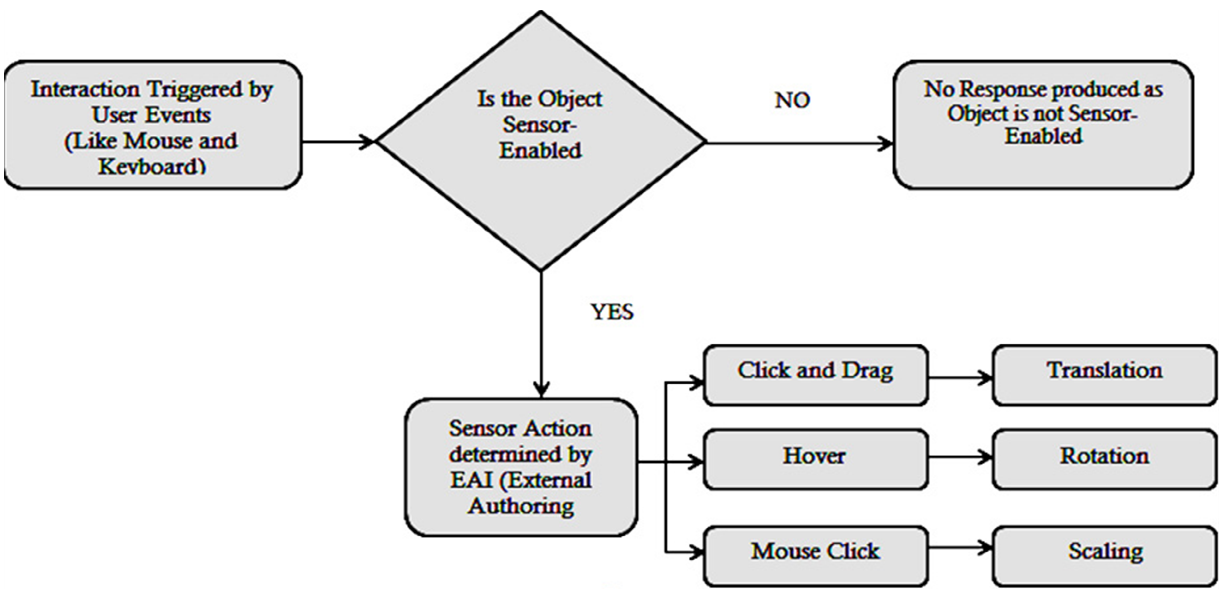

Figure 3. User Interaction via ‘Sensor-Enabled Graphic Objects’ within Virtual Environments.

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The way to correlate variables representing various attributes is to use the quantitative values associated with the dVR object properties. These object properties refer to the attributes constituting the 'geometry' and 'appearance' of the graphic scene objects. So, for a cylindrical object the attributes include values such as radius and height. In our illustration, such values may be made to represent the values of trade flows. Similar to the geometric attributes, attributes determining the 'appearance' of an object also can be expressed quantitatively. However, even though red color can be expressed graphically as (diffuseColor 1 0 0), appearance attributes are more easy to identify as they can be 'seen' directly. Given that we have four dimensions in our illustration, we could also color-code the attributes derived from the fourth dimension in a three-dimensional view. For example, in a commodity-exporter-importer view, trade flows that have declined over the years may be shown in red while the ones that have risen may be shown in green.

The above discussion has exploited only the attributes concerning geometry and appearance. Besides these individual graphic objects can be incorporated with the sensors to respond to user events and this can in turn be used to provide more detailed information. For instance, hovering the mouse on an object shows a JavaScript message providing a snap-shot about that attribute. For detailed info, a spread sheet or a web page or a pdf file can be associated with each object that can be accessed with a mouse-click. In the trade data example, documents about the commodities or countries may be linked to the objects, in addition to their detailed labels.

Programming the Final Graphic Interface for User Interaction

One of the primary reasons for implementing the graphic library using PROTOS is the ability to program the objects hence created. The exposed Fields can be compared with Input and Output jacks and can be wired to create ‘ROUTES’. This event model facilitates controlling behavior, hence paving way to the creation of complex objects and dynamic scenes. These capabilities are very relevant and useful for dealing with multi-dimensional datasets like the bilateral trade data.

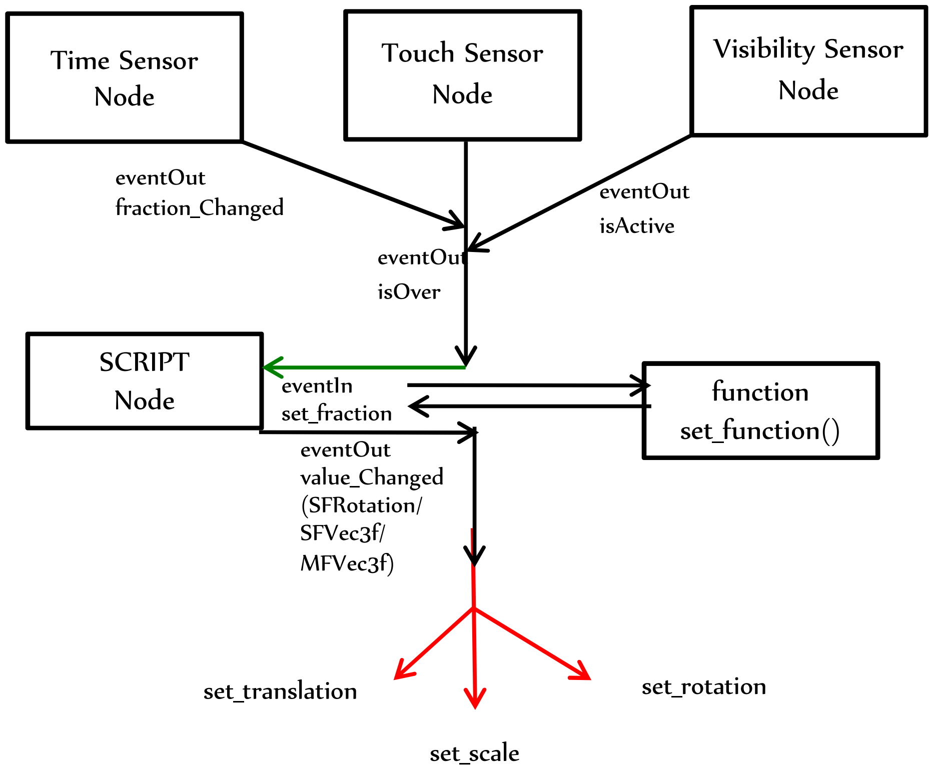

Figure 4. Event-flow within the External Authoring Interface for Enabling Interaction within the Virtual World.

A detailed examination of the shapes illustrates the design complexity, whilst the ‘reusable’ nodes (PROTOS/EXTERNPROTOS) and the scripts associated with the EAI (External Authoring Interface) make the process much less cumbersome. Figure 4 illustrates how these nodes can be programmed to receive these inputs (Figure 4 re-used from Chandramouli et al., 2004). Scripting opens up the EAI of the virtual worlds, thus making it possible to use Java libraries and built-in JavaScript functions. These can be controlled via eventIns and eventOuts. By ROUTING the values obtained from the EAI (using JavaScript/Java) through to the appropriate fields, even complex relationships can be represented visually. This flexibility of I/O sequencing would prove helpful in economic policy applications. Users will be able to exploit the possibilities of dynamic views and analysis in such a framework. For example, they could first click an exporter country to see its major partners and commodities and secondly look at how they have changed over the years, using color codes as mentioned above. This sequence may be reversed as well, by first looking at the declining and rising exporters and then focusing on the commodities and partners of each of them.

Viewing Relationships Using Geometric Objects

Correlations (relationships) among database entities (virtual scene objects) can be demonstrated in a visual manner using line geometry. The thin white line runs across

ISSN: 1949-9167

various spherical objects representing bilateral trade flows. Also, various attributes can be used to differentiate between different kinds of relationships. If we have 50 different commodities represented by lines that connect country-pairs denoted by the spheres, we could draw 50 lines varying in terms of attributes. Alternatively we could represent each sphere as aggregate exports from a country and the lines of different attributes, which are linked with the relative measures of exports to each of the destination country leading to its destinations, as illustrated below in Figure 5. The attributes can be represented using varying line Thickness, color, style, etc.

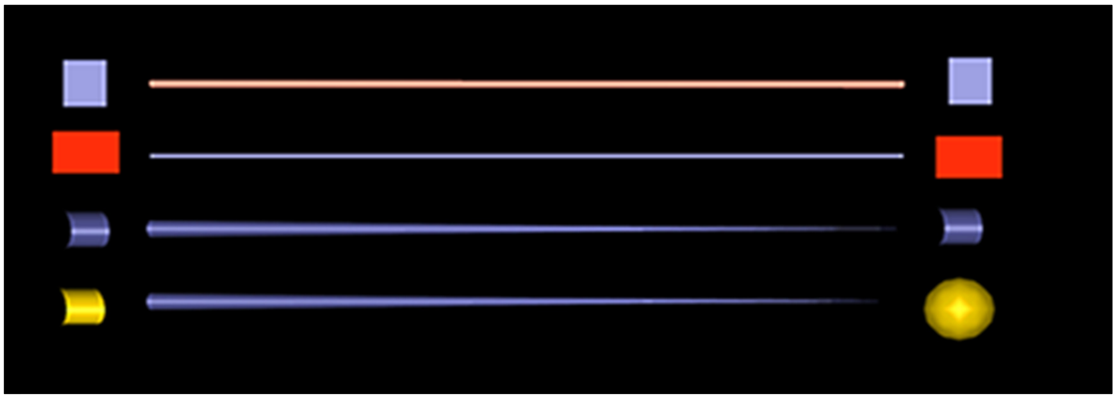

Figure 5. Representing Correlations (Relationships) Using Alternative Line Geometry & Entity Combinations (Color, Style, Thickness).

Results and Discussion

This section discusses the cumulative utility of having a multidimensional representation and demonstrates that using the results of the dVR-based MDV framework does indeed help in data organization, manipulation, and correlation. In Figure 6, the dVR representation on the left shows the regular view and the one on the right shows the representation showing attributes involved in bilateral trade. Attributes that are being included within the sphere can be turned ‘On’ or ‘Off’. One could think of the smaller yellow spheres in Figure 6 as showing the scattered components of US-Brazil trade in 2007, for example. This can be color-coded to denote the trade flow; for instance, blue can corresponds to under 1 billion US Grouping. The green object may alternatively represent trade in a commodity while its components may represent trade in that commodity in different country pairs. Let us consider an example of how this notion of incorporating the capabilities described in the earlier sections can be helpful in multidimensional visualization. Consider one of the two different representations for bilateral trade flows. Both the representations have some kind of hierarchical sorting. In figure 6 the commodity-wise parts of global bilateral trade are represented using the cubical shapes. Figure 7 shows the commodity-wise and country-pair-wise bilateral trade flows using the cubes arranged along the x, y, and z axes. In other words, figure 6 provides information about the relative size of trade in different commodities in global trade, while figure 7 provides information on spatial and sectorial distribution of trade flows. Here, the year dimension is viewed one at a time, but one could easily

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interchange year with commodity or country, to view multiple ways of looking at bilateral trade flows.

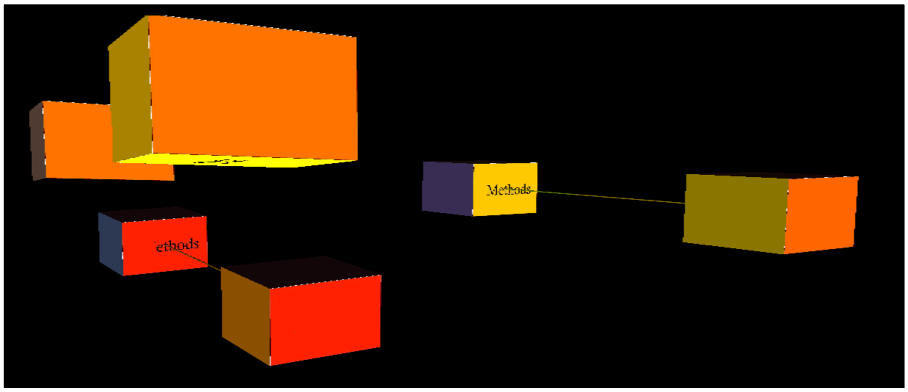

Figure 6. Representation 1: Commodity-Wise Components of Global Bilateral Trade (BT).

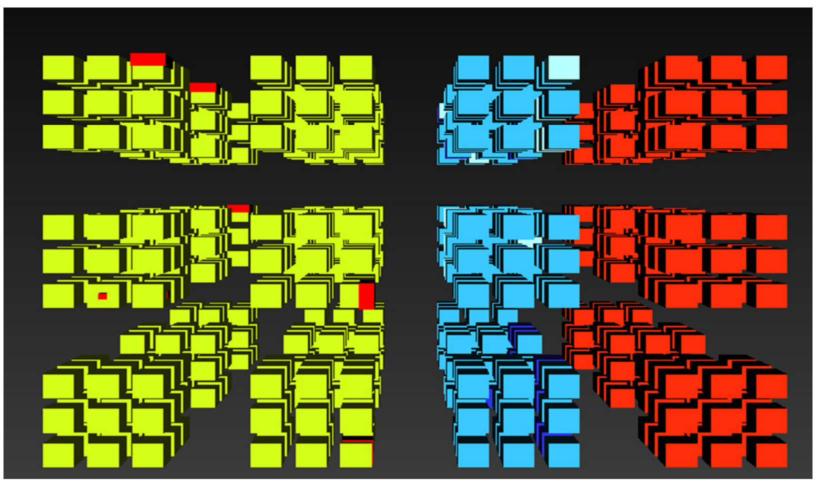

Figure 7. Representation-2: Commodity-wise/Country-pair-wise BT Flow.

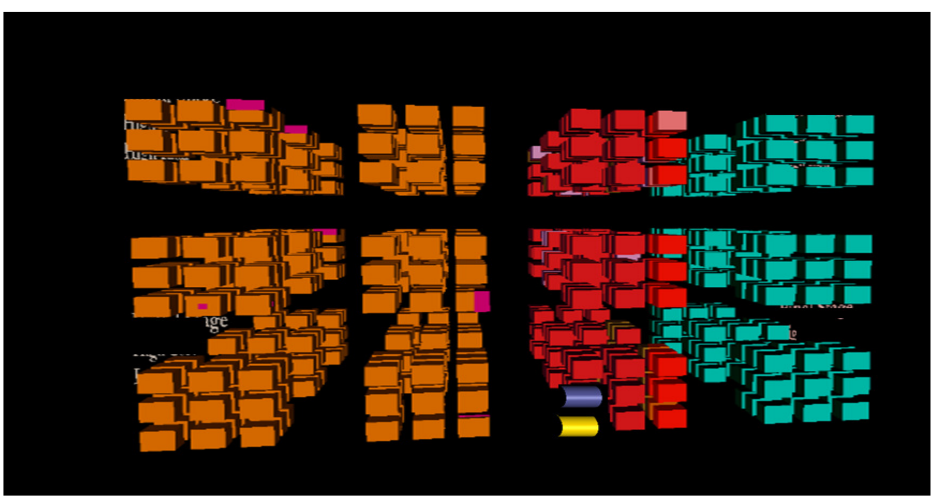

Figure 8. Interface with Filters Activated to enable Multi-Criteria Sorting.

In Figure 8 (above) initially all the entities are represented using the same colored cubical objects. Once the user switches on the attribute of size, flow larger and smaller than a pre-determined size are shown in different colors. The multidimensional representation shows a dVR framework with filters enabled to turn on and off specific attributes or attribute relationships. Objects in red show the trade flows higher than 'x' US$, while others refer to trade flows below that amount (in US$). Trade flows corresponding to countries closer than 'a' KM (kilometer) are denoted by the yellow cylinder. Rigorous modeling using econometric may provide overall insights, but nothing that can be specific to a particular trade flow and exporter-importer in question. CGE (Computable General Equilibrium models such as Hertel (1997)) model results can give some indication, but these are usually as large as the dataset itself (Britz, Perez and Narayanan, 2012) and hence digging deep into the results would probably benefit from a framework like this one. On the whole, the results evince the usefulness of visualizing colossal volumes of economic data and understanding the hidden information and correlations, which may otherwise be quite difficult to decipher.

Through the design and implementation of this prototype framework, the authors demonstrated the potential of alternative multidimensional representations in integrating, presenting, and communicating diverse forms of information in multiple modes. Within this framework, the user is able to dynamically interact, manipulate, modify, and re-arrange the information in accordance with their needs.

Conclusion

The goal of this study was to design an innovative framework integrating geometry and graphics for developing a multi-dimensional visualization framework to analyze economic data. This study illustrated the advantages of using dVR in multi-dimensional data visualization with various examples. This study explained with examples and dVR models, the design and implementation of a prototype application for economic analysis. The information revolution has resulted in vast amounts of data that are far too complex, both in quality and quantity, to be handled by conventional tools and techniques. With increased amount of economic data available, virtual environments are an efficient means of visualizing voluminous data. Such virtual environments facilitate understanding of the complex relationships among the various components of a multi-level scenario.

In this paper geometry and graphics are employed to design and implement an intermodal multidimensional framework for analyzing commodity-wise international trade at bilateral level for multiple years. This framework facilitates visualizing at different levels of detail (LOD) and switching among different modes of visualization. 3D virtual models have been integrated into the framework to facilitate immersion and navigation. The authors believe that this notion can be extended for a wide range of applications across multiple disciplines. This prototype visualization to develop a decision support system can serve planners and policy-makers in identifying the desirable and undesirable factors among those that influence international trade at

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bilateral level. One can quickly filter out conspicuous changes in trade, outliers and the role of attributes such as geographical proximity, in a logical and systematic fashion to arrive at useful observations and informed policy decisions. We showed an example where bilateral trade flows are declining and are low, despite geographical proximity, indicating an immense scope for bilateral policies that can promote trade between the partners in question. Even if the policy maker merely wants to identify ways to enhance exports from his country, he could follow this thought process and take easier steps of promoting trade with neighbors rather than trying to encourage exports to a distant destination.

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