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## **Editorial Board, Advisory Board, and Review Board**

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### **Online Distribution**

The online EDGJ is a reality as a result of support provided by East Carolina University and Biwu Yang, Research & Development, ECU Academic Outreach.

## Message from the Chair


Dennis K. Lieu  
University of California at Berkeley

One of the most valuable benefits of participating in EDGD is the opportunity to attend its conferences. Of all the professional conferences I attend, whether research or education related, my favorite by far is the EDGD Midyear Conference. At the Midyear, I truly feel that I am among friends and family. It is a collection of educators with common goals and interests, but the differences in their means and approaches are what make discussions exciting. The Midyear Conference is small enough to afford a personal touch, and the expenses are always kept to a reasonable level. If you haven't been to an EDGD conference lately, I fully encourage you to do so. While much can be learned from reading papers and watching webinars or video presentations, there is really no substitute for face-to-face discussion. Conferences are the places to make friends as well as professional contacts. They are places to discover new ideas, technologies, and different approaches to common problems. They are places to bounce your own ideas off others who can offer qualified opinions and advice. These types of interaction are best done at a personal level: over a meal, in the hallway, or on a tour. Remember that you can attend a conference even if you are not presenting a paper. I've done this more often than not, and I've always come away refreshed, inspired, and full of new ideas.

The recent 68<sup>th</sup> EDGD Midyear Conference, held on 20-22 October 2014 at Worcester Polytechnic Institute in Worcester MA, carried on the tradition of EDGD conferences that are well-organized, informative, and just plain fun. I wish to congratulate the organizers for a job well-done, especially Site Chair Holly Ault, and Program Chairs Nick Bertozzi and Kathryn Holliday-Darr. The 68<sup>th</sup> Midyear boasted sixty participants from twenty different universities and five industrial partners (Autodesk, Parts Solutions, PTC, Schroff Development Corporation, and Solidworks). Seventeen technical papers were presented and four professional workshops were conducted. The event highlight was a most memorable dinner among the exhibits at the Worcester Art Museum.

At the Midyear Conference, Lulu Sun and Heidi M. Steinhauer, won the Media Showcase Award for their presentation of, "Using Multimedia Online Learning Tools to Supplement the Classroom Instruction." The Oppenheimer Award was won by Thomas Delahunty, Niall Seery, and Raymond Lynch for their presentation of, "Conceptualization in Visuospatial Reasoning Tasks: A Research Direction." In addition the Lulu Sun and Christopher Grant were selected as winners of the 2013 Chair's Award for their paper, "Inquiry-Guided Learning (IGL) in Graphical Communications Course." These papers are fine examples of the expanding scope of the Division, encompassing topics such as visual and learning science, as well as traditional

engineering graphics and practical classroom implementation. I'm looking forward to seeing many more such papers in the near future.

A handwritten signature in black ink, appearing to read 'D.K. Lieu'. The signature is fluid and cursive, with a large initial 'D' and 'L'.

Dennis K. Lieu  
2013-2014 EDGD Chair

## Message from the Editor

Robert A. Chin  
East Carolina University

In an attempt to streamline publication of the *Engineering Design Graphics Journal*, Carolyn Dunn, one of our associate editors, has produced a template for the submission of *Journal* manuscripts. Since it's based on the revised template developed years ago for the production of Mid-Year manuscripts, there should be minimal investment in the way of ramping up for those who've published Mid-Year papers. Never-the-less, we're certain there still will be glitches. Flip a few pages into this issue and examine the template. Feel free to offer suggestions for improvement. Sometime in the future, we'll be seeking input on best practices for submitting tables and other graphics electronically. The editing of tables and graphics can be some of the most time consuming part of manuscript editing.

The *Journal* continues to monitor detailed statistics about the Journal and its traffic and traffic sources with the aid of Google Analytics. GA tracks visitors from address of the webpage that linked to the resource being requested, including search engines and social networks, direct visits and referring sites, among other things.

So how's the *Journal* doing? Since Sep 2011, when we began collecting data, the *Journal* has been visited by almost 52,000 unique visitors. The number of visit during that time was over 60,000. Approximately 85.7% of the visits were new visits and approximately 14.3% were returning visitors. The top ten countries/territories from which visitors originated from most to least included the United States, India, United Kingdom, Philippines, Canada, Australia, Malaysia, unknown, Ireland, and Indonesia.

Of the feature articles viewed, including repeated views, the following were the top five most frequently viewed feature articles since the *Journal* began collecting data:

- Developing 3-D Spatial Visualization Skills by SheryIA. Sorby
- Drafting the Basics by Carol M. Lamb and David G. Kurtanich
- A Review of Spatial Ability Research by James L. Mohler
- Spatial Visualization Measurement: A Modification of the Purdue Spatial Visualization Test - Visualization of Rotations by Theodore J. Branoff
- Assembly Modeling by Vedaraman Sriraman

Please keep in mind that the longer an article has been posted, the greater the likelihood it will have been viewed.

As libraries continue inquiring about visitor traffic, we will attempt to respond.

## Introducing the New *EDGJ* Template

Carolyn Kusbit Dunn  
Associate Editor, *EDGJ*  
East Carolina University

As a technical writing instructor, I know both from the research and experience that when students are focused on a new way of writing, they often disregard items such as spelling and grammar. It's not that the students don't understand the grammar and spelling rules, it's just that they are focused on the content and writing style, and, well, until they become comfortable with the new genre, the nuts and bolts of their writing sometimes suffers. The same can be true for those of us who write for academic journals. We are so focused on the content (and we should be) that non-content related items such as font and font size, heading placement and margins often get overlooked.

When that happens, it becomes the job of the editors of a journal to rework the manuscript to suit the journal's style. There is always "tweaking" to do, even when a manuscript is submitted according to a journal's style guidelines. Graphics need to be moved sometimes, or text shifted – it happens. But when a manuscript is submitted in an entirely different font and with an entirely different layout, the editing takes longer and ultimately the time from submission to publication takes longer as well.

The newly unveiled style guide and manuscript template, that appear on the following pages, are meant to alleviate that. We have tried to make both easy to understand and use, and ask that you subscribe to the guidelines in future submissions. In the meantime, happy writing!

## **Instructions for Preparing a Manuscript for the *Engineering Design Graphics Journal***

Author Placeholder  
Institutional Placeholder

Author Placeholder  
Institutional Placeholder

### **Abstract**

An abstract is a condensation of the entire paper, stating its purpose, methodology, major results and conclusions. Readers look here to see if they wish to read the entire paper. Abstracts are frequently used to index the paper in an academic database. The abstract should be prepared with 10 point Arial. The EDGJ's papers should be formatted using the latest edition of the *Publication Manual of the American Psychological Association* (APA).

### **Introduction**

A uniform appearance for all published papers is important to project a professional image. Such a product will reflect well upon the authors, the *Journal*, and the Division. The entire manuscript must be camera ready. There will likely be no further editing of the manuscript once it is accepted for publication, so please be careful in preparing it. Errors in language and formatting, if not caught, will appear in the *Journal*, reflecting poorly upon the authors, the *Journal*, and the Division. Please have your manuscript proofed read and edited by someone who is completely fluent in English.

The manuscript is to be submitted on U.S. size A paper, which is also known as "letter" size. This paper is 8.5 inches wide and 11 inches long. The margins are to be 1 inch all around. Do not number the pages or use a header or footer, as these will be added during assembly of the issue.

**Text Formatting** [avoid widows or orphans by making use of page breaks]



The title and authors section appears in a single column format at the top of the first page. Placeholders have been provided for the author names and affiliation, which will be added once the paper has been accepted for publication. Lines in this section should be single-spaced. The text for the title and authors is to be centered within the column. The title of the paper is to be in bold, 12 point Arial. Only the first letter of each major word in the title is to be capitalized. Skip one line between the title and the authors. The names of the authors follow in 12 point Arial. On the line after the author's name, give the author's affiliation. Skip one line between each author of a different affiliation.

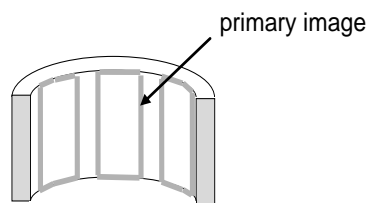
### **The Main Text**

The main text is to be one column wide and placed between the margins without indentations except where APA permits or requires. The font is to be 12 point Arial, single spaced between lines. Insert a blank line between paragraphs. Text alignment should be left justified.

Heading titles are to be a bold, 12 point Arial. The letter of each major word is to be capitalized. Level 1 (primary) headings should be centered and level 2 (secondary) headings should be left justified within the column. Do not number the heading titles. Each heading title is to be preceded by a blank line.

### **Figures, Tables, Graphs, and Equations**

Figures are to be numbered sequentially according to APA format. They should appear in the body of the paper. They may span all or part of the column. Drawings and lettering should clearly legible. Photographs need to be electronic and placed within the document. Because the Journal will be published electronically, the use of color in figures is permitted, and encouraged. Captions lines are to be single-spaced, centered and the font is to be bold, 10 point Arial font. A blank line should be inserted before and after the figure.

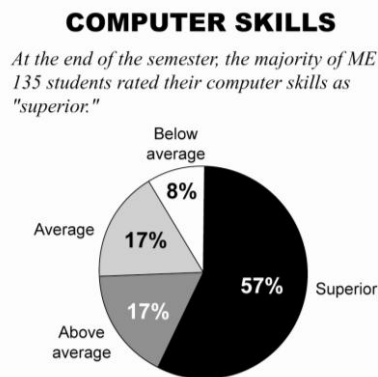


**Figure 1. This is an example of a figure.**

Equations are to be placed within the text and numbered sequentially. The identification numbers are to be placed in parentheses and right justified. A good equation editor in a word processor should be used to produce equations. If possible, equations should be confined to the width of a single column. A blank line should be inserted before and after the equation.

$$GOOD = \oint EXAMPLEdt \quad (1)$$

Tables and graphs should be placed within the paper if possible. They are to be numbered sequentially. Captions lines are to be single-spaced, centered, and the font is to be bold, 10 point Arial. Because the Journal will be published electronically, the use of color in tables and graphs is permitted, and encouraged. Do not place borders around graphs, figures, or tables.



**Figure 2. This is example of a graph.**

A blank line should be inserted both before and after the graph or table. Carefully edit all the numerals, spelling, and grammar. Ensure the story and the details in the table or graph match the details in text.

## Conclusions

The conclusions should be a summary of the major findings of the work, and recommendations for future work. Conclusions should not be a repeat of the abstract, nor should the abstract be a repeat of the conclusions.

## Citations

Citations should be noted by author and date within the context of the paper. Footnotes should not be used. The following paragraph shows examples of cited literature.

Edward Tufte (1983) published a milestone book *The Visual Display of Quantitative Information*, which showcased the weaknesses of the graphs of the 1970s and 1980s. A successful line graph allows the reader to understand the flow of the figures if it clearly shows the relationship of the point immediately before it and the one immediately following it (Miller, 1999).

## References

Cited literature is to be placed in a References section at the end of the manuscript. References should be in 10 point Arial. According to APA, authors are listed alphabetically, by the last name of the first author.

American Psychological Association. (20XX). *Publication manual of the American Psychological Association* (Xth ed.). Washington, DC: Author.

## Acknowledgements

Acknowledgements may be included to fulfill funding requirements or as a courtesy. As an example, the format for this template is based on the template used by the EDGD for the preparation of their Mid-Year papers.

## About the Author Placeholder

A very brief about-the-author statement along with contact information will be added in 10 point Arial during assembly of the issue.

John Doe is an associate professor and program chair of engineering technology in the College of Technology, ABC University. Her areas of expertise include sustainable design and alternative energy. Dr Doe is also an Adjunct Associate Professor in pedagogy at XYZ University.  
Email: [doej@xyz.edu](mailto:doej@xyz.edu)

## EDGD Calendar of Events

### Future ASEE Engineering Design Graphics Division Mid-Year Conferences

69th Mid-Year Conference – October 12-14, 2014, Illinois State University.  
Site Chair - Kevin Devine.

70th Midyear Conference – January 24-26, 2016, Embry-Riddle Aeronautical University.  
Site Chairs - Heidi Steinhauer and Lulu Sun.

### Future ASEE Annual Conferences

<b>Year</b>	<b>Dates</b>	<b>Location</b>	<b>Program Chair</b>
2014	June 15 - 18	Indianapolis, Indiana	Frank Croft
2015	June 14 - 17	Seattle, Washington	Ron Paré
2016	June 26 - 29	New Orleans, Louisiana	
2017	June 25 - 28	Columbus, Ohio	
2018	June 24 - 27	Salt Lake City, Utah	
2019	June 16 - 19	Tampa, Florida	
2020	June 21 - 24	Montréal, Québec, Canada	

If you're interested in serving as the Division's program chair for any of the future ASEE annual conferences, please make your interest known.

## The Distinguished Service Award

The 2013 Distinguished Service Award (DSA) recipient is Kathryn Holliday-Darr of Penn State Behrend. The DSA is the highest award of merit given by the Engineering Design Graphics Division. It recognizes the significant contributions of the recipient to the Division in terms of leadership, authorship, or support.

The awardee is recognized with a framed citation or plaque, which is presented by the Division Chair or their delegate at the Annual Conference Awards Banquet. Following the presentation, the recipient may address those assembled.

The award description can be found at:  
<http://edgd.asee.org/awards/dsa/index.htm>

A complete list of awardees can be found at  
<http://edgd.asee.org/awards/dsa/awardees.htm>

[1] Engineering Design Graphics Division Chair, Nancy Study, (r) introducing the 2013 DSA recipient, Kathryn Holliday-Darr (l).

[2] Holliday-Darr delivering her DSA acceptance remarks.

Photos by *Theodore Branoff*



[1]



[2]

**Kathryn Holliday-Darr's DSA Acceptance Remarks  
ASEE Annual Conference  
Atlanta, GA, June 23-26, 2013**

After I met Tim, he took every opportunity to introduce me to other members of the Division and sponsors, championing me so that I could become actively involved in EDGD, and guiding me with the Do's and Don'ts while I was chair. I can't tell you how many times he said: "Kathy, you can't do that, it's not in the by-laws." So, it only seemed right to ask Tim if he would introduce me one more time. Thank you, Tim!

I thank you, the members of the Division, from the bottom of my heart for honoring me with this Award – what a wonderful way to wrap up a career! When Pat Connolly notified me that I was this year's recipient, I immediately texted my husband John. Since he was so excited for me, he brought home a bottle of champagne to celebrate. I thanked him and told him that without his help and support I would never have accomplished as much as I had in my career. He responded with, "Yes, you would have." I answered, "Maybe so; but, it would have been a much longer and much harder road without you."

John always found ways to support me – whether it was the dinners that would magically appear at my computer and dirty plates that would disappear while I was writing my textbook; his struggling to stay awake while he proofed chapters of my textbook (I still can't believe he found descriptive geometry boring...); bringing drawings and 'parts' home from work to share with my students; pulling over on the side of the road to take pictures of cool real life 'things' that needed descriptive geometry in order to be made; or picking up the slack at home when I was Division chair. In 2009 he really stepped up to the plate by being my right hand man during the EDGD conference we hosted at Penn State Behrend. Thank you, John, for always being there!

As most of you know, I retired last summer (Which I'm sure, Nancy Study is really grateful for!) The other day Alice Scales and I were emailing back and forth about how hard it was to clean out our offices. My thoughts had been: "Wow, I busted my butt for 34 years and at the end of the day – it all goes in the dumpster!" I was questioning myself. I wasn't on tenure track - why did I work so many hours to the exclusion of other areas of my life? Was it worth it? Between writing this speech and emailing Alice, I finally have my answer. While I would strive to do a better job of balancing home and work, I would not change the opportunity to touch young lives and experience the richness the Division has given me professionally and the wonderful friendships that have been forged – need I say more? (Okay, how about 'the great conviviality'!)

As I was reading past acceptance speeches I was touched, and by touched I mean tears in my eyes, by the heartfelt recurring words. Treasured lifelong friendships, going

home from conferences with new ideas and approaches to teaching, and how past winners, giants in our field, did not feel worthy of the DSA.

How did an Industrial Arts high school teacher make it on this list? Especially one that after her first year of teaching in Montana, swore she would never walk into another classroom again. God must have laughed at that one, because two months later, as a favor to the superintendent, I was teaching in my hometown high school without ever having to complete an application form. Six years later, I was so mad at a different superintendent that I called the local university to see if there were any job openings!

My first Penn State boss, Al Pulsifer, knew the value of attending ASEE conferences. He encouraged new faculty to attend the annual conferences years before the Dean's program was started. I attended my first Annual ASEE conference in 1986 in Cincinnati. My first mid-year was in Louisville in 1987. Feeling very out of my element presenting, I decided to do my first presentation in 1988 at the 3rd International Conference on Engineering Graphics and Descriptive Geometry in Austria, where I would probably never see any members of the audience again (plus, who could pass up an all-expense paid trip to Europe!). I'm happy to say, I didn't die of fright and no one boo'ed.

These three events were the most important steps at the beginning of my career. I fell in love with EDGD. The mid-year meeting was my favorite. No distractions, I was able to attend all of the graphics sessions, and the camaraderie was great! It was a time of change for the Graphics world. My first CAD software was home grown and ran on Apple IIe's. Soon we ordered Zennith's, with 10 mb hard drives (with us exclaiming, "Who could possibly ever fill up such a huge hard drive?") Remember the mid-year meetings, where the debates between CADKEY and AutoDESK software were fierce! Solid modeling software becoming affordable and easier to use, which moved the 'discussions' on to whether we should still teach descriptive geometry. I loved it! I would come back from the conferences rejuvenated with tons of ideas to try. In fact, the changes I implemented into a first year course, which resulted in being awarded the Penn State's Provost's Award for Collaborative Instruction and Curricula Innovation, were sparked from a paper presented by Roland Jenison on reverse engineering. I cannot tell you how much I enjoyed the mid-year meetings!

But, believe it or not, I was shy! (I know – hard to believe I was too intimidated to open my mouth!) I would attend the sessions, and then run back to my room to work on school work. I wanted to be involved, but I didn't know how to get involved – which is why I believe so strongly in the Mentor's Program. In the early 2000's, about the same time I met Tim, I had the opportunity to really talk to Frank Croft. He also strongly encouraged me to get involved, and helped champion me. Then I was awarded the Oppenheimer Award and two things happened. First, my confidence level sky rocketed! And, second, I met Mary Sadowski and Sheryl Sorby, whose mission became to assign me to a committee.

These four people were my mentors - thank you for believing in me. There are many others of you who directly or indirectly also helped make me look good – thank you to Bob, Judy, Alice, Jon, Merwin, Clyde, Fritz, Holly, Mike, Norma, AJ, Nick, Kevin, Aaron, Ted, La Verne, Larry, Nancy, Ron, Pat and Dennis! In addition, I would like to acknowledge my past bosses, Richard Progelhof, Ken Fisher, Ralph Ford, Dave Johnson and Bob Simoneau for supporting my trips financially whether I had a paper to present or not. Serving the Division has truly been a labor of love and doesn't even begin to repay what I gained! It is the members that make this Division what it is. If you are not involved, please get involved – it will be worth your time!

I believe the 1974 DSA recipient, Irwin Wladaver, said it best: "...when you have deemed the little I have done worthy of your DSA, ... I humbly thank you and I accept this great honor as though I deserved it, quickly, lest you change your minds."



## The Editor's Award

The 2012 Editor's Award awardees are Theodore J. Branoff of North Carolina State University and Modris Dobelis of Riga Technical University for their paper entitled The Relationship between Spatial Visualization Ability and Students' Ability to Model 3D Objects from Engineering Assembly Drawings. Their paper was published in volume 76, number 3 of the Journal and can be found at:  
<http://www.edgj.org/index.php/EDGJ/article/viewFile/319/240>



Editor's Award recipient, Ted Branoff (r), accepting his framed citation from the EDGJ editor, Robert Chin (l).

The Editor's Award was established to recognize the outstanding paper published in the previous volume of the Engineering Design Graphics Journal. The recognition includes a framed citation and a cash award and is presented during the following Annual Conference.

The award description can be found at <http://edgd.asee.org/awards/editors/index.htm>

A complete list of awardees list can be found at <http://edgd.asee.org/awards/editors/awardees.htm>

## **A Graphics Design Framework to Visualize Multi-dimensional Economic Datasets**

Magesh Chandramouli  
Purdue University Calumet

Badri Narayanan  
Purdue University

Gary R Bertoline  
Purdue University

### **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

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

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 acquisition 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

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.

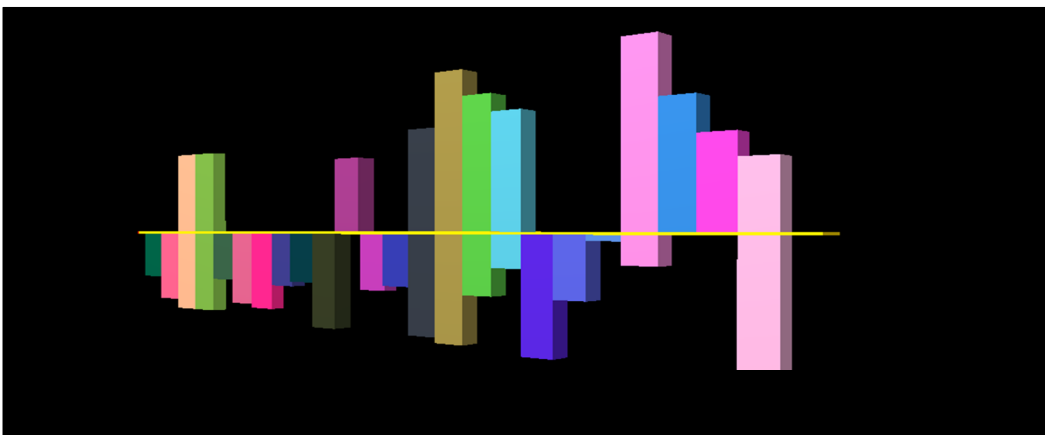


Figure 1. Alternative Representation to Accommodate Additional Dimension.

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.

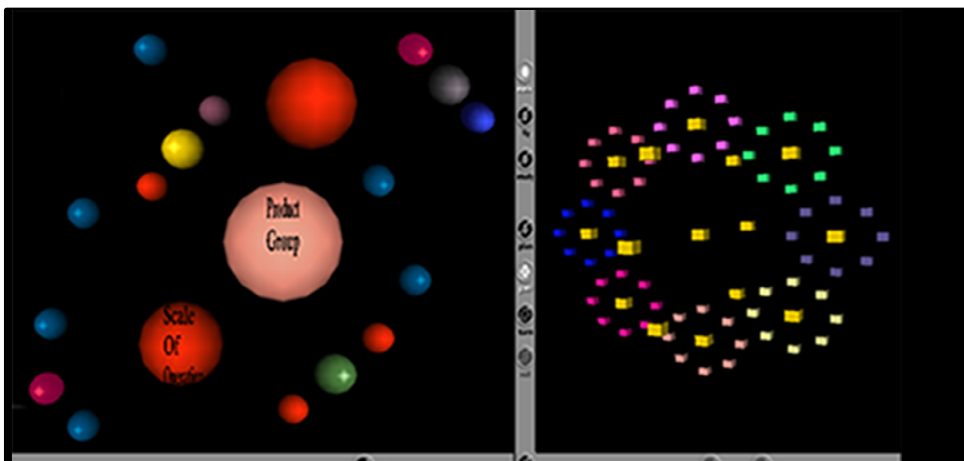


Figure 2. Interactive Virtual Worlds Representing Multidimensional Economic Datasets.

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

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

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 Programming'. 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).

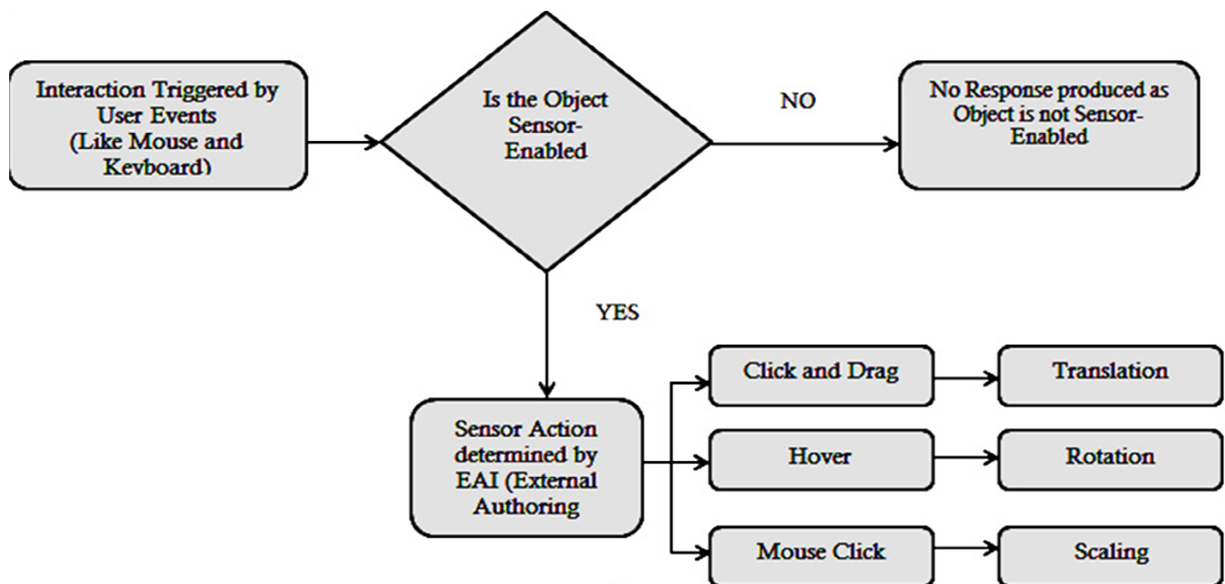


Figure 3. User Interaction via 'Sensor-Enabled Graphic Objects' within Virtual Environments.



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.

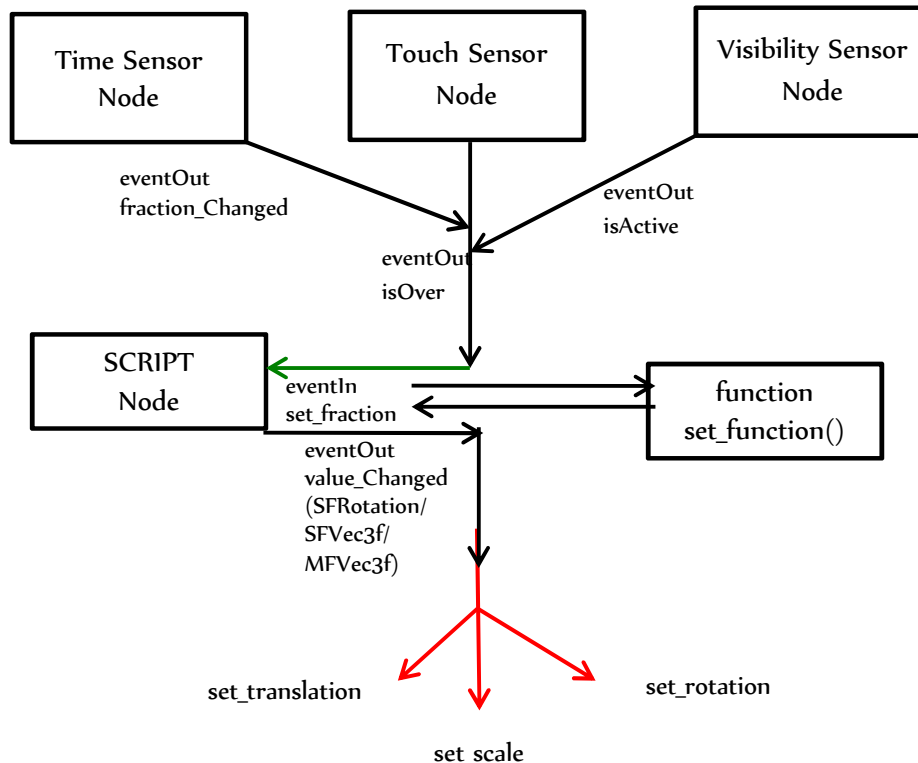


Figure 4. Event-flow within the External Authoring Interface for Enabling Interaction within the Virtual World.

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

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.

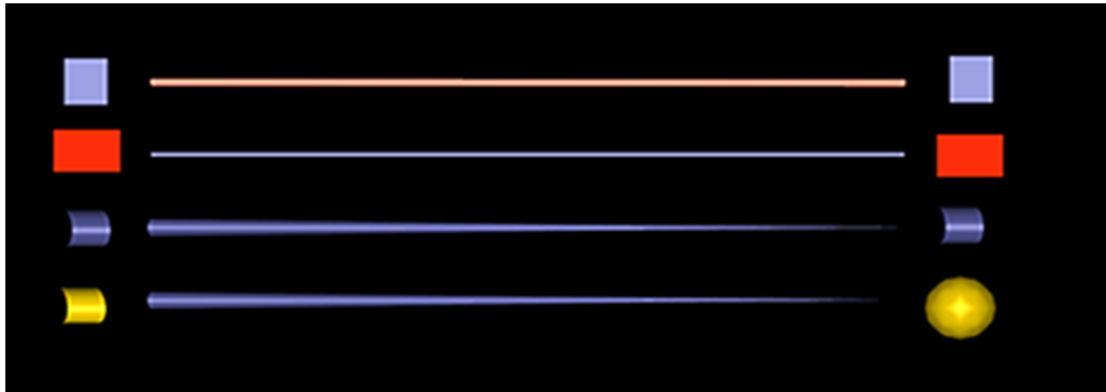


Figure 5. Representing Correlations (Relationships) Using Alternative Line Geometry & Entity Combinations (Color, Style, Thickness).

## 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 correspond 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

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

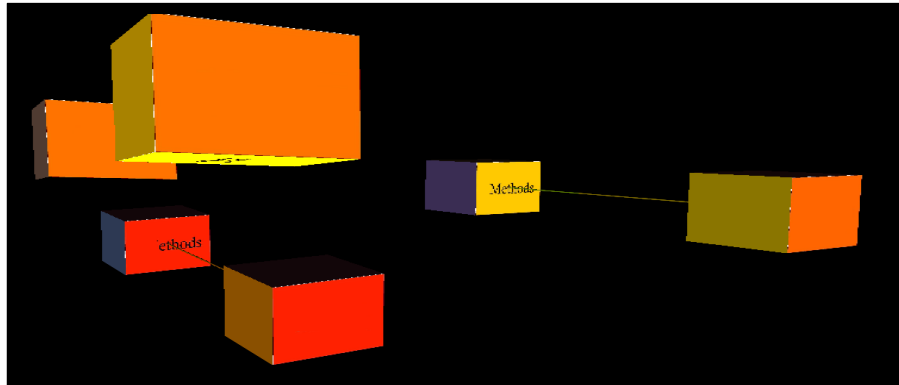


Figure 6. Representation 1: Commodity-Wise Components of Global Bilateral Trade (BT).

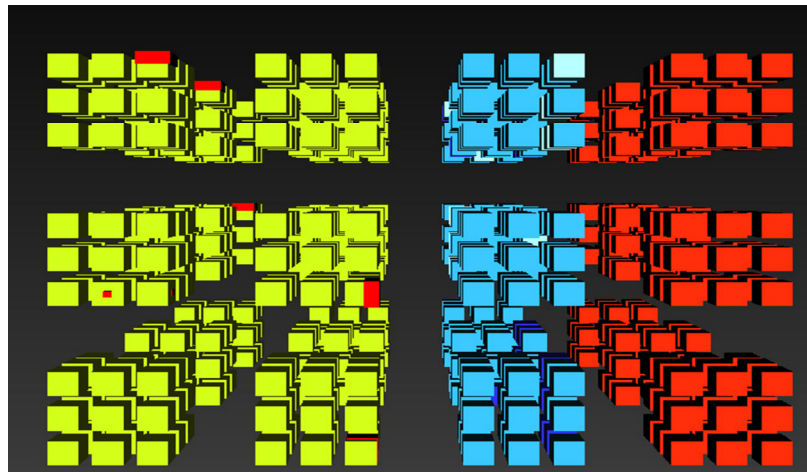


Figure 7. Representation-2: Commodity-wise/Country-pair-wise BT Flow.

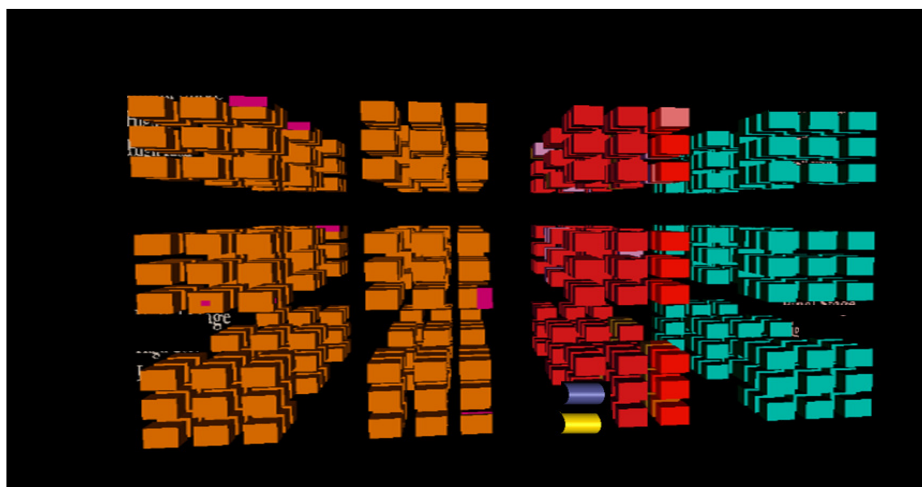


Figure 8. Interface with Filters Activated to enable Multi-Criteria Sorting.

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

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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## Visualizing Compound Rotations with Virtual Reality

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### Abstract

Mental rotations are among the most difficult of all spatial tasks to perform, and even those with high levels of spatial ability can struggle to visualize the result of compound rotations. This pilot study investigates the use of the virtual reality-based Rotation Tool, created using the Virtual Reality Modeling Language (VRML) together with MATLAB and the Simulink 3D Animation Toolbox, to assist engineering students in the visualization of compound rotations made about both fixed and mobile reference frames. This tool allows students to verify the non-commutative nature of compound rotations, as well as the relationship between fixed and mobile frame rotations. The effectiveness of the Rotation Tool is evidenced by the improved ability of students to work through questions pertaining to compound rotations, as well as their increased confidence when doing so.

### Introduction

In mechanically-complex engineering courses, such as those specializing in robotics and mechatronics, it is imperative that students be able to accurately visualize three-dimensional (3D) objects, both as a sum of interconnected parts and as a whole. Moreover, students must also be able to visualize the motion of these objects in 3D space. These tasks require students to conduct complex geometric transformations consisting of translations and compound rotations. Although students typically demonstrate little difficulty visualizing the effect of linear translations, it has been observed that some have more difficulty visualizing the effect of compound rotations. In fact, of the three categories of spatial ability identified by Linn and Peterson, students have repeatedly demonstrated the largest discrepancy in their ability to perform mental rotations (Linn & Petersen, 1985), with rotations about multiple axes among the most difficult types of rotations to visualize (Onyancha, Derov, & Kinsey, 2009).

Traditionally, isometric drawings have been used as compound rotation visualization aids, depicting the starting, intermediate, and final orientations of a rotated object. They are often used in lecture notes and textbooks to demonstrate the non-commutative nature of compound rotations, as well as the difference between rotations made about a fixed frame of orthonormal axes and those made about a mobile frame that rotates with the object. Such static drawings encourage an analytic approach to breaking down compound rotations (Bruder & Wedeward, 2007), but assume that students can envision the correct motion associated with each step. In addition, examples must be



chosen carefully to avoid the interpretation of the isometric views as two-dimensional (2D) patterns instead of the intended 3D representation (Branoff, 2000).

Animated presentations can depict the action of the rotation more clearly than static images, but still make students passive observers rather than active participants. Sketching employs a more active approach and can be beneficial in developing weak spatial abilities (Sorby, 1999), but generally involves drawing isometric views on 2D media that instructors must manually verify. Rotating physical manipulatives allows for a true visualization in 3D space, but has limited accuracy when demonstrating rotation angles that are not integer multiples of  $\pi/2$ . It has also been argued that students rotate physical manipulatives instinctively and too quickly to encourage proper examination of the motion (Gutiérrez, 1996). Instead, a software visualization aid that places limitations on the rotations is advocated to encourage students to predict the outcome of the motion and force a deeper analysis.

Virtual reality, with its interactive capabilities and its accurate 3D depictions, can be incorporated into a rotation visualization tool that does just that. Such a software tool will also be able to automatically verify results, providing students with immediate feedback and the ability to use the tool outside of the classroom. This paper investigates the use of such a virtual reality-based tool, the Rotation Tool, to aid students with the visualization of compound rotations in 3D, allowing them to gain deeper insight into the principles of compound rotations than is generally achieved with traditional teaching techniques alone. In the sections that follow, a review of existing rotation visualization software is provided, followed by a detailed description of the Rotation Tool. The methodology used in this study is then outlined, and the effectiveness of the tool is analyzed by examining student test results and survey feedback.

## Literature Review

The importance of strong spatial skills - including mental rotation skills - in the areas of science, technology, engineering, and mathematics has long been argued (Wai, Lubinski, & Benbow, 2009), garnering the attention of engineering educators hoping to improve student performance and retention with targeted spatial training (Sorby, 2009). Sorby and her colleagues have conducted extensive research in the field (Sorby, 2009; Sorby, Casey, Veurink, & Dulaney, 2013), developing and using multimedia software and a workbook (Sorby & Wysocki, 2003) to train students in multiple aspects of spatial ability. Visualizing single and multiple rotations about a fixed frame are among the topics considered, and the non-commutative nature of compound rotations is emphasized. The modules developed by Sorby and Wysocki, along with a separate spatial assessment and training website (Blasko, Holliday-Darr, Mace, & Blasko-Drabik, 2004), have been successfully incorporated into training courses at multiple institutions (Veurink et al., 2009). Sorby (2011) cautions against using these modules with an audience of mixed spatial abilities, however, as they are intended to target those with weak spatial skills.

Other examples of targeted mental rotation training include the exercises on single rotations developed for handheld touch screen devices by Martin-Dorta, Saorin, and Contero (2011). Rafi and Samsudin (2009) consider compound rotations with their interactive Desktop Mental Rotation Trainer (iDeMRT), prompting students to choose the set of consecutive rotations that will result in the overall change in orientation displayed. The interactive version of iDeMRT was found to be more effective than the animated version (Samsudin, Rafi, & Hanif, 2011), demonstrating the importance of active participation. Display Object (Hsi, Linn, & Bell, 1997) and the Physical Model Rotator (Kinsey, Towle, & Onyancha, 2008) pair the rotation of concrete objects with rotating computer images, allowing students to associate the motion seen on the screen with the corresponding real-world motion.

Wang, Yeh, Wang, Yang, and Rizzo (2011) use stereoscopic technology to help students visualize 3D rotations, finding that incorporating interactive control generates higher levels of student enthusiasm than more passive displays. Price and Lee (2010) also use stereoscopic technology to display rotations in 3D, finding that interpreting such displays increases the cognitive load of students compared to the visualization of rotations displayed on paper. Such findings underscore the importance of using new technology effectively, rather than relying on the technology itself to be the answer.

Desktop virtual reality tools capable of demonstrating important compound rotation principles include VRMath, a virtual learning environment that Yeh (2010) uses to demonstrate the non-commutative nature of compound rotations to disbelieving primary school students. Manseur includes two virtual reality-based tools with his textbook (Manseur, 2006) that demonstrate the motion of fixed and mobile frame rotations separately, each about a different set of non-configurable rotation axes. Bruder and Wedeward's (2007) virtual reality rotation tool, on the other hand, compares the fixed and mobile frame rotations that result from the same set of three user-defined rotation angles and axes.

### **Rotation Tool**

In order to break down the yaw-pitch-roll motion of a robot wrist, as shown in Figure 1a, or keep track of the effects of joint angles and link twists when considering the kinematics of a robot arm, as exemplified in Figure 1b, students must have more than strong visualization skills. They must also possess a solid understanding of the fundamental principles of compound rotations. The Rotation Tool, described below, allows students to explore these fundamental principles before having to apply them to such mechanically-complex examples.

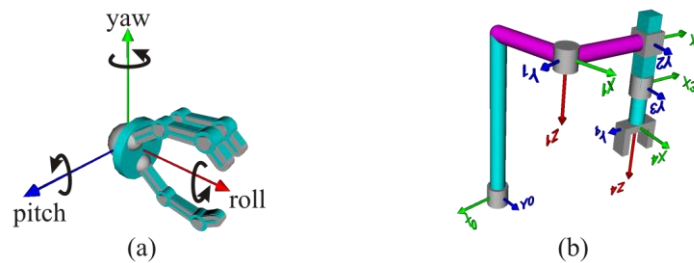


Figure 1. Examples of compound rotations in robotics. (a) The motion of a robot gripper with a spherical wrist can be broken down into compound rotations made about three orthogonal axes. (b) A link-coordinate representation of a SCARA robot arm with four degrees of freedom (DOF). Each DOF has two rotations associated with it, resulting in eight compound rotations to be considered for this relatively simple robot arm.

### Tool Description

The Rotation Tool is an interactive educational tool that consists of a custom MATLAB graphical user interface (GUI) and a virtual reality window, as shown in Figure 2. Students use the GUI to enter up to three consecutive rotations about both the fixed and mobile reference frames, with complete freedom in their choice of rotation angles and axes. The GUI is designed to provide separate control of rotations made about the fixed and mobile frames, allowing students to verify the conditions that will lead to different and matching final orientations when making the two types of rotations, as exemplified in Figures 2b and 2c.

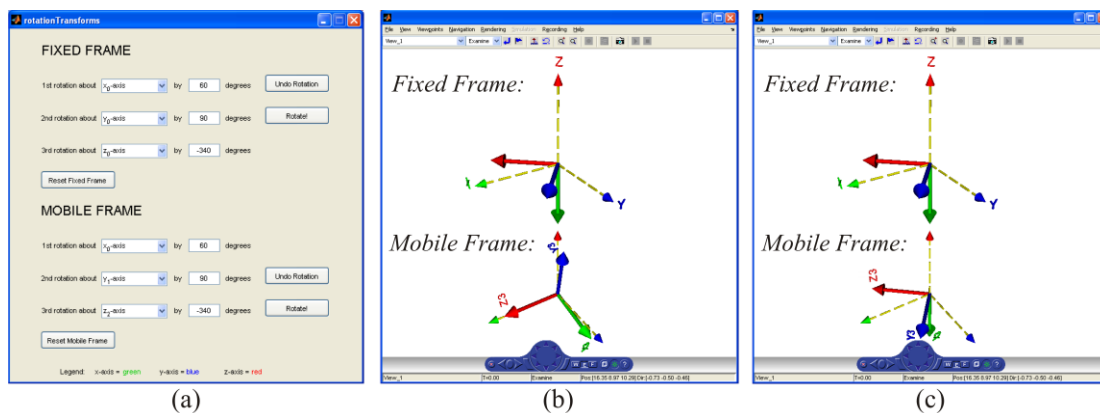


Figure 2. Rotation tool. (a) GUI showing values for three consecutive rotations around fixed and mobile frames, after the first fixed frame rotation and the first and second mobile frame rotations have been executed. (b) Virtual reality window showing final orientations based on the data entered in a). (c) Virtual reality window showing identical final orientations for both frame types when the order of the mobile rotations in a) is reversed. The comparison of the mobile frame orientations in b) and c) demonstrates the non-commutative nature of compound rotations.

The 3D animation of each rotation in the virtual world is initiated by pressing the “Rotate!” buttons on the GUI, giving students complete, real-time control of the visualization. Undo options are also available to allow students to step back and forth between orientations, as needed, to gain a clear understanding of the rotation action. To preserve the order of the rotations, only the relevant rotation and undo buttons are enabled at any time. This built-in software constraint also serves as a way to encourage deeper analysis and understanding of the effect of each rotation on the overall orientation. Each frame can be reset at any time, and a new set of rotations can be entered and visualized.

Every effort has been made to ensure that the Rotation Tool is a user-friendly and engaging learning tool. It was designed with features intended to offset the increased cognitive load demands that virtual reality-based tools can place on students, and it incorporates feedback from students who used the tool prior to this study. For example, visual cues normally present in the virtual world’s background (removed in Figure 2 for clearer printing) allow students to navigate the virtual world with ease, enabling them to change their viewpoint when occlusion occurs and gain a real sense of the 3D space being represented. The inclusion of both rotation frame types in the same virtual window guarantees that they are viewed from the same perspective, ensuring an accurate comparison of resulting orientations. Simple 3D graphics are used to represent the rotating frames, placing the focus on the rotations themselves, rather than on the visualization of geometrically-complex rotation objects. Similarly, a simple color scheme and clear axis labels ensure that minimal mental effort is required to correctly interpret the scene. Finally, smooth, animated transitions between initial and final orientations give students an unambiguous sense of the motion associated with each rotation.

### **Technical Considerations**

The Rotation Tool’s virtual world is defined by a Virtual Reality Modeling Language (VRML) (International Standard, 1997) file, and is controlled by MATLAB via the Simulink 3D Animation Toolbox. Although many programming languages can be used to interface with VRML, MATLAB was chosen because of students’ existing familiarity with its environment from use in prerequisite courses and its proficiency in performing matrix multiplications. Within the MATLAB program, rotation matrices are used instead of other rotation representations, such as quaternions, to make the underlying code readable for students and to reinforce the mathematical difference between fixed and mobile rotations that is taught in the lectures. The resultant rotation matrices must be converted to their equivalent axis-angle representations in order to be displayed in VRML, and Paul’s (1981) approach is used to avoid singularities when the net rotation angle is an integer multiple of  $\pi$ . In the case of no net rotation, the rotation axis is arbitrarily set to (1, 0, 0) to ensure that the VRML rotation axis remains well defined at all times.

## Methodology

There are two robotics courses offered by the Department of Electrical and Electronic Engineering at the authors' university: "Mechatronics and Industrial Automation" offered to fourth year Electrical Engineering undergraduates, and "Mechatronics and Robotics" offered to students in the taught Masters in Mechanical Engineering program. Although these are separate courses, the classes were combined for the lectures on compound rotations.

### Before the Rotation Lectures

To avoid making assumptions regarding students' spatial abilities and pre-existing knowledge of compound rotations, the students were given an Initial Rotation Knowledge Assessment (IRKA) before attending any lectures on rotations. The IRKA contained eight questions to test students' mental rotation skills, carefully chosen from the rotation section of the Purdue Spatial Visualization Test (PSVT:R) (Guay, 1976). As summarized in Table 1, these eight questions included both positive and negative rotations about single and double axes. They also encompassed all of the geometries identified by Onyancha et al. (2009), and special care was taken to correct any errors present in the original questions (Yue, 2007). Although a number of standardized mental rotation tests exist (Ekstrom, French, Harman, & Dermen, 1976; Gittler & Glück, 1998; Vandenberg & Kuse, 1978), the PSVT:R questions were chosen as the most appropriate because they do not contain impossible rotations or questions that rely on pattern recognition.

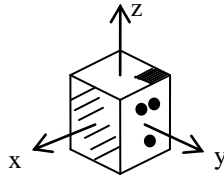
Table 1. Subset of Questions Selected from PSVT:R for IRKA

Number of Questions	Rotation Type	Rotation Angle
2	Single	$\pm \pi/2$
2	Single	$\pi$
2	Double	$\pm \pi/2$
2	Double	$\pm \pi/2, \pi$

The IRKA also contained a question to test the students' knowledge of the non-commutative nature of compound rotations, shown in Figure 3. The term "non-commutative" was strictly avoided in the question because the students may have been taught the terminology in the past without really understanding it. A cube with a regular geometry and uniquely patterned faces was used to simplify the visualization, in order to ensure that the focus remained on determining the non-commutative property of compound rotations. Rotation angles of  $\pi/4$  made sketching the intermediate and final orientations difficult, forcing students to answer based on their existing knowledge or intuitive beliefs.

**True or False?**

You are given a cube (with 6 different faces) centered on the orthogonal frame  $\{x, y, z\}$ :



Rotating the cube 45 degrees about the z-axis, followed by a rotation of 45 degrees about the y-axis gives a **different** final orientation than rotating the cube 45 degrees about the y-axis, followed by a rotation of 45 degrees about the z-axis.

Figure 3. Non-commutative question on the IRKA.

Students were given approximately 15 minutes to complete the IRKA, after being told that participation was voluntary and would have no impact on their marks for the course. It was determined that this time interval would remove the time pressure normally associated with the PSVT:R, and allow students to solve the visualization questions either holistically or analytically, as suited their preference and visualization abilities. To avoid influencing the students' choice of strategy, coordinate axes were not added to the PSVT:R questions (Branoff, 1998); however, students were allowed to add their own axes or make sketches directly on the IRKA, if desired. Students were also encouraged to provide feedback at the end of the IRKA in the form of open comments.

### Tutorial After the Rotation Lectures

After the relevant material on rotations had been covered in the traditional lecture format, the students were invited to attend a voluntary tutorial in the computer lab that would use a virtual reality-based tool to reinforce the topics covered in class. The tutorial was held during regularly scheduled class time so as not to interfere with the students' schedules. The students were again assured that participating would have no impact on their grades for the course.

The tutorial was formatted to follow a time-interrupted series method of evaluation appropriate for small populations, and consisted of a pre-test, treatment, and a post-test. In this case, the treatment was the use of the Rotation Tool to complete a worksheet. It was hypothesized that the students would have a better understanding of the fundamental principles of compound rotations after the treatment, as measured by the pre- and post-tests. It was further expected that the treatment would increase the students' confidence in their ability to understand fundamental compound rotation principles, as measured by survey feedback.

**Pre-Test.** The pre-test was designed to determine the students' level of understanding after being taught about compound rotations in a traditional lecture setting. Rather than

testing students' abilities to perform mental rotations, as was already tested in the IRKA, this test was designed to focus on how well they could apply the fundamental principles of compound rotations. The first page contained detailed instructions on how to complete the test, along with two examples to ensure that there was no ambiguity or confusion over nomenclature or what was being asked. This was followed by six questions on the visualization of compound rotations and the application of their principles, as summarized in Table 2, as well as one Likert-style survey question asking students to rate their understanding of the difference between fixed and mobile frame rotations based on what they had learned in the lectures.

Table 2. Pre-Test Questions

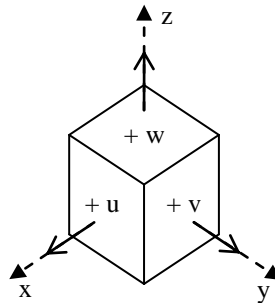
Question	Task required
1	Visualize double rotation about fixed frame.
2	Apply knowledge of non-commutative nature of compound rotations.
3	Apply knowledge of relationship between fixed and mobile frame rotations.
4	Visualize triple rotation about mobile frame.
5	Apply knowledge of non-commutative nature of compound rotations.
6	Apply knowledge of relationship between fixed and mobile frame rotations.

The visualization questions involved the rotation of a cube by  $\pm \pi/2$  or  $\pi$ , about either a fixed frame or a mobile frame, as illustrated in Figure 4. A cube was selected as the rotation object to simplify the visualization task, concentrating instead on testing each student's ability to make rotations about the specified frame type and to correctly apply the right-hand rule. Each pre-test question was designed to build on the previous question, thereby also minimizing the visualization effort required. For example, Questions 2 and 3 are simply permutations of the rotations done in Question 1, and do not require students to visualize the rotations if they understand the underlying compound rotation principles. Similarly, the visualization required in Question 4 is actually just one rotation added to the result of Question 1, and Questions 5 and 6 are permutations of Question 4. All of the questions that did not specifically require visualization included a choice of "Don't know" as an answer to discourage students from simply guessing.

The students were given approximately 20 minutes to complete the pre-test, an adequate amount of time for students who realized the relationship between the questions and had a good understanding of the underlying theory.

**Treatment.** Once the pre-tests were collected, a brief demonstration of the main features of the Rotation Tool was given. During this demonstration, two examples were completed that emphasized the main principles of compound rotations. Detailed written instructions on the Rotation Tool's use and main features, as well as the examples covered in the demonstration, were provided during the tutorial. They were also made available online to all students registered in the course, for easy reference throughout the term.

You are given a cube with an attached orthogonal *mobile* frame  $\{u, v, w\}$ , where each face of the cube is labelled according to its corresponding mobile axis. This cube is centered on the orthogonal *fixed* frame  $\{x, y, z\}$  so that the two frames coincide initially, as shown:



If you rotate the cube from its initial position by  $-90^\circ$  about the fixed **x-axis**, and then  $90^\circ$  about the fixed **z-axis**, what is the final orientation?

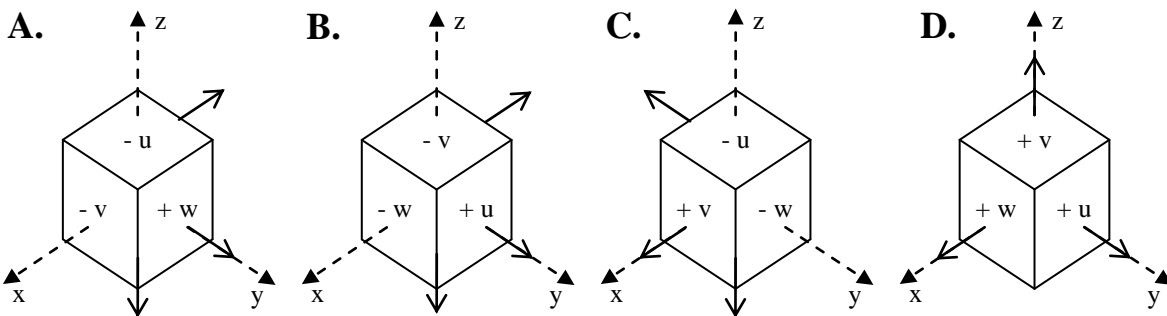


Figure 4. Question 1 from the pre-test. The incorrect solutions include the results of rotations made about the wrong rotation frame type and/or in the wrong direction.

After the demonstration, the students were asked to use the Rotation Tool to complete a worksheet, encouraging the students to explore the capabilities of the Rotation Tool with purpose. The students used the Rotation Tool to visualize different sets of compound rotations made about both fixed and mobile frames, and identified which conditions yielded the same, or different, final orientations. They were then asked to generalize their findings, thereby deriving the universal principles of compound rotations.

The students were given approximately 20 minutes to complete the worksheet using the Rotation Tool, either on their own or in pairs. They were encouraged to discuss results with each other and ask questions of the instructors as needed.

**Post-Test.** The general format of the post-test matched that of the pre-test, with six multiple choice questions testing the students' abilities to visualize different sets of compound rotations and their understanding of the compound rotation principles. A survey consisting of five Likert-style questions and two open comment questions was



also included. The students were given approximately 20 minutes to complete the survey and post-test without the aid of the Rotation Tool.

## Results and Discussion

### Before the Rotation Lectures

A total of 28 students completed the IRKA. The percentage of students who correctly answered each question is shown in Figure 5.

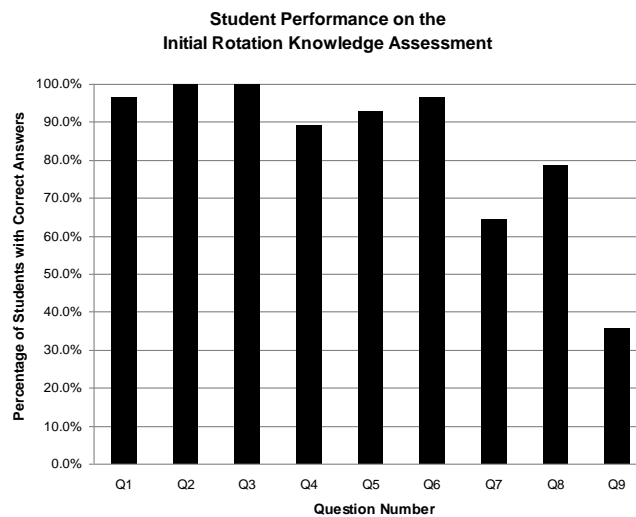


Figure 5. The breakdown of correct answers on the IRKA, where Q1-Q8 are the PSVT:R questions outlined in Table 2, and Q9 is on the non-commutative nature of compound rotations.

**Mental Rotation Skills.** The mean score for the subset of PSVT:R questions was 89.7%, with a standard deviation of 10.8%. Although a direct comparison with previous studies using the same subset of questions is not possible, such a high score clearly demonstrates that the students entered the course with high spatial skills and a good ability to perform mental rotations. Therefore, poor spatial abilities can be definitively ruled out in this study as a contributing factor to students' difficulties in visualizing the result of compound rotations.

As Figure 5 shows, Questions 7 and 8 each received a lower percentage of correct responses than all of the other PSVT:R questions. This indicates that double rotations with rotation angles of  $\pm \pi/2$  and  $\pi$  are the most difficult rotation types on the PSVT:R for students to perform, consistent with the findings of Onyancha et al. (2009). In turn, this suggests that regardless of a student's ability to perform mental rotations, compound rotations become increasingly more difficult to visualize as the number of rotations and unique rotation angles increase. This could be because of increased spatial memory requirements. Regardless of the underlying reason, a visualization tool

like the Rotation Tool will remove the ambiguity and difficulty in visualizing the orientation, allowing students to focus on examining the underlying compound rotation principles.

It should be noted that no distinction is made between the performance of female and male students on the PSVT:R questions, as is done in other studies. The small class size and small percentage of female students, typical of many high-level engineering courses, made such a distinction impractical. However, the large discrepancy in scores seen in other studies was not present in this study. This could be because the group of students tested here was well advanced in their engineering studies and either had naturally strong spatial abilities that enabled them to remain in engineering, or had developed them during their studies. It could also be because a subset of the PSVT:R questions was used, and measures were taken to remove biases favouring holistic strategies over analytic ones.

**Non-commutative Nature of Rotations.** Contrary to the high performance on the PSVT:R questions, only 35.7% of students answered the question on the non-commutative nature of compound rotations correctly. Such a low percentage indicates that the intuitive belief that rotations are commutative held by primary students (Yeh, 2010) persists into higher levels of learning. Although assumed to be a straightforward fact to teach students, this could be a significant contribution to students' inability to effectively visualize compound rotations and understand their underlying principles.

**Student Feedback.** Seven out of the 28 participating students chose to leave comments at the end of the IRKA. Most seemed to enjoy working through the IRKA, leaving comments along the lines of, "that was fun," and a couple of students commented on the increasing difficulty of the questions as the test went on. One student did comment specifically on having difficulty visualizing the 3D shape in Question 8, stating that the "shape can be interpreted in different ways." Although questions were carefully selected in an effort to avoid these types of problems, this does highlight the difficulty of visualizing 3D shapes from isometric drawings on a 2D medium.

One student "didn't really understand [the] last question [Q9]" and thought that a "sample would help." Although all 28 students answered the question and only one student commented on the difficulty of it, it is possible that other students also found the change in format for the last question confusing. On closer examination of the returned IRKAs, it was found that nine students made deliberate marks on their paper, indicating a good understanding of what the question asked. Of these nine, only 33.3% answered the question correctly. This corresponds closely with the overall percentage of students who answered the question correctly. Thus, despite any possible confusion with the change in question format, it can be confidently concluded that the majority of the students did not understand that rotations are non-commutative.

## Tutorial After the Rotation Lectures

During the tutorial, the students were asked to return three items: the pre-test, the worksheet, and the post-test. Of the documents that were returned, 21 complete sets could be matched up based on anonymous student identification numbers. The results for these 21 students are reported below.

**Worksheet.** In general, the students used the Rotation Tool to complete the worksheet without difficulty. There were very few questions asked of the instructors, and all students were observed to be eager to try the tool out for themselves, even those who were working in small groups.

Overall, students performed very well on the worksheet, further demonstrating their ability to use the Rotation Tool correctly and easily. The mean score on the worksheet was 86.2%, with a standard deviation of 19.6%. Of particular note, all 21 students correctly identified that compound rotations are non-commutative because the order of the rotations affects the final orientation. In addition, 19 of the 21 students correctly identified the relationship between fixed and mobile frame rotations.

**Pre-Test vs. Post-Test.** The mean pre-test score of 42.9% (standard deviation of 25.0%) was lower than expected, given that the students had already attended lectures on compound rotations, and demonstrates the need for the addition of non-traditional teaching methods. The mean post-test score was 70.6% (standard deviation of 29.3%), resulting in a mean gain of 27.8% (standard deviation of 31.8%). Despite the small sample size, the distribution of gains in test scores follows a normal distribution, as determined by visual inspection and tested using the Kolmogorov-Smirnov test ( $p = 0.6512$ ), the Shapiro-Wilk test ( $p = 0.5374$ ), and the Anderson-Darling test ( $p = 0.4034$ ). The improvement in test scores after the treatment is highly significant ( $t = 4.01$ ,  $p < 0.001$ ), with seven students earning perfect post-test scores compared to just one earning a perfect pre-test score.

Despite the improvements in the post-test performance over that of the pre-test, it was observed that many students struggled to finish both the pre-test and post-test in the allotted time. In fact, only 11 students completed the pre-test, whereas 15 students finished the post-test. Although the Wilcoxon signed-ranks test indicates that the median increase in the number of questions answered after the treatment is statistically significant ( $z = 1.91$ ,  $p < 0.05$ ), it is clear that some students still had trouble finishing all six questions on the post-test. Closer examination of the returned tests reveals that a number of students made sketches for the questions that did not strictly require visualization, with a higher percentage of students making sketches for every question of the post-test than for the pre-test. Although it is encouraging to see the students take an analytical approach similar to the breakdown of rotations advocated by the Rotation Tool, it is clear that the students either did not realize the relationships between the questions or they did not trust their understanding of the relationships. Instead of applying the compound rotation principles that most were able to correctly identify when

completing the worksheet just moments before, they relied on the concrete visualizations provided by sketches to answer all of the post-test questions.

**Student Feedback.** The students were asked to rate how well they understood the difference between fixed and mobile frame rotations, both before and after using the Rotation Tool. These ratings are compared in Figure 6, and clearly illustrate the students' increased confidence in their understanding after using the Rotation Tool. This corresponds with the increase in general rotation knowledge that the large majority of students felt resulted from using the Rotation Tool, as shown in Figure 7.

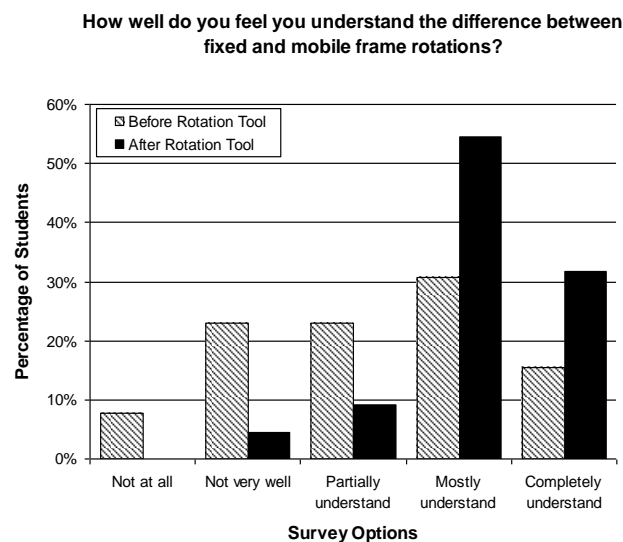


Figure 6. Comparison of students' self-rated level of understanding of the difference between fixed and mobile frame rotations, before and after using the Rotation Tool.

To what extent has the Rotation Tool increased your knowledge on rotations?

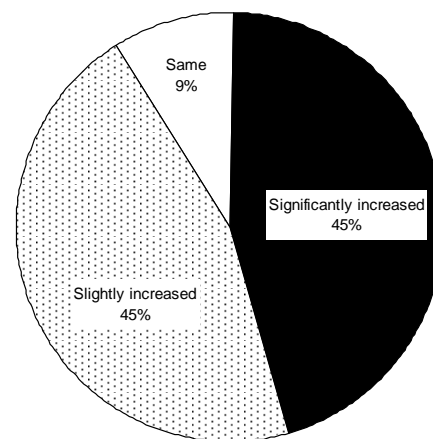


Figure 7. Student feedback after using the Rotation Tool. Note that no students felt that the Rotation Tool had significantly or slightly decreased their knowledge of rotations.

The written comments received from students at the end of the tutorial were overwhelmingly positive, with multiple comments along the lines of "this was cool" and "I'd [like] to have more classe[s] like this." The value of the Rotation Tool as a visualization aid was made particularly clear from the enthusiastic comments left by students who felt that they had struggled to understand the concepts taught in the lectures, with one student stating, "I will use it after this because I don't get this stuff at all but this will make it [a] lot easier." Even students entering the tutorial with confidence in their knowledge and ability to visualize compound rotations saw the benefit of the Rotation Tool, as evidenced by the student who commented, "Feel as if I may already have some degree of spa[t]ial awareness; however this tool definitely allows one to visualize this better."

## Conclusions

Although the students demonstrated strong mental rotation abilities, many exhibited relatively low self-confidence in their understanding of fundamental compound rotation principles when taught using traditional methods. This could be because traditional visualization aids are unable to overcome incorrect intuitive beliefs held by a majority of students, such as the belief that compound rotations are commutative. Focused use of the Rotation Tool yielded significant improvements in test results and an increase in students' self-rated confidence in their understanding of compound rotation principles. This demonstrates the power of the interactive, virtual reality-based visualization aid, even when used for a very short time.

Despite the improvements seen, it is clear from the number of sketches on the returned post-tests that the students were still not completely confident in applying their knowledge of compound rotation principles, preferring to verify their answers with concrete visualizations. Although a perfectly acceptable method of solving the questions, it indicates room for improvement in how the Rotation Tool is incorporated into the curriculum. Going forward, the worksheet will be modified to encourage a deeper analysis of *why* certain combinations of rotations result in different, or matching, orientations, and will ask students to apply the compound rotation principles to predict the resulting orientations of compound rotations before checking it with the Rotation Tool. In addition, the relationship between questions on the pre- and post-tests will be made more obvious, something that may have been easily overlooked by students under pressure to complete the tests.

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