Stimulating Interest in Technological and Engineering Literacy Using a Multidimensional Desktop Virtual Reality Framework

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In this paper geometry and graphics are employed to design and implement a multidimensional dVR (Desktop Virtual Reality) framework to stimulate interest in technological/engineering literature. Students, especially those at the beginner’s level, typically tend to associate literature with ‘textual information’ and huge volumes of books. While a seasoned faculty member or a researcher is quite used to reading voluminous literature, students and non-domain audience may find this challenging. Hence, this paper puts forth a novel approach wherein an interactive multidimensional dVR framework is used to methodically organize and present engineering and technological literature. Technological literature is represented as geometry objects embedded in a graphic interface that facilitates viewing from multiple perspectives (literature-wise) and sort and re-structure the literature as required. Users can navigate within this 3D environment and interact with scene elements. The Virtual scene elements represent various elements of technological literature in different formats that include 3D representations as well as conventional files such as word documents, web pages, etc. One primary drawback with a vast majority of visualization systems is that information is presented to the audience in a pre-determined fashion. Nevertheless, there may be times when the information receiver may want to view the information in other ways. A good visualization platform should be flexible enough to allow the user (audience or the information receiver) to interact with the information. The user should be able to dynamically interact, manipulate, modify, and re-arrange the information in accordance with their particular needs. Hence, the authors have enabled dynamic interaction capabilities within this framework that facilitates ‘re-arranging’ the way in which the information is presented. The application is being built using web-friendly technologies such as VRML/X3D and Java/JavaScript to facilitate online dissemination.

**Keywords:** Engineering literature, Technological literature, Multidimensional Visualization.

1. **Introduction**

This study employs desktop Virtual Reality (dVR) based information visualization to organize and present engineering and technological literature. The visual nature of the information presented not only elicits students’ interest but also facilitates better understanding the literature. Students in engineering and technology schools across the nation and all over the world typically learn various functional aspects of their specific discipline (e.g. civil, mechanical, etc.). These are invariably application-oriented and theoretical material also intends to strengthen the foundation of students towards building better applications. While this is important, a grasp of the fundamental ET literature by students enrolled in ET departments and schools in universities, is inevitable to enhance the quality of the graduating engineers and technologists. Over time, researchers and academicians are used to visualizing particular information in a specific way; sometimes, discipline-specific approaches may exist for disseminating the ‘body of knowledge’. However, today’s research and academic scenario is extremely interdisciplinary, wherein any research and even teaching venture necessitates people from diverse disciplines to collaborate. Several engineering and technology disciplines
collaborate with various other schools and departments, whose members may not necessarily be cognizant of engineering/technological literature. However, interdisciplinary ET (Engineering & Technology) courses and research grant applications stand to gain immensely when the collaborators from the non-technological side are exposed ‘technological literature’. An easy-to-use interface that appeals to students as well as non-domain audience can serve as a significant milestone in fostering collaboration between engineering/technological departments and other departments.

Hence, this paper presents a prototype multi-dimensional framework that uses a multidimensional dVR system to generate a ‘visual-analytical database’ of engineering and technological literature. Virtual reality based visualization not only facilitates viewing complex and multidimensional information, but also enables comprehending even hidden or ineffable information. The 3D virtual scenes besides enabling navigation also provide a sense of immersion whereby the users 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 potential of dVR based visualization to promote ET literature.

ET literature is inherently interlinked with numerous other disciplines and this complexity makes teaching and learning ET literature a tedious process. ET literature is so multifaceted and interrelated that understanding one aspect (e.g. mechanical engineering) requires understanding aspects of foundational science like physics and math. The main source of such linkages is the correlation among the disciplines and the theoretical foundations that are common to ET disciplines. Academicians often use tables, graphs, and maps to condense and visualize facts pertaining to ET literature. Although such visual representations are widely comprehended by ET professionals and researchers, these may not be so much appreciated by students and other stakeholders. One reason for this lack of comprehensibility is that these may involve colossal amounts of textural information as well as huge datasets of numbers, with a host of underlying mathematical formulae and statistical relationships. When confronted with innumerable texts and graphs/tables with details pertaining to diverse ET aspects, students may be perplexed and may at times be demotivated. Hence, in this paper geometry and graphics are employed to design and implement a multidimensional dVR framework to stimulate interest in technological/engineering literature.

The rest of the paper is organized as follows: Section 2 is the literature review that addresses the related work. Section 3 explains the methodology involving the framework for creating the desktop VR scenes. The results and discussion are covered in Section 4 and finally, Section 5 offers the summary and conclusion.

2. **Key Assumptions and Limitations in the work**

As this is a prototype framework that is trying to merge two different fields such as
dVR-based visualization and ET literature, some important assumptions had to be made and these in turn led to limitations as well. These assumptions and limitations are summarized here:

i. The classification of the disciplines shown here is not a rigid classification. In other words, the hierarchical organization of the disciplines is ‘merely one way’ of organizing the disciplines from the point of view of literature. This is done primarily to explain the usefulness of the framework demonstrated in this study. The framework is extremely flexible and allows re-organizing the structure of the dVR scene elements in any manner that suits the needs of the user.

ii. The number of elements chosen for any branching within the hierarchy (shown in figures in subsequent sections) is, once again, not comprehensive. While just about half-a-dozen branches of engineering are mentioned here, numerous other branches of engineering and technology do exist and for the sake of brevity and clarity, the authors have restricted the elements in a branch to just a few.

iii. Various parameters of the dVR scene objects such as appearance and geometry are used to depict dimensional attributes of the literature elements. However, even though several dimensions have been expressed using different shapes and varying colors, there is practically numerous ways such as radius, height, textures, etc. to distinguish between or group together scene elements.

iv. Most importantly, this framework has immense applications in depicting ET literature, de-cluttering the colossal amount of work done in these fields; this not only stimulates interest for a student, but also serves as an organizational tool for an advanced researcher. However, as this paper is proposing this novel framework here, some subjective aspects or qualitative research elements within the ET disciplines may have been overlooked. While writing this paper, the authors have tried to balance the explanation of the VR framework and tying it up with the ET literature, however, a lot of work can be done further in this area to exploit the potential of this framework.

3. Related Work

This paper describes the development and implementation of a multidimensional framework that serves as a ‘visual analytical database’ for visualization of ET literature. This paper uses a multi-dimensional framework that extends the notion of ‘geometry and graphics’ and exploits them as tools to facilitate understanding ET literature. The framework uses the ‘geometry’ of objects and subsequently employs ‘graphics’ as the medium to serve as an interface to the ‘visual-analytical database’. 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, several authors (Berry et al. 1998, Tufte, 1990, 1992) emphasize the importance and usefulness of visualized data. Recently, 3D visualization of information has turned out to be an essential tool in demographic, medical, land-use, infrastructure, meteorological, hydrological, and several other environmental applications. Modern sophisticated data acquirement technologies have made it possible to acquire complex data which were primarily much more difficult to procure; nevertheless, to extract useful information from this sea of data volumes is an overwhelming chore.
With increasing data accessibility and the development of a plethora of tools for visualization, there is a mounting need to sensibly and efficiently model data and phenomena eventually. Visualization practices not only enable the user to obtain an insight into the data being analyzed, but also facilitate effective presentation of the results of the analytical process (Koppers 1998, McGaughey, R.J. 1998). Visualization enables combining diverse information to present an integrated view of the multi-dimensional information (Chandramouli et al. 2009, Tufte et al. 1990).

Many researchers in education have shown that the use of instructional methods other than the traditional lecture format is much more effective in facilitating student learning. Literature pertaining to the disciplines of engineering and technology is not only inherently multifaceted but extremely complex, especially for students’ at the beginner level. Unfortunately, students in engineering and technology do not always understand or appreciate the need to know at least the foundational aspects of such literature. To stimulate students’ interest in ET literature, alternative modes of information presentation need to be used. Several key components impacting student motivation must be considered for effective instruction and learning. Driscoll (2005) stated that instructional material must appeal to learners and motivate learners in their goal achievement. Keller and Litchfield (2002) claimed that considering student motivation “is particularly important because it pertains to a person’s basic decisions as to whether or not to accept responsibility for a task and to pursue a given goal” (p. 86).

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 visualizing, understanding, and analyzing ET literature. The purpose of visual representation of data varies across individuals and quite frequently, is motivated by the need for information visualization. For example, one may be interested in the aggregate picture of thermodynamics, another person may be interested in kinematics, and yet another may be interested in engineering drawings. However, one who is interested in the history and the role of engineering drawings in construction would need a whole lot of specific details concerning such literature. Thus, the level of detail (LOD) varies across the disciplines and is again, motivated by purpose of visualization of data. The framework explained in the study helps both spatial and temporal visualization. More importantly, this is an interactive framework that can be re-arranged according to the users’ needs and requirements. On the whole, this framework facilitates active learning (Prince and Felder, 2006), problem solving (Jonassen, 2002) and project-based learning (Hadim and Esche, 2002), which are encouraged as ways of exciting students.

Also, besides facilitating understanding ET literature, this framework facilitates comprehending ET datasets that involve diverse data formats (or modes) including drawings, 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 inter-related aspects of ET literature. This is accomplished by enabling visualization, exploration, and analysis of ET literature in multiple modes and dimensions. This also enhances understanding the correlation among various data variables. One
of the primary goals of any kind of visualization is to extract useful information from colossal volumes of literature and more importantly, communicate the information that is extracted. The efficiency gains from such a cognitive exercise are enormous and may result in faster, easier, effective, teaching and understanding.

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. One primary drawback with a vast majority of visualization systems is that information is presented to the audience in a pre-determined fashion, which may or may not be understood by students and 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. The user should be able to dynamically interact, manipulate, modify, and re-arrange the information in accordance with their needs.

On the whole besides facilitating teaching and learning ET literature, the interactive nature of the framework enhances their problem solving experience. This also facilitates increasing transfer of critical skillsets from the classroom to the workplace, especially in engineering and technology-based learning (Roblyer, 2004).

4. Methodology

When considering ET literature we need to be aware of the temporal and spatial dimensions besides dealing with the discipline-specific dimensions. For instance, when dealing with engineering graphics communication, the various dimensions could be geometry, projection, data structure, solid modeling, and so on. The users should be able to view the complete dataset at the same time, by holding one dimension constant. If geometry is held constant (say, at 2D or 3D, for example), the user will be able to navigate through various projection systems as applicable to graphics communications. Many different transformations and combinations may be envisaged at this stage. Some of them could even be used to examine ET-related hypotheses and debates. Such deep insights may be obtained from these visual representations of ET literature.

When discussing about 3D visualization another term that needs to be discussed is ‘Virtual Reality’. There exist numerous definitions for ‘Virtual Reality’. 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 the objects in the worlds, rotate or scale them, and transform them in multiple ways. These virtual worlds facilitate user interaction with the 3D objects and provide a sense of immersion.
There are three modules (Figure 1) in the design and implementation of the prototype dVR framework for generating virtual representations for the ET literature. The first component involves a basic classification of ET literature and a ‘purpose-driven’ classification based on the specific purpose of the visualization. The second part involves taking the parts from the earlier module and creating a library of CG (Computer Graphics) objects in Virtual Reality. The third component involves the CG module wherein the virtual worlds are generated for viewing the plans in desktop Virtual Reality. The following sections provide a detailed description of the individual components of the aforementioned framework.

4.1 VR-based ET Scene Construction

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.
For example, objects denoting literature related to thermodynamic can have their size proportional to actual values of temperature-ranges (for specific categories). Even though the purpose of this paper is not to dwell on the advantages of such virtual world representations, some important functionalities that add to the utility value of a virtual world include:

- The ability to move about in the 3D space,
- Walk through the dVR (desktop Virtual Reality) Application
- Locate and navigate to particular points of view (POV)
- Select a particular path and display a video sequence along
- Provide different levels of detail (LOD)

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

4.2 Desktop Virtual Reality (dVR) Scene objects:

The scene is defined by "nodes" (X3D/VRML). A visualization scene can be considered to be composed of objects with properties as described earlier. In the preceding sentence, the phrase ‘objects with properties’ needs to be noted. A scene is composed of elements or objects, each of which has its own properties or attributes. A parent object can include any number of children, which can be grouped or assembled to function as one single entity. This sort of hierarchical arrangement helps in the step-by-step design of the object and also understanding the framework at any later stage.

![Hierarchical Depiction: A Possible Approach to Organize Engineering Literature](image.png)
A scene-tree construction is used in Virtual Scene Renderings. The root or the parent object consists of whole scene grouped together and all the other components are grouped under this parent object using ‘parent-child’ relationships. Individual scene elements (children) within the engineering literature (lit.) hierarchical classification (Figure 2) can correspond to engineering disciplines such as Civil Engineering lit., Electrical Engineering lit., Mechanical Engineering lit., Aeronautical Engineering lit., Biomedical Engineering lit., and so on. Likewise, individual children elements within the technology hierarchy can correspond to child objects such as Information Technology lit., Computer Graphics Technology lit., Building Construction Technology lit., Aviation Technology lit., and so on. For complex objects including multiple parts, various object parts are grouped to form parent objects, leading to complete objects that are once again combined and positioned properly to form bigger objects resulting in the final 3D scene.

As can be seen from Figure 2, the root object (the topmost parent object) is Engineering Literature and its immediate children objects include different branches such as Mechanical Engg., Civil Engg., etc. Each of these, in turn, has its own ramifications. For instance, Civil Engg. has various sub-disciplines such as Structural Engg., Foundation Engg., etc., which can have additional classifications and so on. Also, it is important to note the overlap among the various branches. Parts of literature falling under Mechanical Engg. can coincide with parts of Civil Engg. literature. Figure 3 below corresponds to the desktop VR representation of the classification represented in Figure 2.

(Clockwise from Top-Left) Figure 3a. Engineering Literature Represented by Spherical dVR Objects 3b. Alternative Representation using Cubical dVR Objects 3c. Re-Classification Enabled by Vertical/Horizontal Alignment & Color Differentiation 3d. Sub-classification within Disciplines
All the elements in the dVR scene (Figure 3a, 3b, 3c, 3d), are enabled with the following functionalities

1. Translation (ability to move about along XY, YZ, or XZ planes)
2. Rotation (about its own object space along any one of the three axes)
3. Scaling (they can be scaled up or down)

Java-Script enabled sensors are built into these dVR scene elements to accomplish the above transformations. This provides excellent control to the user in selecting and transforming them to re-arrange the scene in accordance with the user’s needs. The object properties can also be viewed by user actions such as mouse hover, left-click, right-click each of which corresponds to providing the user with informative messages corresponding to the object (e.g. category or sub-category, historical context, quantitative information, etc.)

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. 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.

User-input involves two levels
- Scene arrangement showing classification based on meta data
- Problem-based customization according to User-specific needs

The meta data based classification is explained in Section 4.3 below. Figure 4 below explains how user input can be used to re-arrange objects in a scene based user input (user-initiated events) such as mouse-click, drag, hover, etc.

One obvious and inevitable consequence of the increase in number of objects (disciplines) is their inherent characteristics (attributes) of the disciplines such as the time-span during which the discipline significantly evolved, the key aspects of the discipline, etc. These in turn creates the need to measure quantitatively or qualitatively and this manifests itself as dimensions within the dVR world. For instance, if there are four dimensions in a representation, the attributes derived from color-coding can be used as the fourth dimension in a three-dimensional view. For example, in a view of construction technology literature, studies in areas that have declined over the years may be shown in red while the ones that have risen may be shown in green. Once again, the red-green difference can be based on the purpose of the study. For instance, if a particular study or student researcher is interested in ‘eco-friendly’ construction technologies, literature pertaining to eco-friendly construction can be depicted in green, while those that are not eco-friendly can be placed on the other side of the spectrum (red).
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 info about the literature covered in 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. Documents about the technology practices in different countries may be linked to the objects, in addition to their detailed labels.
4.3 Structural Organization Using Descriptive Meta-data (keywords)

A very important component that serves as the interface between the dVR scene representations and the actual literature are the key words that serve as ‘meta data’. Several definitions exist for ‘meta data’ and there is significant ambiguity surrounding the usage of meta data. However, for the purposes of this study and especially clarity, the authors prefer to stick to the definition that describes meta data as ‘data about data’. The following tables explains how keywords (meta data) can be demonstrated using various graphic attributes such as geometry and appearance, which can be used to differentiate as well as group scene entities.

Table 1: Content Organization and Classification using Meta-Data

<table>
<thead>
<tr>
<th>Content Organization</th>
<th>Keywords* (meta data)</th>
<th>Attributes of Graphic Elements (Within the X3D Scene Graph)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Procedural</td>
<td>Red</td>
</tr>
<tr>
<td>Information Technology</td>
<td>Programming languages</td>
<td>Object-Oriented Blue</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Java Transparent Blue</td>
</tr>
<tr>
<td></td>
<td></td>
<td>C++ Solid Blue</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Declarative Green</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Operating systems Spherical</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Windows Macintosh Cylindrical</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Linux Cubical</td>
</tr>
<tr>
<td>Computer Network</td>
<td>Internet Solid blue line</td>
<td>Intranet Solid Green</td>
</tr>
<tr>
<td></td>
<td>Extranet Solid Red</td>
<td></td>
</tr>
<tr>
<td>Data Structure</td>
<td>3D Modeling, Video Games, Display Systems Animation,</td>
<td></td>
</tr>
<tr>
<td>Computer Graphics Technology</td>
<td>Casting, Welding, Steam Engines, Gas Turbines, Automotive Vehicles, Material Science</td>
<td></td>
</tr>
<tr>
<td>Mechanical Engineering Technology</td>
<td>Construction Technology</td>
<td>Reinforced Concrete, Foundation Engineering, Construction Safety, OSHA,</td>
</tr>
</tbody>
</table>

* This table is only for illustrative purposes – to demonstrate the linking of visual elements using attributes to the metadata. The list of keywords is by no means an exhaustive list.
X3D (Extensible 3D), in confirmation with the recent XML (Extensible Markup Language) standards incorporates the use of metadata to structurally organize data. The dVR scene is organized in the form of scene components, which in terms of code, translates to ‘nodes’. Within an X3D scene graph, this metadata node is used to provide additional information about node defining appearance or geometry of the scene objects. The keywords from the literature can be incorporated within these metadata tags of the X3D scene graph that serve to organize the multi-level information within ET literature.

4.4 Effective visual presentation using the dVR Framework

The effectiveness of a visual representation is determined by the composition which represents a set of associated visual rules (or principles) that is governed by theories grounded in cognitive psychology. Colors are extremely an important element of visual communication and hence, composition. Colors can not only capture attention, but can communicate information. (Birn, 2006, Davis, 2009). However, not all colors attract attention equally. Warm colors such as red tend to appear closer than cool colors or background colors like blue and green.

Among the various elements affect the final composition of a visual representation, following are some of the crucial components that can instinctively direct the viewer’s attention:
- Shapes & Lines
- Color
- Topological relationship ((Spatial arrangements)
- Patterns

The dVR scene is made up of graphics objects that have their parameters such as appearance and geometry. These are used to depict the dimensional attributes of the literature elements. The distance along the x-axis can be used to represent their chronological sequence. (farther away from the origin along the x-axis, longer from the time period represented by the origin). The distance along the y-axis from the origin can be used to represent the actual development towards a particular aspect being studied. For instance, if studying the development of animated graphics movies, the greater the impact of the contribution, the farther away from the origin. However, even though several dimensions have been expressed using different shapes and varying colors, there is practically numerous ways such as radius, height, textures, etc. to distinguish between or group together scene elements.
4.5 Viewing ET Literature Relationships Using Geometric dVR Objects

Figure 5. illustrates an alternative dVR representation to represent the concept of discipline and sub-disciplines of literature. This framework can not only be used to represent the disciplines, but also show relations using the lines. These can be used to illustrate networked (interconnected) relationships among the disciplines as well as the ramifications. If we take a closer look at the network elements (Figure 6) constituting the inside of the elliptical representations above, this becomes more evident. The blue circular object shows a major discipline in technology and the yellow circular objects show the sub-disciplines within the broader discipline. In this case, all the green lines are of equal length, however, this can be varied to show varying relationships if the need be.

Figure 6. Structural Component of a ET Literature Network from Figure.4

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 related aspect among various disciplines. For instance, literature pertaining to ‘semi-conductor devices’ that can be found under various engineering disciplines can be depicted using this line and the thickness of the line can be used to refer to the strong presence of ‘semi-conductor’ related literature in the discipline (Figure.6). Also, various
attributes can be used to differentiate between different kinds of relationships. If we have a dozen different semi-conductor materials represented by lines that connect discipline-pairs denoted by the spheres/lines, 12 lines varying in terms of attributes can be created. These attributes include:

- Line Thickness
- Line Color
- Line Style

Using this prototype framework, objects can also be grouped into ‘clusters’ to illustrate objects more closely related than others which are not. Grouping literature of quantitative research within a discipline apart from qualitative research or clustering applied research literature from basic research are examples of how this dVR representation can be applied. In Figure 7, the dVR representation on the left shows the regular view and the one on the right shows attributes involved in quantitative vs. qualitative research. Attributes that are being included within the sphere can be turned ‘On’ or ‘Off’. By turning the ‘On’ or ‘Off’ buttons, literature of one type will be enclosed within the Sphere and literature of the other type are placed out of the sphere. Those that have an overlap between the two are placed on the circumference as shown in Figure 8.

Figure 7. Relationships Using Varying Line Geometries (Color, Style, Thickness)

Figure 8. Creating Clusters to Group ET Topics
4.6 Programming the Graphic Interface for User Interaction

One of the primary reasons for implementing the graphic library using PROTOS is the ability to program the objects thus 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 inter-disciplinary research data. 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. The nodes can be programmed to receive these inputs. 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, intricate designs can be generated (Figure.9). This flexibility of I/O sequencing would prove helpful in inter-disciplinary research applications. Users will be able to exploit the possibilities of dynamic views and analysis in such a framework. For example, researchers could first click a particular domain (e.g. Nanotechnology) to see its major related disciplines and sub-disciplines and secondly look at how they have evolved over the years, using color codes as mentioned above.

![Figure 9. I/O sequence (Event-Response) Framework](image)

5. Results and Discussion

This section discusses the cumulative utility of having a multidimensional dVR representation of technology and engineering literature. This section demonstrates of the use of the dVR Visual Representation for specific case-based scenarios.

![Figure 10a. Alternative Hierarchical Representation1](image)
![Figure 10b. Alternative Hierarchical Representation2](image)
Let us consider an example of how this notion of incorporating the capabilities described in the earlier sections can be helpful in ET lit. visualization. Consider one of the two different representations for evolution of hardware resources across disciplines. Both the representations have some kind of hierarchical sorting. In figure 10a (on left) the literature pertaining to hardware components of computer hardware are all tied to the yellow cubes representing the discipline and the smaller color coded cubes represent the specific area within the discipline where hardware components are used. The specific/detailed literature information is embedded within the individual object which can be obtained by hovering, or left-click or right-click on the object.

![Figure 11. Filters applied to ET Literature Search](image)

- **11a. Initial Representation of Engineering Literature without filters turned on**
- **11b. Filter: Based on relevance to ‘atomic physics’**
- **11c. Filter: Based on the geospatial aspect**
- **11d. Filter: Based on the work related to WW Era**
Figure 10b shows the discipline-wise as well as inter-disciplinary literature pertaining to common hardware components using spheres arranged along the x, y, and z axes. In other words, someone interested in knowing the literature pertaining to hardware component in a discipline-specific manner would look at 10a), while a student/researcher interested in the inter-disciplinary distribution of the literature pertaining to hardware would look at 10b).

The multidimensional representation shows a dVR framework with filters enabled to turn On or Off specific attributes or attribute relationships when performing a literature search (of all Engineering literature). Figure 11a) is the representations that results once the user switches on the attribute of ‘Time’, elements greater than and smaller than a pre-determined ‘year’ are shown in different colors. In figure 11b), Objects in red show the engineering literature that is related to the atomic physics. It may also be required to keep track of the various authors and researchers who did notable work in this discipline. Figure 11c) shows blue Cylindrical Objects that denote the prominent work by contributors within a particular geographical area as narrowed down by 11a and 11b already. Figure 11d), in addition, shows the specific work from the above narrowed down search that is especially tied down to the world war era (the time period between the first and second wars). So, ultimately the yellow cones correspond to ET literature that meet the following criteria
- Engineering literature related to Atomic Physics
- ‘Atomic Physics’ related Engineering literature by specific geographical region
- Region specific Atomic Physics Engg. Lit pertaining to World War Era

Spatio-temporal relationships are essential for advanced exploratory analysis and can be modeled effectively using the multi-dimensional framework. For each of the above category, filters are applied. These are enabled using ‘Sensor-Enabled’ On/Off filter (as illustrated in Figure 10. Starting with an initial representation without any filter turned on, at each level filters are turned on to identify the different categories.

6. Considerations for future study

The authors intend to extend this study in future along the aspects mentioned below:

1. As mentioned earlier, this is a prototype study that attempts to bring together two diverse fields namely dVR-based Visualization and ET literature. Hence, the limitations of the study are explained in Section 2. Consistent research involving further considerable work along the proposed lines is required for implementing a fully functional framework that can be synchronized real-time for dynamic interaction.

2. As this is a prototype study proposing a new idea, there were limitations faced by the authors in explaining the application to a wide range of areas. So, this paper especially focused on a research-based approach; however, the notion explained under the methodology can easily be extended and applied to PBL exercises. For instance, let us consider an IT project involving generation of a taxonomy to classify operating systems or programming languages for a Computer Information Technology course. A hierarchical classification can be used to classify programming languages or operating systems (Table 1) and this can use the geometric and appearance attribute of graphic
objects to generate such a dVR classification. In future works, the authors intend to
demonstrate the usefulness of this framework to PBL exercises in detail.

3. In order to measure the impact or the effectiveness of the proposed framework, this
framework can be included in the form of PBL-based exercises or within course
curriculum in ET departments/schools. After allowing the students to use this framework
in classrooms or labs or PBL exercises, the performance metrics of students can be used
to evaluate the impact of such visualization systems in studying ET literature. This, in
itself, can constitute the focus of a future paper and the authors intend to carry out this
study and analyze the performance metrics reported from such analysis.

7. Conclusion

The goal of this study was to design an innovative framework integrating geometry and
graphics for developing a multi-dimensional visualization framework to stimulate interest in ET
literature and also help organize the colossal volumes of literature in this area. This study
illustrated with various examples the advantages of using dVR-based multi-dimensional
visualization for stimulating interest in ET literature. 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 ET literature 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 ET literature and sorting them using a dynamic
mode. 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 framework also has the ability to link
various file formats such as documents, spread sheets, and other statistical diagrams and
representations into the application.

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 relevant and not-so-relevant literature when
considering a particular area of interest. One can quickly filter out conspicuous areas, outliers
and the role of attributes such as geographical proximity, in a logical and systematic fashion to
arrive at useful observations and informed decisions based on literature.
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