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Suitability of Searching and Representing Multimedia Learning Resources in a 3D Virtual Gaming Environment

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SUITABILITY OF SEARCHING AND REPRESENTING MULTIMEDIA LEARNING RESOURCES IN A 3D VIRTUAL GAMING ENVIRONMENT

by

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A Master's thesis submitted to the
Faculty of Graduate and Postdoctoral Studies
in partial fulfillment of the requirements for the degree of
Master of Computer Science

Ottawa-Carleton Institute for Computer Science
School of Information Technology and Engineering
University of Ottawa

Your file Votre référence
ISBN: 978-0-494-49268-0
Our file Notre référence
ISBN: 978-0-494-49268-0

Abstract

Search engines usually publish search results in web pages that are filled with a certain number of matched records that can be navigated further through successive back and forth operations. While this approach proves to be useful, it fails to show the context and relationship among displayed results. We argue that new and intuitive user interfaces, such as a 3D virtual environment, may provide an alternative to the traditional presentation techniques, especially in a learning environment where learners are looking for multimedia learning resources that match their interests. We propose a 3D car gaming environment as a search metaphor and analyze the suitability of such an approach in terms of user perception, interaction, visual quality, graphics rendering performance and other parameters. Our experiment suggests that the proposed approach not only shows an intuitive way of information visualization but also integrates education and entertainment to serve the vision of Edutainment.

Acknowledgements

This thesis is based on research conducted during my years at the Multimedia Communications Research Laboratory (MCRLab), University of Ottawa. The work presented here is the result of highly collaborative efforts and I owe thanks to the people I have worked with.

First and foremost, I would like to convey my sincere gratitude and indebtedness to my supervisor, Dr. Abdulmotaleb El Saddik, for giving me the opportunity to pursue research on this rapidly emerging field and to move forward along the path of innovation and novelty. His invaluable research ideas and experience kept me motivated all the way towards the completion of this research work.

I would like to give my sincere thanks to my beloved parents for their love and support throughout my graduate studies. I am also grateful to all my friends and fellow MCRLab students for their support, suggestions and constructive discussions. My special thanks go to Anwar, Anis, Shamim, Mehedi, and Amin. Thanks also to the people at the MCRLab for creating a pleasant and inspiring working environment.

I thankfully acknowledge the financial assistance of the National Capital Institute of Telecommunications (NCIT) and of the Natural Sciences and Engineering Research Council of Canada (NSERC) through its Learning Objects Repositories Network (LORNET).

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List of Abbreviations

2D: Two dimensional

3D: Three dimensional

AICC: Aviation Industry CBT Committee

AR: Augmented Reality

DB: Database

EAI: External Authoring Interface

ECL: eduSource Communication Layer

EIS: Enterprise Information System

Eye&Why: 'Eye' is for Visualization and 'Why' stands for Search

HCI: Human Computer Interaction

IMS: Information Management System

JDBC: Java Database Connectivity

LTSC: Learning Technology Standards Committee

LMS: Learning Management System

LO: Learning Object

LOM: Learning Object Metadata

LOR: Learning Object Repository

LORNAV: Learning Object Repository NAVigator

LORNET: Learning Object Repositories Network

LWJGL: the Light Weight Java Game Library

MediaMetro: Browsing multimedia document collections with a 3D city metaphor

MVC: Model-View-Controller

SCORM: Sharable Content Object Reference Model

UI: User Interface

VE: Virtual Environment

VR: Virtual Reality

XML: eXtensible Markup Language

Chapter 1

Introduction

1.1 Background and Motivation

Information visualization is a method of presenting data in non-traditional and interactive graphical forms that may leverage 2D or 3D color graphics and animations. It offers several possibilities that include visualizing the structure of information, navigating through it, and modifying the data with graphical interactions. The discovery of appropriate visual metaphors for interactive representation of search results is quite challenging. This is especially important when the target audiences are the learners. Hence, representing the information in intuitive and meaningful ways needs to be addressed.

The widespread use of the Internet and the advancement of computer technology have made learning in the distributed network-based environment a common practice. More and more learning materials are constantly being added to repositories by the distributed learning communities. These large sources of information, when organized according to standards, create a huge learning base on the Web.

Considerable efforts in the past few years have aimed to standardize metadata elements as a common method for identifying, searching, and retrieving Learning Objects (LOs). Learning Object Metadata (LOM) [3] is one outcome of such an effort. With the steady increase of LOs and LOM-based repositories, the challenge has now shifted to novel access paradigms [1] in order to facilitate learners' or teachers' effectiveness in navigating, exploring, and searching interesting LOs. The traditional form-based method of searching information might be helpful in this respect. However, 3D visual interfaces could be explored in this area without substituting the traditional ways, which would enhance the learner's experience in the intuitive visual environment.

3D information visualization [14] offers several possible benefits. We can perceive more information at a time in the 3D spatial metaphor. In addition, such an environment can provide a different perspective of the information [17], display meaningful patterns in the data, enhance grouping facility, and offer a better understanding of the relationships among different data items. Furthermore, the 3D interfaces may be augmented with game-like interaction to bring an attractive element into the searching and learning process.

1.2 Existing Problems

The increasing learner's community of information visualization systems is facing a growing demand in proposing a dynamic, extendable visualization model that could present the data in an organized way to foster reusability of the information. Furthermore, incorporating entertainment in education is the goal of many visualization systems that can intrigue the learners and engage them in their learning process [62, 60]. Most systems, particularly the 3D visualization systems, visualize data in the form of 3D objects in particular metaphors [44, 10, 39, 8]. Also, the data used are based on some local repositories that do not follow any standard structures [45, 11, 13]. These restrictions made the use of those systems restricted to the domains that they were originally intended.

Data is worthless if lost within a mass of other data. Even if an entity is discovered, if the user cannot determine the context about the entity—how it is supported, who owns it, what it does, etc.—the user cannot effectively interact with the entity. In other words, being able to distinguish and differentiate data is as important as being able to find data. Furthermore, an organized and grouped information visualization system improves the information perception and advances the overall information navigation process. Clustering information requires certain characteristics that often are not necessarily explicit in the metadata fields. It makes the categorization algorithm very difficult to implement and use in the system. For example, the system could arrange the objects based on the similarity of words present in the title and description, similar pedagogical styles, or even the quality of the metadata records themselves. Furthermore, the user profile information could be incorporated into different clusters of learning objects with real users to visualize social networks of learners.

One alternative is to cluster all the learning objects in the visualization of the Learning Object Repository (LOR) by using the general classification scheme as described by the LOM in the application profile [3]. This approach has two major disadvantages. First of all, each element of a LOM is optional; hence, it is difficult to consider general classification taxons that are defined in a LOM, which makes the adoption of clustering algorithms particularly impossible. Secondly, general clustering technique does not offer the information visualization process with any metrics (eg. semantic metrics between different groups of clustered data [40]) that can be taken into consideration in rendering the information in its organized form. We think proposing such a semantic metrics from the clustering data is where the visualization scheme can really benefit from a cluster service in order to provide an organized picture of the learning objects.

Gaming is another interesting way of learning. Considering this assertion, there is no specific system that attempts to visualize distributed LOs as a form of educational data in a gaming metaphor to foster entertainment in learning. We particularly focus on this direction and leveraged existing methodologies in order to deliver the distributed and standard learning content in the 3D game like metaphor.

1.3 Objective and Contribution

The increased demand of distributed and tele-collaborative learning pushes the organization and delivery of LOs to be more intuitive and interactive to the learning community. Learners and teachers are not satisfied with the traditional way of exploring LOs [46]. The objective of this research is to enhance the typical navigational experience of the learner in order to explore LOs from distributed LORs. Currently, users are able to search for learning objects in LORs by filling out electronic forms that specify one or more search criterion. We designed a framework with the requirement that it should be extendable. More specifically, it is possible to add new visualization techniques and components that are described by other metadata-schemes in a simple way. With this framework we developed a prototype application that helps to present an intelligent LO grouping mechanism in the visualization process, where the users are able to continuously keep track of the overview and map relevant search information very easily. Overall, the objectives of the research can be summarized as the following:

- Development of an extensible framework to present the distributed data (learning objects) that are huge in numbers and have a generic interface to the information.
- Creation of an intuitive and user-friendly interface for sharing the learning objects.
- Producing an entertaining and intriguing gaming metaphor for Learning Object visualization based on the categorization of the searched LOs and on the information provided by the user as tag.

- Using 3D information visualization techniques to present the standard LOs in an intuitive and meaningful approach and the adoption of personalization as a means of filtering the data of interest in a gradual manner.
- Using optimization techniques in delivering the targeted personalized 3D metaphor. To foster efficient 3D rendering of different graphics objects (terrain, 3D models, billboards etc.), multi-resolution level-of-detail techniques are taken into consideration.
- Using a gaming metaphor in order to foster entertainment in the learning and navigational experience of the user.

The research in this thesis has been performed by leveraging several existing techniques on information visualization and data access mechanisms. However, most of the formulation, implementation, and experimentation found in this thesis are original works. The contributions of this thesis as a whole could be summarized as the following:

- Design and development of a dynamic and extendable visualization model that could present the standard learning content in an organized way to foster reusability of the information. Various schemes of the model have been accepted for publication in [27, 42, 39].
- Design and development of a 3D virtual game like environment for the representation of the search results. The approach suggests a unique endeavor to visualize distributed LOs as a form of educational data in a gaming metaphor. The results are published in [27, 40].
- Development of a weighted keyword clustering algorithm to calculate the semantic distance between the keywords. The contribution received excellent reviews and is published in [27].
- Devising tag based LO sharing framework in peer-to-peer environment. In EYE & WHY prototype we have instigated both tag based (published in [39]) and

automated way (published in [41]) of standard LOs sharing schemes in a peer-to-peer networking environment.

1.4 Publications Resulting from this Research

The following six papers have been published. The first five are directly related to the thesis topic while the last one is an effort towards suggested future work.

1. Abdulmotaleb El Saddik, **ASM Mahfujur Rahman**, and M. Anwar Hossain, "Searching Distributed Learning Objects in a 3D Virtual Gaming Environment" IEEE Transactions on Instrumentation and Measurement (accepted, to appear).
2. Qing Chen, **ASM Mahfujur Rahman**, Ayman El-Sawah, Xiaojun Shen, Abdulmotaleb El Saddik and Nicolas D. Georganas, "Access Learning Objects in a Virtual Environment with Hand Gestures and Voice," International Journal of Advanced Media and Communication (accepted, to appear).
3. **ASM Mahfujur Rahman**, Abdulmotaleb El Saddik, "A 3D Notice Board Metaphor for Visualizing, Categorizing, and Sharing the Learning Objects," The Second International Conference on Systems (ICONS 2007), Martinique, French Caribbean, April 22 - 28, 2007.
4. **ASM Mahfujur Rahman**, Abdulmotaleb El Saddik, "Traffic Architecture Driven Organization and Visualization of Learning Objects Metadata in a Virtual Environment," 3rd Annual E-learning Conference on Intelligent Interactive Learning Object Repositories (I2LOR), Montreal, Quebec, Nov. 8-10, 2006.
5. **ASM Mahfujur Rahman**, Abdulmotaleb El Saddik, "An Algorithm for Search and Organization of Learning Objects in a 3D Virtual Environment", 2006 IEEE International Conference on Virtual Environments, Human-Computer Interfaces, and Measurement Systems, La Coruna, Spain, July 10-12, 2006.

Poster-Demonstrations:

6. **ASM Mahfujur Rahman**, Abdulmotaleb El Saddik, "LOVVE: Distributed Learning Object Visualization in a Virtual Environment," 3rd Annual E-learning Conference on Intelligent Interactive Learning Object Repositories (I2LOR), Montreal, Quebec, Nov. 8-10, 2006. [**BEST DEMO AWARD**]
7. **ASM Mahfujur Rahman** and Abdulmotaleb El Saddik, "Eye & Why: A Prototype for Learning Object Visualization in a Virtual Environment," IEEE International Symposium on Multimedia (ISM2006), Dec 11-13, 2006, Paradise Point Resort & Spa, San Diego, California, USA.
8. **ASM Mahfujur Rahman** and Anwar Hossain, "Learning Object Visualization in a Virtual Environment," 4th Toronto-Montreal Computer Vision Workshop 2006, SITE, University of Ottawa, Ottawa, Canada, May 29-30, 2006.
9. Anwar Hossain, **ASM Md. Mahfujur Rahman**, Jamil Melhem, Md. Abdur Rahman, and Abdulmotaleb El Saddik, "Interactive Navigation of Distributed Learning Objects in a 3D Game Environment," 2nd Annual Scientific Conference of the I2LOR-05, Simon Fraser University, Vancouver, Nov. 14-18, 2005.

1.5 Thesis Organization

The remainder of the thesis is organized as follows:

Chapter 2 presents an overview of background literature and related studies. Background concepts on learning objects, learning object metadata, 3D visualization, virtual reality, and so on are provided first. Next, several 3D information and document visualization systems are described in a general manner, with an emphasis on learning object repository visualization.

Chapter 3 proposes our idea and elaborates on the system design phase. The design phase includes the dynamic 3D visualization technique, the Learning Object clustering technique and the LOM sharing technique in a peer-to-peer network environment.

Chapter 4 focuses on the implementation of the system. This includes our choice of technology, software architecture, and sample user interfaces of the system.

Chapter 5 covers the evaluation results of our system, focusing on evaluations of system usability and user studies.

Finally, the work is summarized in **Chapter 6,** which also includes a conclusion and a discussion of potential future work.

Chapter 2

Background and Related work

2.1 Literature Background

The work in this thesis is an attempt to visualize distributed LOs in a 3D virtual environment. Firstly, the notion of a Learning Object (LO), the metadata standard that describes LOs, and the repositories that are used to store LOs and/or associated metadata are introduced. This is followed by an overview of 3D visualization, metaphor and virtual environment, the 3D rendering language, and the graphics libraries to render the 3D models to produce realistic animation on the applet as well as in the prototype application. The system uses data from three primary sources. The first source is the distributed learning object repositories provided by NSERC LORNET (Learning Objects Repository Network, http://www.lornet.org), the second is the P2P directory that maintains and delivers learning resources separately as implemented in our laboratory, and the third is the web search results generated by the traditional search engines such as Google and Yahoo using their web services interfaces. In the following, we specify these data models and describe the standards they follow.

2.1.1 Learning Objects

According to the IEEE Learning Object Metadata (LOM) standard, Learning Objects (LO) are digital or non-digital entities used for the purpose of learning or training [3]. This is a very broad definition and we would like to narrow down our selection to digital entities that can be accessed through the Internet. A Learning Object can also be defined as an educational object used to enhance learning. It could include text, images, web sites, videos, animation, audio, photographs, or presentations. For example, a module or object within an online course might consist of all of the objects listed above and yet be a learning object [5].

Other definitions have attempted to narrow down the above definition. In [47], a learning object is considered as a reusable digital resource to support learning. This also emphasizes those resources that can be accessed via the network irrespective of its granularity. The main idea of a LO is to promote sharing and reusing learning resources among practicing communities.

2.1.2 Learning Object Metadata

In order to promote sharing and reusing LOs, IEEE Learning Technology Standards Committee (LTSC) defined Learning Object Metadata (LOM) [3] as a common method for identifying, searching and retrieving LOs. LOM is defined as a hierarchical structure consisting of nine broad optional categories (see table 2.1), having multiple metadata elements in each of them.

Table 2.1 Base schema categories of LOM

No.	Category	Explanations
1.	General	General metadata, such as the identifier, title, language, keyword, structure, or description of a LO.
2.	Life Cycle	History and current state information, such as status, version, and role of a LO.
3.	Meta-MetaData	Metadata that describe the metadata of the LO itself.

4.	Technical	Covers all technical information about a LO, such as format, size, location, duration, browser requirements, etc.
5.	Educational	Describes educational and pedagogic characteristics of the LO, such as interactivity, difficulty, end-user type, etc.
6.	Rights	Intellectual property rights for commercial use and ownership of a LO.
7.	Relation	Relationship in between other LOs.
8.	Annotation	Provides additional information about a LO including assessments and suggestions by other learners.
9.	Classification	Classifies a LO with respect to a classification system.

The optional constraints have given much freedom to the metadata tagging process that causes people to only fill data into a few of the elements. However, this does not undermine the presence/existence of a standard that a community can use for the greater good. Figure 2.1 shows a sample xml excerpt of a LOM record consisting of few elements.

```
<lom xmlns="http://ltsc.ieee.org/xsd/LOMv1p0"…>
<general>
  <title> <string language="en">Java tutorial</string> </title>
  <keyword> <string language="en">java</string> </keyword>
</general>
<technical>
     <format>application/pdf</format>
     <location>www.uquebec.ca/java.pdf</location>
</technical>
<educational>
     <intendedEndUserRole>
        <source>LOMv1.0</source>
        <value>Teacher</value>
     </intendedEndUserRole>
     <intendedEndUserRole>
        <source>LOMv1.0</source>
        <value>Learner</value>
     </intendedEndUserRole>
</educational>
<rights>
   <copyrightAndOtherRestrictions>
        <source>LOMv1.0</source>
        <value>yes</value>
   </copyrightAndOtherRestrictions>
   <description> <string language="x-none">UQuebec</string>
```

Figure 2.1 Sample XML excerpt of a LOM record

2.1.3 LOM Repositories

Learning resources are created and stored by the learning communities in distributed repositories. The LOs, or their references along with the LOMs, are stored in the Learning Object Repositories (LOR) [2], which allows for searching and retrieving of LOs through simple keyword-based or even advanced elements-level search interfaces (see figure 2.2). The search may be performed on multiple heterogeneous repositories in a unified way using a federated search mechanism [1] that hides the underlying locations of the repositories and provides the user with an interface of a single virtual repository. In our system, we use this federated search approach to respond to a user query and later pass those results to the graphics-processing engine to map them in the 3D environment.

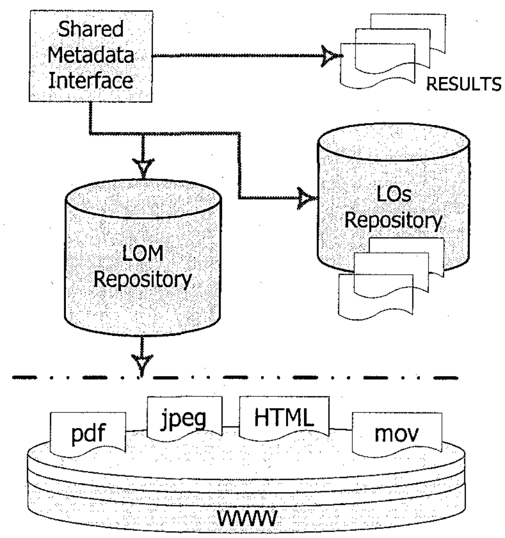

Figure 2.2 Learning Object access paradigms

The proposed system uses EduSouce [5] repositories to retrieve the search results that come in the form of LOM records. We use these metadata elements to associate them with the 3D representation of the LOs and allow the viewing of them by the navigating user in the virtual environment (VE). The actual content is referred via the 'location' element of the 'technical' category of LOM and is made available to the user through interaction. There are several communities who maintain LORs to share and distribute knowledge. Examples of some LORs include ARIADNE [55, 51], eduSource [5], EdNA LOR [53], and LORNET [52].

2.1.4 LO in the P2P Directory

LOs may be maintained and shared via the P2P network infrastructure in order to provide a more scalable data management service. Our system also uses such a P2P infrastructure [19] as another layer of the LO's access and retrieval. In this case, we allowed each peer to maintain a separate repository of multimedia resources and provide an access mechanism so that others can access and share their resources as well. In fact, the shared autonomous LO description used in a P2P search model does not conform to the LOM standard; it was implemented to test the different parameters of shared P2P LO access [27, 41].

2.1.5 Web Search Results

In order to provide more resources to the learner and to populate the virtual world with additional resources, the system also uses the search results obtained through the traditional web search engines. Although the web search results provide fewer metadata attributes (such as title, description, url) to identify the learning resources than are provided by the LOM attributes, we used this data to leverage the ever-explosive growth of web resources.

2.1.6 OpenGL in Java

OpenGL [36] is a low-level, procedural API, which offers a portable development environment to build interactive 2D and 3D graphics applications. OpenGL's low-level design requires programmers to have a good knowledge of the graphics pipeline, but also gives a certain amount of freedom to implement novel rendering algorithms. With its portable and enriched graphics libraries it has become one of the most widely adopted and supported graphic application programming interfaces [64]. OpenGL fosters innovation and speeds up application development by incorporating a broad set of rendering, texture mapping, special effects, and other powerful visualization functions. The OpenGL has standardized access to hardware, bringing thousands of applications to a wide variety of computer platforms. With so many different kinds of graphics hardware, getting them all to speak the same language in this way could have a remarkable impact by giving software developers a higher level platform for 3D-software development.

OpenGL is well structured with intuitive design and logical commands, which can be used in a procedural or in an object oriented fashion. OpenGL serves two main purposes:

- To hide the complexities of interfacing with different 3D accelerators, by presenting the programmer with a single, uniform API. Thereby, produce consistent visual results on most of the graphics hardware, regardless of the operating system.
- To hide the differing capabilities of hardware platforms, by requiring that all implementations support the full OpenGL feature set.

The light-weight binding of Java with OpenGL (LWJGL) [12] is a collection of bindings for OpenGL that allows Java developers to produce high quality professional games. It has been specially tailored for game development and robustness in its functionality. LWJGL presents a platform-independent and easy to use java powered graphics API, which can work in a network environment with very low bandwidth requirements. This has influenced many communities to use LWJGL for their virtual reality tool of choice.

2.1.7 The Need for 3D Visualization

Information visualization is a popular and advancing field of study that is defined as the use of computer supported, interactive, visual representations of abstract data to amplify the user's cognition [14]. The limitation of memory and perceptual ability of the human brain makes it difficult to relate huge amounts of information with each other. Information visualization schemes assist in building an interactive construct that establishes a relation between the user and the knowledge stored in the computer. Graphs or charts are more popular to aid in understanding progress or determining relations than real or abstract numerical information [12], [56]. It is evident that the brain's computational ability prefers the visual representation of a system rather than its written description as it influences the cognitive ability of humans [57]. However, the transfer of knowledge to learners' understanding is challenging and difficult to manage because of the trade off between the overview and the details that are needed to be communicated. Appropriate information visualization tools [14, 58] and [59], are needed to be addressed for efficient data representation. 3D information visualization facilitates the information transformation process and provides an attractive, large display space as well as natural and cognitive aspects of visualizing more information at a time [7, 14].

Furthermore, a visually organized representation of the information allows the users to get insight into the data, directly interact with it, draw conclusions, and come up with new hypotheses. Its target is to not only reinforce the traditional presentation concept but to also open up multiple avenues to foster a greater understanding of the information presented, enhance learning based on preferences and learning contexts. With the dramatic improvement in 3D graphics hardware it has now become easy to address 3D virtual environments in visualizing LORs in order to navigate and explore learning objects in a natural way that is different than just "filling in electronic forms" [1].

2.1.8 Visual Metaphors

Visual metaphors are the mapping between data and visual models. It is crucial to have a suitable metaphor to visualize and understand information presentation. Many researchers have stressed the importance of finding appropriate information space metaphors for effective information visualization. The need for appropriate metaphors is important for 3D visualization. Several attempts to use different types of metaphors have been made such as the 3D room [37] shown in Figure 2.3.

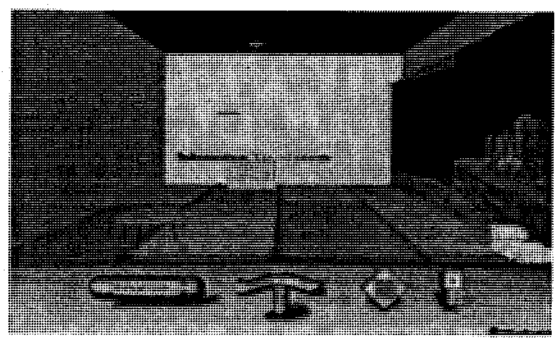

Figure 2.3 The 3D-Room information space metaphor

The use of visual metaphors is effective for the transfer of knowledge [31]. Eppler [28] has mentioned, there are six advantages of using metaphors, they are listed as follows:

I) To motivate people.
II) To present new perspectives.
III) To increase remembrance.
IV) To support the process of learning.
V) To focus the attention of the viewer, and
VI) To structure and coordinate communication.

To adhere to the hypothesis, we have designed our 3D highway metaphor prototype with a game like interface in order to promote entertainment and comfort in the learning process. New users will find it easy to navigate the virtual roads of the exotic landscape using the car metaphor. The customizable road network based visualization is promising as it presents both an overview and detailed information all in one place. This is augmented by an easy to use interface, and multi-modal interactions for better navigation. The road network uses real world traffic symbols and a mapping paradigm so that the learners feel comfortable to find information of interest. In effect, searching for information is replaced by the discovery of destinations with guided road directions.

2.2 Related Work

Few comparable works have been carried out in visualizing LOs in VEs while allowing dynamic interactions with the displayed objects. However, several systems do attempt to visualize database contents, web documents, hierarchical information, multidimensional datasets, and others. These works stand as a guideline for our work. This section briefly discusses some of these systems and the basic concepts and architectures behind them.

2.2.1 LORNAV

To visualize Learning Objects in a 3D environment over the Web, LORNAV [38] uses a 3D modeling language to design the 3D environment. As LOs are represented using the IEEE LOM [3] standard and are stored in distributed repositories, the 3D representation of each LOM record is visualized dynamically in the virtual environment, which eventually points to the actual LO by means of a hyperlink. In addition, the following contributions of the prototype should be mentioned:

- Visualize LOs distributed over multiple repositories where the LOs are described by IEEE LOM standards and retrieved via a web service based interface.
- Creation of multiple visual metaphors to navigate Learning Object Repositories in a 3D virtual environment.

- Providing personalization in the 3D environment that facilitates the user's navigation of the LOs of interest.

The 3D representation of a LOM record is a template 3D object that is replicated dynamically for each LOM record. Instead of considering all the LOM elements to be included with the 3D representation of a LOM, a subset of elements (for example title, language, format etc.) have been taken into consideration. Furthermore, the interface permits the user to perform search operations over a number of repositories based on those selected LOM elements. Figure 2.4 shows the overall system architecture of LORNAV.

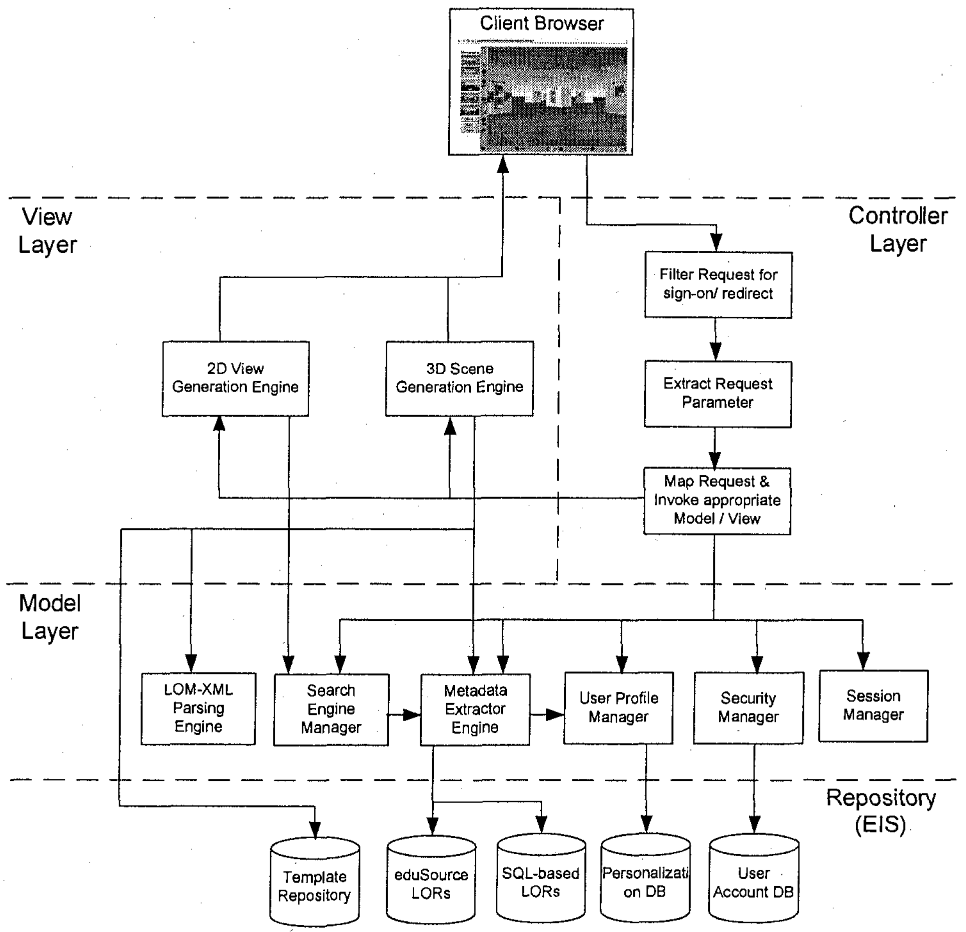

Figure 2.4 Model-View-controller Architecture in LORNAV [38]

The learner or teacher, once logged in, can navigate the 3D world that is generated by the 3D scene generator engine. The 3D world includes LOM records represented using 3D objects. Navigation facilitates the user to perform several other operations such as visual exploration, metaphor selection, searching and maneuvering.

In the case of LORNAV, one of the categorization techniques followed is based on keywords. This way, when the user poses a query consisting of, for example, four keywords, LORNAV categorizes the returned LOM records based on these keywords. The keywords are displayed on top of the object container that would hold LOM records according to its predefined capacity. Several LOM records can be returned for each keyword. In this case, an additional container will be added for the same keyword in the 3D environment.

Figure 2.5 shows the screen that appears after the user has performed a search based on the keywords. The metaphor is created dynamically using familiar objects such as a shelf and a table. In this view, the user can rotate the shelf and/or table by walking close to it and use the mouse to go in the XY plane while holding it down. The user can also change the background color using the 3D switch in the virtual environment.

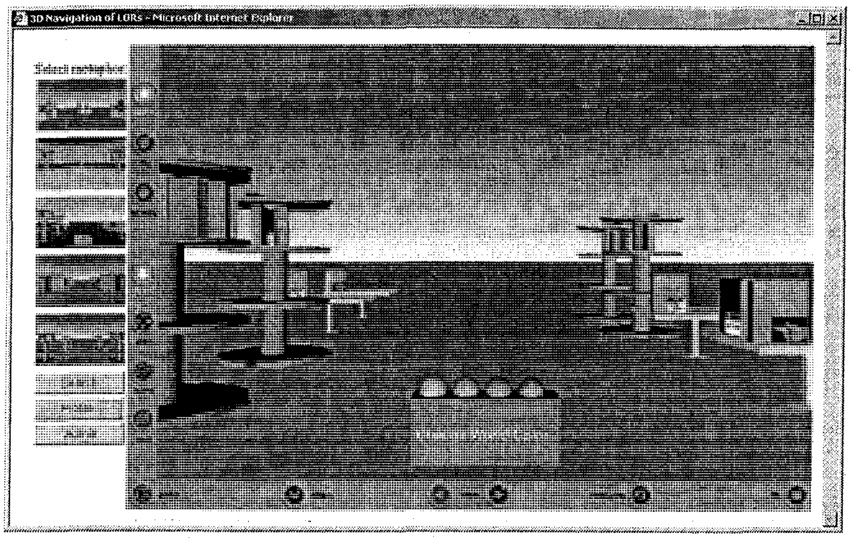

Figure 2.5 Sample 3D environment in a familiar metaphor

Other clustering techniques are used based on specific LOM elements, such as document format. The LOs that are similar in technical format are sub-grouped under the main keyword-based category. Apart from the visually appealing interface, adoption of a standard data system and flexible visualization architecture, the following advantages can be observed when comparing the proposed work to LORNAV implementation:

- The LORNAV visualization scheme adopts an unfamiliar metaphor (table and shelf on the open field, where a room would be preferable). No user avatar animation model has been proposed. As will be discussed in chapter 3, our approach has been adapted with a natural and familiar car gaming metaphor with roads for navigation and traffic signs for information representation. 3D cars have been used to represent the user in the virtual environment.
- Keyword based clustering of the LOMs is not an technically-adequate choice, because the keyword LOM element is optional and in many cases not included in the LO description. For the same reason, title or description based organization

schemes will not pervade. This needs a content based LOs organization model to be addressed.

- In the visualization, the number of search results a group (as table or shelf) can hold is limited and in order to accommodate more results, which are from the same search group, a separate visual group instance needs to be created.
- No semantic relationship path is considered for implementation (no point of interest) between the group elements that tend to obscure the user's information of interest and make it hard to construct meaning from the information organization.
- In LORNAV, rendered LOM elements are always fixed, which is contrary to the users personal customization. This is unlike our approach, where users are free to choose any LOM elements (though a limited number) to visualize.
- No sharing scheme has been proposed.

LORNAV has been a very encouraging example towards the development of our 3D prototype system, which shares the same motivation with our research (leveraging information visualization using a 3D VE from distributed LORs). In our approach, the above issues are carefully handled by incorporating a familiar 3D car based information navigation, clustering the LOs based on their content (text) information (see section 3.4), and a LOM sharing model that is proposed in section 3.5.

2.2.2 MediaMetro

The Mediametro prototype [10], presents a visualization scheme of multimedia document collections using a 3D city metaphor. Each multimedia document is represented by a building and visual summaries with thumbnails of the slides and text that are rendered onto the sides of the building. The document thumbnails are depicted over the buildings from which it is easy to discriminate their type information. The most important frames are located on the roofs of the buildings in the city so that a high altitude fly-through would result in viewing a single frame-per-video. The images resemble windows on a building and can be selected for media playback. See Fig. 2.6 with the current graphics performance of desktop PCs. An interactive 3D visualization can be generated in real-time that shows visual summaries for a large number of the multimedia documents.

The users are able to fly-through the 3D city and browse all of the videos (or documents) in a directory. To support more facile navigation between high overviews and low detail views, a novel swooping technique was developed that combines altitude and tilt changes for zeroing in on a target while moving seamlessly from a high altitude overview of the collection's structure to a low altitude detail view of a document's contents.

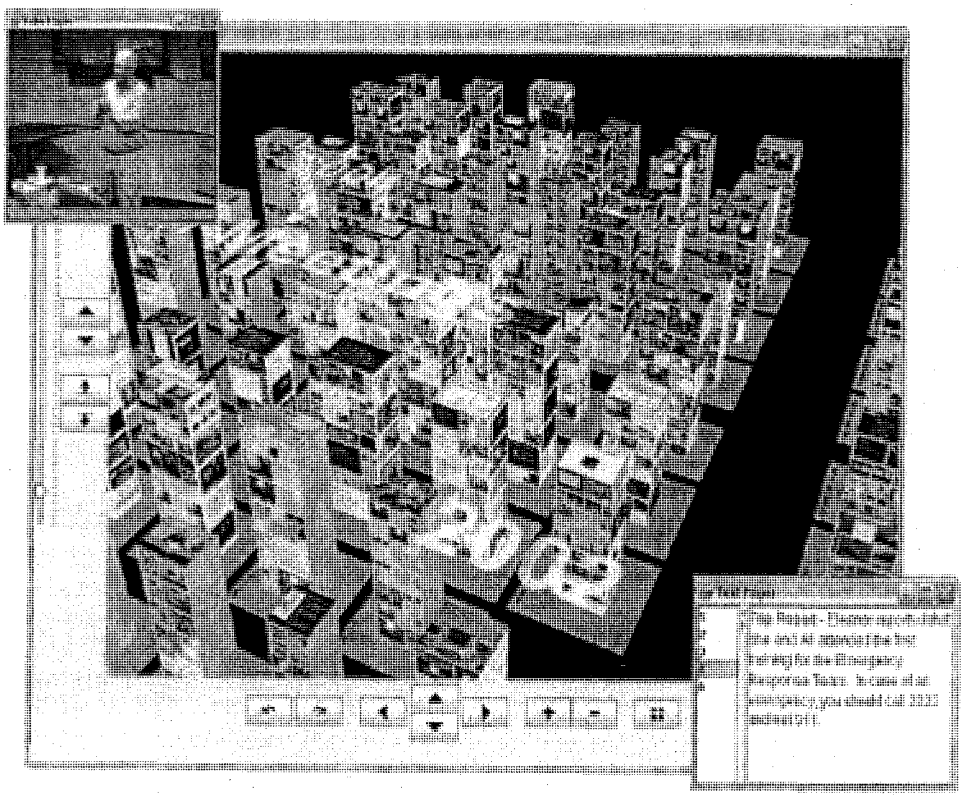

Figure 2.6 An interactive 3D visualization of video documents of a directory [10]

Virtual helicopter-based landscape navigation had been introduced to perceive the media information. Such a navigation scheme and selection tactics are tedious and may require practice to become accustomed. In addition, the system may not be scalable to accommodate and process distributed multimedia collections, and be accessible over the Internet in real time. The documents are organized over a fixed grid layout and an inter-document relationship has not been considered in the image organization [27], [40]. The user experience could be enhanced by presenting a game-like user avatar model (car avatar in horizontal navigation and helicopter in vertical) to entertain the learner. We have presented a 3D gaming metaphor for visualizing search results in a virtual environment and gaming is one of the most effective ways of teaching about complex scenarios [61, 62], which entertains as well as keeps the users engaged.

2.2.3 Gesture Recognition based Avatar Navigation

One of the supporting works that we want to address is the gesture recognition based avatar navigation [42]. The work in [42] presents a human-computer interface based on gesture recognition to navigate a learning object repository mapped in a 3D virtual environment. With this interface, the user can access the learning objects by a set of hand gesture commands controlling the movements of the Avatar car. To achieve the real-time performance, appearance-based gesture recognition, based on Haar-like features and the AdaBoosting learning algorithm, has been employed. With this approach, satisfactory gesture classification accuracy has been achieved. The learning object repository and the virtual environment consider the semantic meaning of the query and apply context-based peer address mapping to search metadata [41]. The search results of the learning objects can be grouped along the virtual highways represented by different traffic signs. Based on the testing results, it is more intuitive and interesting for the users to use hand gestures to control the movement of the Avatar car, compared with controlling the Avatar car using the arrow keys on the keyboard.

Virtual environments provide a new paradigm for human communication, interaction, learning and training. To interact with the virtual environment, besides traditional human-computer interaction devices such as keyboards and mice, different sensing modalities and technologies can be utilized and integrated with the virtual environment for a more natural user experience [32]. Devices that sense body position and orientation, speech and sound, facial expression, haptic response and other aspects of human behavior or state can be used for communication between the human and the virtual environment. These devices and techniques make natural and immersive human-computer interfaces (HCI) for applications in 3D virtual environments promising [33] [35] [34].

The three-dimensional (3D) information provided by virtual environments offers several possibilities such as perceiving more information at a time, displaying meaningful patterns in the data and understanding the relationship among different data items, Card et al. [14]. These possibilities may be utilized in different contexts especially in visualizing learning objects as it requires novel and more intuitive presentation techniques than what is provided by the traditional 2D approaches [9]. To access the learning objects in the 3D virtual environment, the traditional mouse and keyboard are limited as the mouse itself is a 2D device and the arrow keys on the keyboard are not an intuitive approach for human beings.

To overcome these limitations, a multi model-based approach has been employed to achieve more powerful and natural interaction between the user and the virtual environment. Besides the mouse and the keyboard, other modalities can be the human voice, hand gestures, haptic devices, etc. Figure 2.7 shows this multi modal-based HCI architecture. Vision-based hand gesture classification can be a feasible and efficient alternative for human-computer interaction, especially for applications in 3D virtual environments [34].

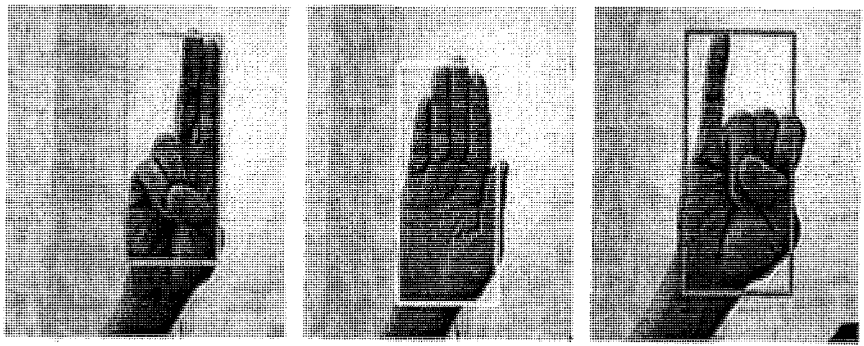

Figure 2.7 The recognition result with the parallel cascades structure.

With the vision-based hand gesture interface, the user can navigate the 3D virtual environment and access the learning objects by controlling the movements of the Avatar car with a set of hand gesture commands. A set of hand gestures are tested with the cascade classifiers trained with the AdaBoosting algorithm and the Haar-like features under constrained background conditions. The authors have tested the navigation of the prototype with proposed gesture commands (see Figure 2.8).

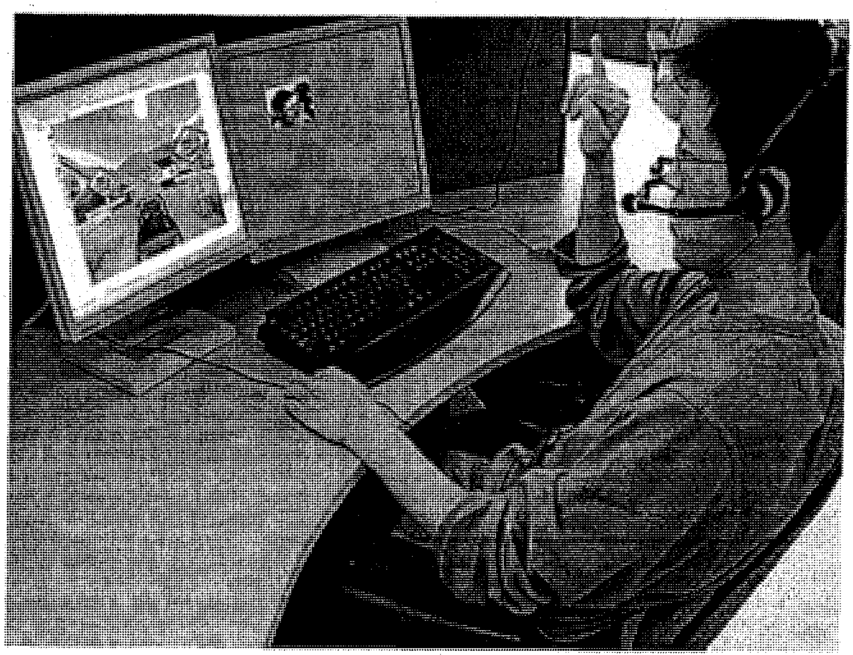

Figure 2.8 Navigating the learning object repository with proposed gesture commands

However, the proposed gesture-recognition based approach can distinguish only a limited number of gesture commands. Moreover, the system needs calibration and performs better when it has a white (or constant color) background. Considering these aspects, we have adopted a sound recognition based navigation model in our prototype.

2.2.4 CiVeDi

The system presented in [11], named CiVeDi, aims to integrate a multimedia database and a virtual reality environment for customized visualization of cultural heritage information over a museum metaphor. Customization can be performed by the user on many aspects. The user is able to specify the appearance of the virtual environment by choosing any museum architecture that is available in the system. The user can determine the type of tour as linear or non-linear, customize the duration of his/her visit, and specify clustering criteria to define grouping of artifacts in the virtual scene. The idea of tour generation, although different in nature, is also adopted in [43, 13], which creates guided tours to aid users while navigating in the virtual world.

Other systems similar to CiVeDi create dynamic virtual museum exhibitions with artifacts. One is ARCO [44], which attempts to take the benefit of virtual and augmented reality and provide a more realistic virtual environment to the user. ARCO also provides additional user interaction with the displayed 3D artifacts than is possible with CiVeDi.

CiVeDi [11] and its earlier version, ViRdB [45], adopted a modular architecture that consists of several functional units as shown in Figure 2.9. The main unit in this architecture is the Scene Repository that contains a Virtual Scene Unit (e.g 3D template of a room), the Db-driven Objects (e.g. 3D abstract representations of images), and Autonomous Objects (e.g. plant, door).

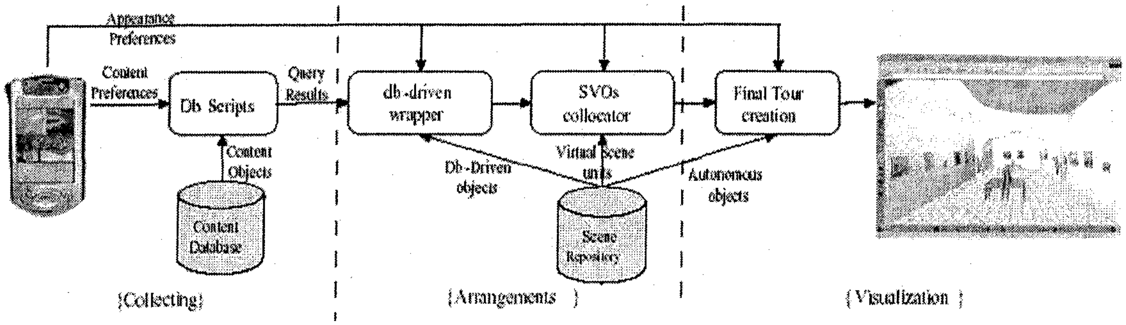

Figure 2.9 CiVeDi tour generation process [11]

While CiVeDi offers many possibilities, it has several limitations. It needs to maintain a lot of physical dimensions to arrange specific kinds of multimedia elements into the virtual scene unit. This complexity is shown to take a considerable amount of time and special requirements for the museum curator to customize the system for certain other multimedia contents, thereby reducing its expendability. The CiVeDi system does not follow any existing metadata standards such as IEEE LOM [3], Dublin Core [48], or MPEG-7 [54], which makes it less adaptable with a distributed data model.

Furthermore, the CiVeDi system does not specify the actual user interaction with the displayed 3D objects. Contrary to these, the proposed architecture called Eye & Why [27, 41], aims to visualize LOs in a VE that are defined using LOM metadata standards and are distributed over the Internet and accessed via a web services call. It is also capable of integrating data from Yahoo or Google search services that follow a different standard by using a simple mapping mechanism.

2.2.5 Periscope

The Periscope [8] system attempts to visualize web search results using several 3D metaphors including a city metaphor. The search results are presented as groups based on document language, server domains, number of matching keywords, document types, and so on. These groups give an overview of the overall search results. The user can further navigate the 3D space by selecting any specific document class which in turn displays the actual document links represented as 3D objects. The overall display is represented using any of the predefined visual metaphors. Figure 2.10 represents the several components of the Periscope visualization engine.

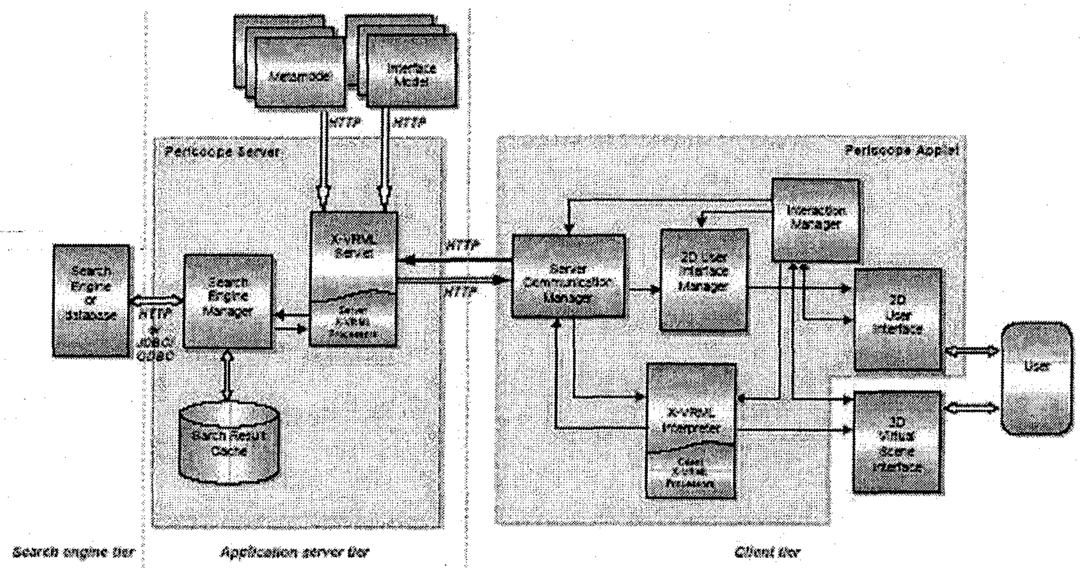

Figure 2.10 PERISCOPE visualization engine [8]

However, this approach requires multiple interactions to access targeted document content, which is sometimes frustrating. Also, the system does not provide any textual cues with the individual 3D object representation of the search results. Moreover, the 3D objects are often laid on top of each other due to the high volume of search results. This makes selecting individual objects very difficult and sometimes impossible. The system does not keep track of the user's current viewpoint in the 3D scene. Hence, in case of any refresh actions performed by users, the viewpoint is set to its initial position. This is very frustrating, especially if the search results are huge and the user has already navigated to some area of his/her interest.

Another notable fact with Periscope is that system performance is indeterminable when connecting it to a massive real life search engine database. In our approach, the above issues are carefully handled by attaching visual cues to each of the learning objects and storing the users' current viewpoint. Among other developments, users can perform several interactions such as view the metadata of the LO, view content, play multimedia objects in the 3D VE, select any particular object and store that object to his/her personal favorite directory for sharing with other users across a peer-to-peer environment[19].

2.3 Comparison

This chapter offered an introductory overview of Learning Objects, Learning Object Metadata, Learning Object Repositories, LWJGL, The Need of 3D visualization, and Visual Metaphors. The chapter then illustrated the design principles of several related tools including LORNAV, MediaMetro, CiVeDi, Periscope, and Gesture Recognitions based Navigation. The chapter also highlighted the similarities and differences among these tools and Eye & Why. A comparative study of the features provided by these tools is summarized in Table 2.2.

Table 2.2 Summary of features in related tools

Tool/ Architecture	3D Visualization elements	Metaphor	Multi-modal interaction	Grouping	Data sharing	Data source
LORNAV	Distributed LORs	Books on table/shelf	Keyboard, Mouse	Keyword based	Not available	Local, Distributed
MediaMetro	Multimedia elements of a directory	Buildings in a city	Keyboard, Mouse, Joystick	Not available	Not available	Not distributed
CiVeDi	Multimedia database of cultural heritage information	Museum	Keyboard, Mouse	Supported	Not available	Local, Distributed

Periscope	Web search results	Familiar, Holistic	Keyword, Mouse	Supported	Not available	Not known
Gesture based Navigation	Distributed LORs Traditional Yahoo, Google search services	Familiar car metaphor with gesture based navigation	Gesture, Keyboard, Mouse	Semantic [20] ranking of the search result [41]	With peers	Distributed
The proposed Eye & Why	Distributed LORs Traditional Yahoo, Google search services, favorite user (peer) directory	Familiar car gaming metaphor	Gesture, Keyboard, Mouse, Voice, Joystick	Text analysis of the content	With peers, using tags	Local, Distributed (LORs, Yahoo, Google), Peers

The tools summarized in Table 2.2 acts as a base of this research in terms of 3D visualization of information. Our information visualization prototype supports the integration of many search services including the standard LOM [3] data model. Furthermore, a 3D gaming metaphor for visualizing search results in a virtual environment is one of the most effective ways of teaching about complex scenarios [62, 61], which entertains as well as keeps the users engaged. The development of Eye & Why aims to achieve these fundamental goals.

Chapter 3

System Design

This chapter illustrates the overall system architecture along with detailed descriptions of the main features offered by the 3D prototype tool. Firstly, the data model and the graphical model of the system are presented. Then the functional aspects of the prototype, e.g multi-modal interactions, navigation, personalization, etc. are discussed in detail. Furthermore, the clustering and sharing framework of the search results are presented in separate subsections.

3.1 EYE & WHY Overall Architecture

3.1.1 Overview

We propose a 3D car gaming environment as a search metaphor to analyze the suitability of information visualization in a 3D spatial landscape. The main idea behind our approach is to dynamically generate the virtual gaming environment and populate it with the 3D representations of the search results. Figure 3.1 shows a schematic view of the overall system. In this section we describe our proposed prototype system, Eye & Why, in terms of data model and graphical model specifications, which are the core ingredients of the virtual environment (VE) metaphor. As can be seen in Fig. 3.1 layer 1 comprises of two main models, which are the data model and their respective graphical representation model. The data model describes the different data formats, their associated standards and sources. The model explains the adoption of standard Learning Object (section 2.1.1) and its metadata descriptor LOM (section 2.1.2), followed by detail discussion of the three major data sources of the LOs. LOR is discussed in section 2.1.3, LO depiction in P2P fashion is explained in section 2.1.4 and lastly web search result integration is illustrated in section 2.1.5. Consequently, the graphical model of layer 1 would be discussed in section 3.2. At the end in layer 2 (section 3.3), various gaming features of the 3D virtual environment will be presented.

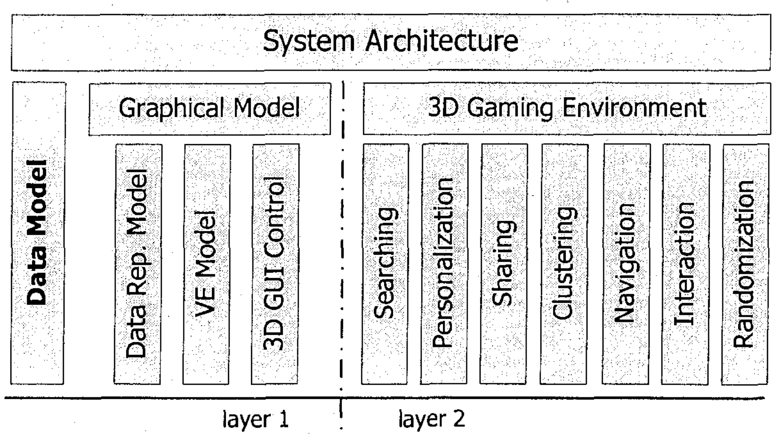

Figure 3.1 Schematic diagram of the proposed system

3.1.2 Use Case Model

We will consider a high level overview of the system that focuses on the specific features required to bring effective interactions to the participating users. Figure 3.2 illustrates the use-case diagram to summarize the core requirements of the prototype system. Generally, two basic actors will comprise the interaction process – teacher and learner, where the users could be further separated into sharing and shared types of users. Below we have discussed different core use cases of the model through the roles that are played by the actors in the system.

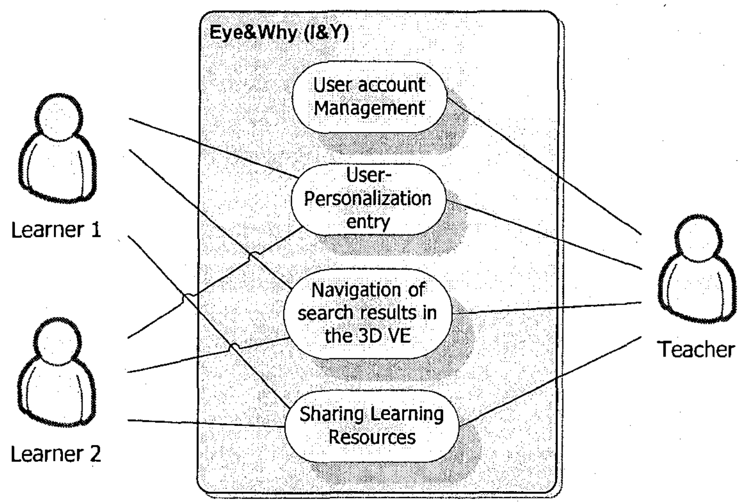

Figure 3.2 Use case diagrams to summarize the core features of the EYE & WHY prototype system.

1. *Teacher's Role*:
    a. Managing Accounts: The use case of the teacher's role is to manage and administer the user accounts. Typical system administration tasks vary from assigning user roles, user profiles, system preference maintenance, etc. In addition, the users are given individual user-names and passwords, so that their access to the system can be authenticated
    b. Guided Tour: In this use case the teacher creates a content oriented guided tour for the learners in the 3D learning environment. The learner can download and play the guided tour as a file to get an enriched knowledge about a specific learning subject.
    c. Creating Learning Content: In addition, the teacher consistently supplies (as shared learning resources) high-quality and relevant learning resources for specific subjects to a specific group of learners.
2. *User's Role*:
    a. Personalization: A learner or teacher can create or modify his/her profile. The user updates his/her preference choices, which are later used to build

a personalized learning environment. Furthermore, the user enhances the personal directory space by adding more and more tagged learning meta-data.

b. Navigating the 3D VE: The learner or teacher, once logged in, can navigate the 3D world that is generated by the 3D scene generator engine. An individual user-profile is scanned to access their personalized 3D learning environment. The user is also offered an intuitive multi-modal interface to perform several other operations such as visual exploration, metaphor selection, searching and maneuvering.

c. Sharing the User Directory: In this use case, the role of the users involves sharing the personalized user directory comprising of individual learning resources to different learning groups. Furthermore, by tagging and commenting, the learners are able to share their perspectives, which motivate discussion and foster the learning process.

3.1.3 System Features

The prototype tool Eye & Why presents an implementation in accordance to the presented architecture, which is introduced in section 3.1.1 and offers the following highlighted features:

- Visualizes LOs represented in an IEEE LOM standard. LOM is defined by IEEE LTSC for identifying, searching, and retrieving LOs across the communities using different elements and vocabularies.
- Presents a highway metaphor interface for searching LOs. The aim is to examine and present an intuitive way of information visualization that integrates education and entertainment to serve the vision of Edutainment.

- Retrieves the LOs from a selection of distributed and web multimedia repositories and renders the 3D representations of the results in a virtual environment.
- Presents a range of data access mechanisms including web services based on XML-SOAP, XML-WS, and a local or shared peer-to-peer directory network.
- Creates and maintains individual user profiles to record end-user preference parameters. The profile reflects the user's choice and is used to deliver a personalized 3D learning environment.
- Offers several interaction mechanisms including but not limited to keyboard, mouse, and speech recognition based commands, and haptic gesture controls.
- The prototype presents several personalized or randomly created 3D template appearances as the visual metaphors to display search results.
- Permits users to perform several interaction tasks in the 3D environment. The user is able to select, view and play the learning objects associated with the rendered search results using the integrated browser.
- Provides users with a personal space in the 3D environment where he/she can view previously selected objects.
- Grants the user with a suitable interface for searching and sharing LOs in a peer-to-peer fashion.
- Gives the user dynamic audio synthesis based feedback to guide the user through illustrating different system events and parameters.
- Introduces a 3D graph based navigation layout for rendering the clustered search results.
- Displays a world overview layout for efficient navigation in the 3D virtual environment.
- Portable and accessible through standard web-browsers as a standalone java applet.

Audio synthesis based feedback adds an extra dimension to the interface. The learner is notified of the status and the results of all his/her major actions in the prototype. Basically, it acts like a virtual assistant in the interface. For example, after committing a search, the audio synthesizer will notify the user of the maximum number of search results found or it may simply store the learning object into the favorite directory upon the user's request. Of course there are simple shortcuts in the keyboard, but the audio based command and interaction makes the learning process more interesting.

3.2 Graphical Model Specification

We use several 2D and 3D models for designing the 3D virtual gaming metaphor. Some of the models are used to generate the basic scene structure, while others are used to decorate the 3D world. These objects are stored separately and are not influenced by the data returned by the user query. On the other hand, we use templates for representing the LOs that the user can search. Each search result has a representation in 3D and therefore any high-volume of search results need an efficient mechanism to represent the 3D models and dynamically arrange them efficiently in the VE. As shown in Figure 3.1, the graphical models used by our system may be of the following types.

3.3.1 Data Representation Model

In our system, data refers to multimedia learning resources and their metadata, which are represented by 3D models. The cornerstone of our approach is the usage of traffic signs to represent LOs and their presentation in the VE. The design of traffic signs are influenced by a particular LOM element such as the format and title of the LO. The format element actually represents the mime types of the LO. Therefore, if a LO has the mime type as text/HTML, an icon representing the HTML document will surface on top of its 3D representation. Figure 3.3 shows a template representation of a LO of the type 'HTML'. Similarly, other mime types are represented with meaningful icons.

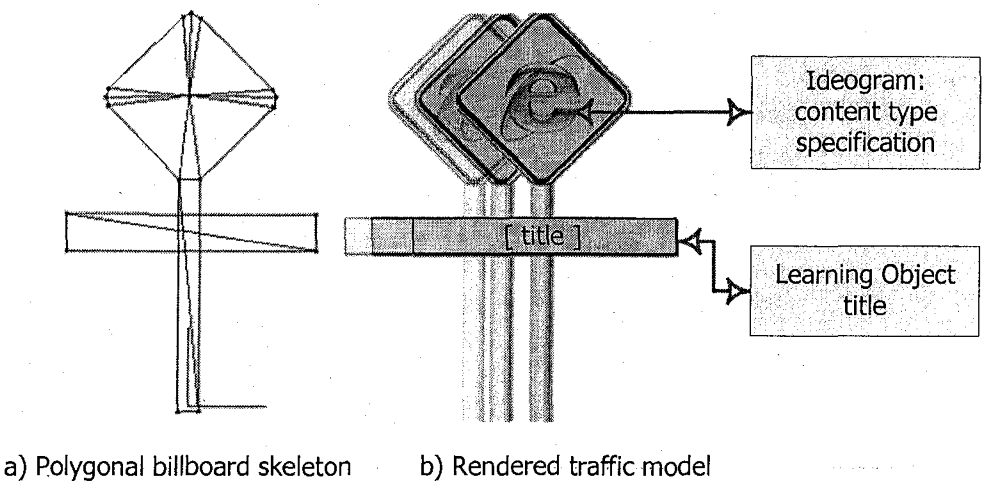

Figure 3.3 3D Traffic Sign Template for the representation of LOs
(e.g. template for traffic signs of html type LOs)

The object in Figure 3.3 has two clear design alternatives when it is to be represented in the 3D virtual environment metaphor. Table 3.1 shows these two options in terms of several criterions. Obviously, a billboard model representation is a possible design choice. However, billboard models suffer from the imprecise selection limitation, which is a very important factor in terms of user interaction with the model. Therefore, we have created a 2D polygonal billboard template (see figure 3.3a for the representation of LOs). The polygonal model requires fewer triangles than 3D models, it always faces the camera as a billboard, and it provides higher selection precision than that of billboard models (see Table 3.1).

Table 3.1 Model template representations of Learning Objects

Model Selection	Collision Detection	Number of Polygon	Selection Precision	Memory Requirement	Resultant Frame Rate/sec.
Billboard	Easy	Less (2 triangles)	Imprecise	Less	Optimal
3D polygonal	Difficult	More (100+ triangles)	Precise	More	Average
Polygonal billboard	Easy	Moderate (15 triangles)	Precise	Less	Optimal

3.2.2 Virtual Environment Model

This section describes the 3D models that are used for different purposes such as, representing the avatar, decorating the virtual world, and embedding the reference point in the VE. Some of the key objectives of constructing the VE model are to reduce the CPU usage, send less data to the Graphics Processing Unit (GPU) to avoid exceeding its throughput, utilize less bus bandwidth while moving data into the graphics unit, and enhance graphics rendering performance by adopting a geometric Level-of-Detail (LOD) reduction algorithm. In this section, we describe the different VE models such as avatar, terrain, 3D reference models etc. to construct the basic environment and decorate it in order to create a navigational space for the users to search.

A. **Avatar**: In our prototype system, a car is used as the virtual avatar of the user that one can control to explore and navigate the VE. The avatar, that essentially represents the user in the search environment, has a number of automated event-driven animations associated with it. These animations such as the rotation of the wheels, collision responses, and other transformations have been controlled based on the interaction of the avatar with the VE. The car avatar could also be replaced by the human avatar and a layer based animation control could possibly be adopted as proposed in [16]. However, in a highway metaphor, a car is a more appropriate choice. Each avatar is characterized in terms of its speed, steering handling, vehicle type, color, and acceleration parameters. The system matches these parameters with user preferences (colors, car types, age, gender etc.) and proposes an optimized avatar model to the user by considering the available system resources (CPU time, memory). In addition, a user can manually select his/her preferred avatar from the predefined set of 3D avatar models. However, the avatar proposed by the prototype always shows better rendering performance.

B. **Terrain**: Terrain geometry represents a topographic model of the bare earth. The elevation data of the terrain is kept inside a data file that relates to a rectangular grid. In order to enhance terrain rendering performance, we adopt a block based simplification model of the geometry to prune out essentially all patches that are outside the field of view. This is followed by per vertex simplification that considers the view dependent scheme to use screen space geometric error metrics for producing multi-resolution details [15]. In order to enhance rendering time, the system dynamically listens to the available system resources and adjusts the error metrics calculation accordingly. Appropriate shading and texture based lighting were applied to produce a realistic image of the terrain.

C. **Reference Models**: We have carefully used 3D models for real life objects such as houses, trees, elevated ground, light pillars, stone pillars, road block signs, and water animation to imitate a realistic VE. The aim is to provide the user with a 3D metaphor with familiar surroundings. The 3D objects are used carefully so that the user can remember these models as references points (such as the main road is situated by the school building, etc.) in the VE, which improves his/her navigational experience.

3.2.3 GUI Control

The graphical model includes GUI controls that are used to input the user commands such as query parameters, user authenticated information, preference selection, toolbar commands, etc. These controls are graphically enhanced with animation, intuitive colors, and detailed texture to enrich the user's experience.

3.3 3D Gaming Environment

The 3D gaming environment is the global interface for the users to search, navigate and interact with the search results. To generate this environment, the Data Model and the Graphical Model (see section III) are used and several functionalities such as searching, personalization, clustering, visualization, navigation, interaction, and randomization are incorporated. In the following, we describe the underlying principles for each of these functionalities.

3.3.1 Searching

Searching is the primary operation that a user usually performs. Figure 3.4 shows the layered search model. From the query interface layer (layer-1), the users can perform a basic keyword-based search or an advanced search specifying different attribute values of the LOs. In order to expand the search boundary, the user specified query parameters are semantically translated based on the WordNet dictionary [20] in layer-2. The translated query is executed in a federated search mode to fetch the search results from different search services (layer-3). The search request is performed via web-service calls.

The search results are retrieved in XML format and hence need to be parsed by the system to get the values of the individual data elements. Our system parses the XML messages and passes those values to layer-2 where the results are clustered into groups (see section 3.4 below) and mapped onto the 3D spatial layout to generate the 3D virtual traffic architecture.

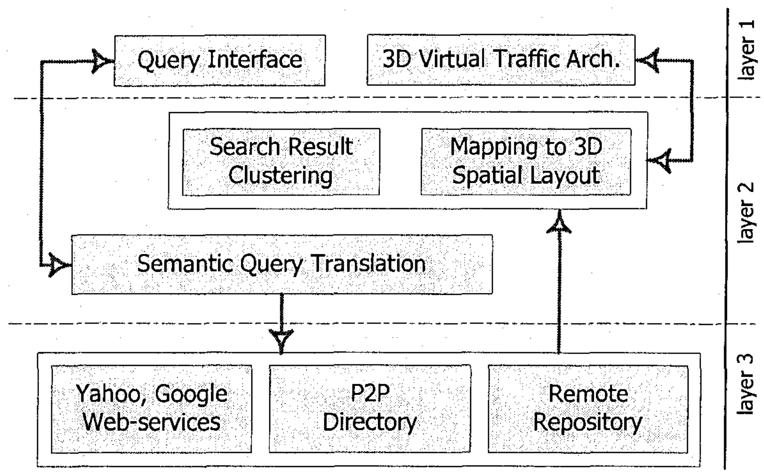

Figure 3.4 Layered search model

3.3.2 Personalization

The system enables users to personalize their searching, navigating, and learning experience within the 3D world. This is performed in several ways. One of the approaches we adopted was to maintain an individual user profile that includes the user's demographic information, age limit, area of expertise, topics of interest, search history, among others. These factors are taken into consideration while searching the LOs and delivering the targeted 3D virtual environment to the user.

The next approach we followed was to enable a user to choose the 3D shape of the learning objects and the virtual avatar such as selecting a car from an available list. The selection of the objects will be reflected in his/her next search operation. Furthermore, a user is able to select any visited object and put it in his/her favorite list. Later, the system provides options for viewing those selected objects by mapping them in the 3D world.

3.3.4 Navigation

The car avatar model is used to navigate through the road architecture in the virtual environment. In case the user tries to drive the car off the road or approaches a road end position, the collision detection algorithm is used to slow down the speed of the car. To augment the user's navigational experience appropriate ideograms, landmarks, and reference models are provided. In addition, a preview of the 3D landscape is used as a navigational map (figure 3.5) in order to show the navigating user his/her point of presence in the 3D environment. Furthermore, a direction indicator that always points to a reference position prevents the user from getting lost in the 3D world.

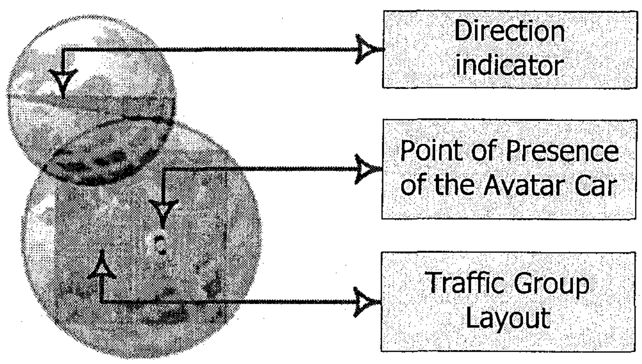

Figure 3.5 Navigational layout of the 3D metaphor

3.3.5 Interaction

While navigating in the 3D environment, the user interacts with the displayed search results for viewing the associated metadata description, playing/previewing the LOs, and saving the search history in the local repository for later review. The user's interactions can be performed through the keyboard, mouse, joystick, microphone or any combination of these devices. A typical user may interact with the 3D representation of search results with a mouse by clicking on the object. Our observations in the usability testing show that, more than one interaction device facilitates the users to efficiently interact with the application. Figure 3.6 depicts a high-level hierarchical interaction model adopted by the Event Processing Engine of our prototype. The GUI controls, car avatar, and LO models listen to different interaction devices through the Global Event Listener.

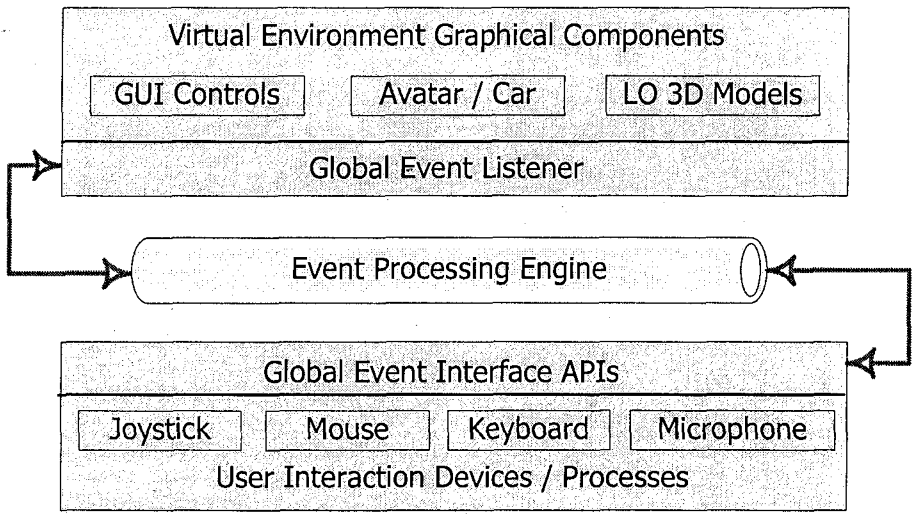

Figure 3.6 High level user interaction model

3.3.6 Randomization

Randomization is the process that is intended to bring a new look and feel to the 3D world. The random world is generated by selecting arbitrary objects from the existing object repository. The navigating user may choose this option at any time during their presence in the 3D world. Although the randomization process changes the look and feel of the 3D world with new terrain, sky, background, trees, houses, and others, the search results that are currently displayed will remain unchanged in the new randomized world.

3.4 Learning Objects Clustering

Unlike any traditional information visualization techniques, our system uses a 3D highway metaphor to display the LOs. The highway metaphor facilitates the use of roads and crossroads in the environment. The focus is to display relevant and grouped search results in the 3D road layout so that navigation and information selection becomes easy. Based on the searched keywords, the prototype applies heuristic methods to create relevant metrics to construct groups from the search results. Figure 3.7 summarizes the overall algorithm to group the search result.

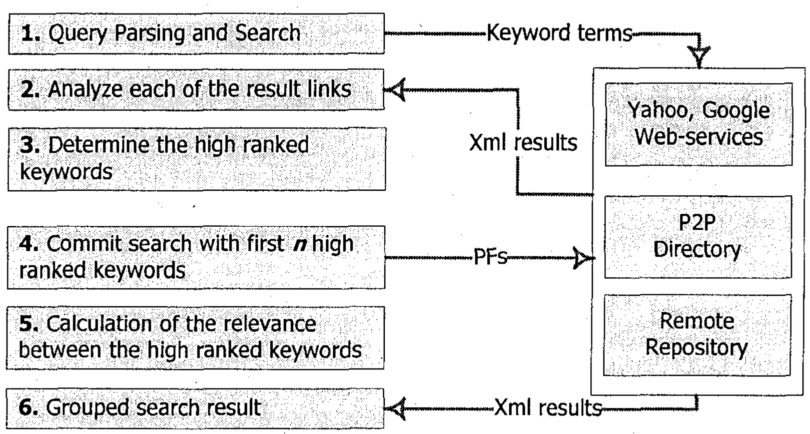

Figure 3.7 Algorithm for clustering the search result over the 3D virtual environment.

Clustering of the search results requires a grouping scheme, which is dependent on a number of components. We have adopted an intuitive search result grouping scheme, which is described in the following:

1) The learner constructs the query to be searched from the multimedia repositories. The initial search is carried out with the learner's query.

2) A constant number of search results are obtained and then investigated in order to determine high ranked and weighted keywords, which are relevant to the search terms.
3) Afterwards, for each of the first ***n*** high ranked and weighted keywords, subsequent and separate searches are carried out. This results in ***n*** groups of search results.
4) Furthermore, semantic relevance of the high ranked keywords is determined. Later, these metrics are used to calculate the 3D coordinates for each of the ***n*** search groups.

In the next three sub sections, we shall discuss some key methods of the algorithm. In the beginning, we will illustrate the ranking process of the keywords that takes place while investigating the initial search results. In the next subsection we will describe a new method of calculating the semantic relevance between the high ranked keywords. At the end, we will present algorithms on how these high ranked keywords and their associated relevance metrics are used to estimate the visualization parameters of the grouped search results in the 3D virtual environment.

3.4.1 Weighted Keywords

In this section we will discuss and define our postulates in order to find metrics that could be used to cluster the search results. An initial inquiry suggests that the ranking of keywords is related to the frequency of the keywords found in the search results.

The rank of the keyword $\Re(\kappa)$ [78] in a set of documents is a way to weigh the keywords in order to evaluate how important a keyword is to a document. In this weighting function, the importance of a keyword increases as the frequency of the keyword increases in a document, but the degree of importance diminishes depending on how common the keyword is in all the documents. The rank or weight of a keyword κ_i is calculated with the following formula:

$$tf = \frac{c_i}{\sum_d c_d} \tag{1}$$

Where, c_i is the number of occurrences of the keyword, κ_i and c_d are the number of occurrences of all words in the document. Inverse document frequency is calculated by the following formula:

$$idf = \log\left(\frac{|D|}{|\kappa_i \in d_u|}\right) \tag{2}$$

$|D|$ is the number of all documents in the system, d_u is the document being considered. Then,

$$\Re(\kappa) \cong tf * idf \tag{3}$$

A high rank is reached by a high term frequency in the given document and a low document frequency of the term in the whole collection of documents.

3.4.2 Keyword Relationship Metrics

The semantic relevance metrics calculation of the high ranked keywords is the main issue of this section. Later, the metrics will be applied to compute the 3D coordinates of the group symbols. Specifically, we are interested in the hypernym semantic distance of the keywords as they are more related with human reasoning and association of the keywords. However, it is unlikely that the hypernym distances of the keywords will always be found. Therefore, the hypernym relation calculation algorithm has to be modified to consider certain special cases. Using the Wordnet lexical thesaurus database we can determine and calculate hypernym relation metrics between keyword κ and keywords g using the following equation:

$$\Im(\kappa, g) \cong \sqrt{\left|\hbar(g)^2 - \overline{M}^2\right|} \tag{2}$$

Where, *0<g<length(K)* and *K* is the set of keywords for a given search result. Whenever possible, a direct hypernym relation between the search keywords should be calculated using the equation 2. However, if there is no direct hypernym distance $\hbar(g)$ that exists for the keyword pair <κ, g> then a third keyword could be used to establish the relationship.

$$\Im(\kappa, g) \cong \sqrt{\left|\underbrace{\min[\hbar(\kappa,\ell) + \hbar(\ell, g)]^2}_{\ell \exists K} - 2\overline{M}^2\right|} \tag{3}$$

Again, in order to apply the equation 3, two parameters needed to be present in the keyword matrix. A hypernym relation is needed between κ to ℓ and another between ℓ to g. For trivial cases, let us consider that no such keywords exist for which both of the parameters could be deduced. For example, let us consider the case where we have calculated the hypernym distance $\hbar(\kappa, \ell)$ but are unable to process $\hbar(\ell, g)$ in the above equation. In this case, we can apply the following postulates to assign a reasonably less correct value and apply clustering in the 3D environment.

In order to calculate $\Im(\kappa, g)$ we will choose a certain value $\hbar_\delta(\ell, g) \approx \varepsilon$, which maximizes the assigned value of the equation.

$$\Im(\kappa, g) \cong \sqrt{\left|\underbrace{[\hbar_\delta(\kappa,\ell) + \varepsilon]^2}_{\lambda_{\min} \le \varepsilon \le \lambda_{\max}} - 2\overline{M}^2\right|} \tag{4}$$

In equation 4, $\lambda_{\min}, \lambda_{\max}$ are the minimum and maximum values respectively returned by the $\hbar_{\delta}(\kappa, g)$ in the entire calculation of the hypernym distance set for the keywords. Finally, the relevance metrics that would be used to calculate the distances of the keywords in the virtual environment could be found by the following equation,

$$H(\kappa) \cong \sum_{0<g<length(K)} \Im(\kappa, g) / \Re(\kappa) \tag{5}$$

In equation 5, the lower value of $H(\kappa)$means the higher relevance of the keyword compared to other keywords in the overall set. In the following we will provide step-wise descriptions for constructing search groups that use the reliance metrics stated in the above equations. The algorithm effectively uses the common parent index and the relevance metrics calculating procedure to deduce the relationship matrix. This is fundamentally the reason why the least valued keyword is considered as the root (starting node) in the final constructed road network. In the visualization procedure the root is the group that will be mapped in the first road in the metaphor as it contains the most relevant information sought by the learner.

3.4.3 Construction of the Road Network

After calculating the matrix values for the keyword sets the next major step is to use the metrics in clustering the groups in the virtual environment. In order to determine the clustering and degree of the group nodes we have applied the minimum spanning tree (MST) over the matrix. Therefore, the resulting spanning tree consists of the edges from individual keyword nodes that are of the minimum semantic distances. Minimum spanning trees are proven to be useful in our case for the following reasons:

- The computation time is quick and simple.
- The algorithm results in a sparse sub graph that reflects a lot about the original graph, which is suitable with our approach.

- There is no cycle in the final sub graph that offers the possibility of designing a road network very easily (as described in the following algorithm).

The resultant sub graph is further sent to the visualization engine where the semantic distances are converted into a visual representation (in this case, road network) to establish meaning and pattern. To construct such a visualization approach, the following algorithm has been proposed:

Algorithm SEMANTIC_ROAD
Begin

/* *The algorithm takes the vector graph containing the semantics of the keywords in matrix form (calculated hypernym distances). MST is applied to get the sub graph, which is then processed considering various customizable parameters to form the road network where the search results can be easily mapped.* */

1. Extract the graph information and apply the MST /* *After that, we have a sub-graph where all the nodes are connected and no cycles exist in the graph**/
2. **For** each element *E* of the sub graph *S* **do** the following
3. **If** (*E*.exploredFlag = **false**) **then** /* *The node is the root of the whole road structure* */
    a. Mark the node as taken, *E.exploredFlag*=**true**;
    b. Calculate the color value for the group to distinguish itself from the others, *E*.color = **new** Color(*Keyword*) /* *Each keyword is unique in the keyword set**/
    c. Therefore, the minimum length of the road could be determined as the following: *E*.roadLength = $\max\langle \deg ree(E) * \eta, count(E) * \delta \rangle$, where η = minimum distance

between two parallel branch roads and δ = minimum distance between two traffic signs containing LOM records. /* *Hence, the size of any road is decided considering the number of partitions in the road (node degree) as well as the number of search results associated with the keyword for which the road has been constructed* */.

d. Assign predefined 3D positions for the root road.

e. Calculate the position values for each node that is connected with E and toggle the direction of the branch roads so that one road directs to the left and the next one to the right, thereby effectively positioning the roads to use available space over the virtual environment. Finally, mark all the connected roads as taken.

4. **else** /* *The node is a child node and its position has alreadybeen calculated* */ Repeat steps **b** and **c** of the above in order to calculate the distinct color value and road length of this node and hence apply step **e** to determine the position values for each of the connected nodes with E.exploredFlag = **false.**

End *SEMANTIC_ROAD*

It should be noted that though very unlikely the roads comprising greater semantic distances may cross each other. Therefore, a unique color value is chosen from the keywords (as keywords are unique) and is applied to respective roads to separate them. This is essentially the reason we toggle the directions of the side roads while connecting them with the parent road. Moreover, using MST [21] instead of pure graph is one of the tactics we employed to avoid the cross between roads in the final road network. The road size calculation is another important issue. The number of side roads (to connect relevant search groups) that appear from a parent road depends on the degree of the node as well as the number of search items in the parent group. Therefore, the trade off is to take the maximum size that would accommodate all the search items and will connect all the side roads to the parent road while keeping a moderate distances between them.

The MST creates the clusters (see figure 3.8a), which are then considered for road architecture construction and object mapping. The road architecture construction procedure assigns 3D coordinates and employs the following techniques. The root (*T*) node is the first road (the position of which is known). All the connected nodes of the *T* node are considered as branches. The *T* node is partitioned equally by the number of connected nodes, *CT*. The coordinates for the *CT* nodes are calculated based on the partition value. Each *CT* node road becomes the opposite type of *T* node, i.e., if the *T* node is horizontal, the entire *CT* node roads become vertical and vice versa. In addition, *CT* nodes flip direction (see the example in figure 3.8 below). The length of a *CT* node depends on the minimum traffic object distances and the actual number of connected nodes it contains. Furthermore, each of the *CT* nodes is recursively processed as that of the root node *T*.

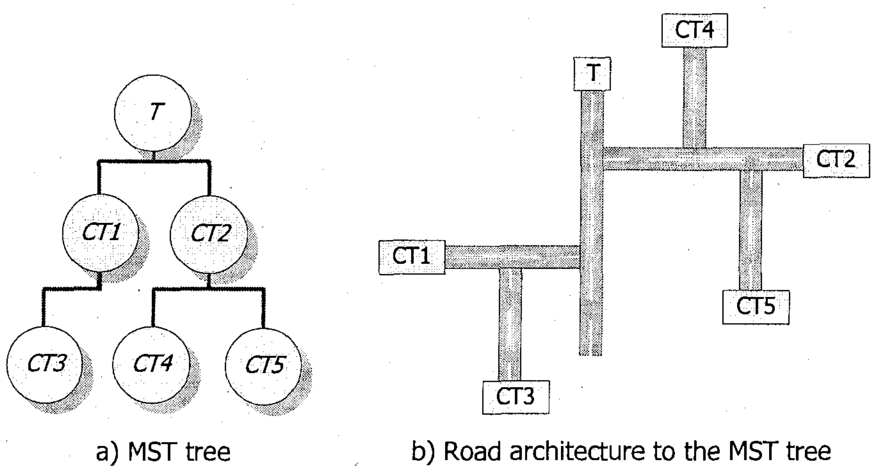

Figure 3.8 Semantic keyword metrics of the MST tree and the corresponding road architecture.

The object representations of the user search results are dynamically arranged in the aforementioned road layout. If the number of results returned is more than what the system can handle efficiently, the result is prioritized and displayed accordingly. Overall, the technique effectively illustrates relations, creates identifiable patterns and reduces the information overload to facilitate learners' or teachers' effectiveness in navigating, exploring, and searching information.

3.5 Data Sharing Architecture

The application framework is comprised of components to share, search and visualize the LOMs in a peer to peer network. The information mapped in the 3D metaphor allows an intuitive way to perceive the content information and assists in finding and sharing related resources. In this section, we want to present the peer to peer network model followed by some of the major software component models of the application framework.

3.5.1 Peer Architecture

Let us look at defining the components of an interoperable framework; the peer to peer network will tie them all together and the description of their model will allow other institutions to use the services. Hence, to promote 'share and reuse' multimedia learning materials, the peer network as depicted in figure 3.9, has been logically categorized into three main types – user peer, address mapping peer, and search service peer. Any peer requesting services is termed as a user peer. Usually it sends the search keywords to the address mapping peer of a particular group, $\hat{G}$. The address mapping peer applies procedures (described in the next section) and returns path information. The user peer uses that information to send the search keywords to the search service peers of $\hat{G}$.

A search service peer in the system allows registered users to search and retrieve LOMs. Hence, the shared information from the peer is used to access the content from standard LORs and browse in the 3D virtual environment. The distributed processes combine their computational processing power to adapt to the search quarries.

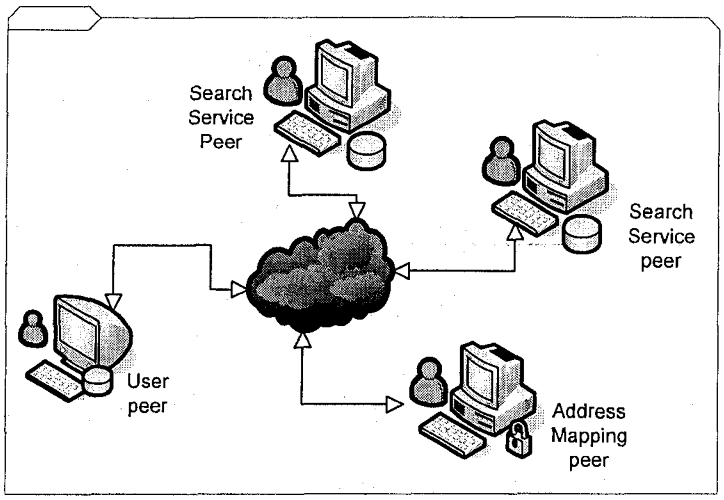

Figure 3.9 A sample peer to peer searching environment. Peers can register in the group's address mapping peer and voluntarily serve as a search service peer.

It is implicit that each of the participating peers in the data sharing model is not dedicated. In practice, a peer can act as a user peer, address mapping peer or search service peer in various states. In order to share information to group Ĝ, a peer can register to Ĝ's address mapping peer by providing appropriate authentication information and make the service available to others. In addition, service to a peer could possibly be provided if it is registered in the address mapping peer thus forcing the peer to participate in the process.

3.5.2 Discovery Peer Model

The discovery peers are responsible for producing reliable peer addresses that can serve search services. The search service peers are partitioned (any heuristic suitable to a group) according to the various requests they can perform. Whenever a peer wants to provide service to a peer group, it registers itself to the addressing mapping peer of that group by providing information on how its service will be mapped.

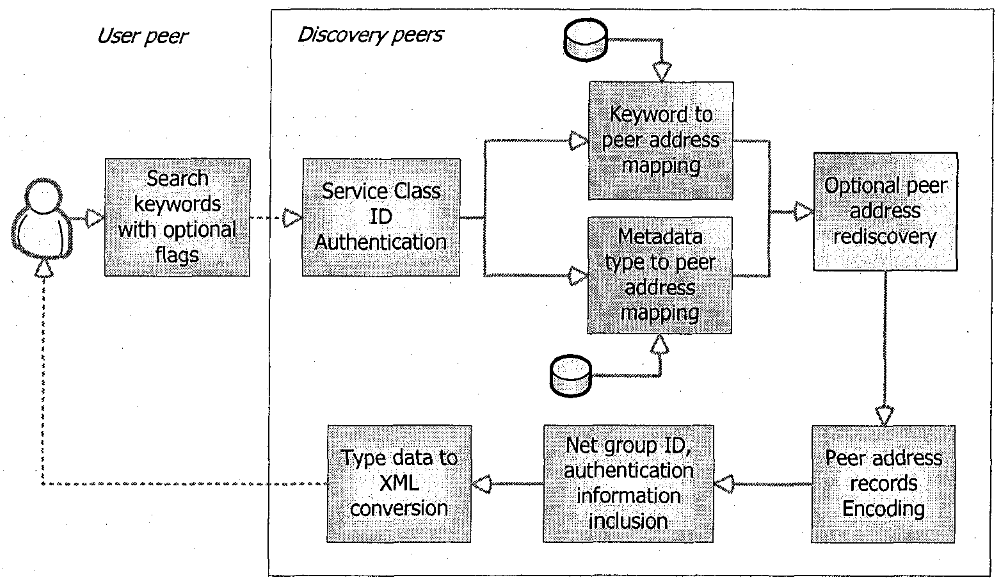

Figure 3.10 Different functional components of a discovery peer

As depicted in figure 3.10, to access search services from a group, Ĝ, the user peer must first send its search keywords to the address mapping peer of Ĝ. The discovery system then uses the heuristics to map keywords to the relevant search service peer address of Ĝ and includes authentication information. By altering the optional flags, the user peer can request address rediscover so that the search service addresses returned will be validated before sending. Peer address encoding and XML conversion are another two optional services the peer can request. It should be noted that, any group can restrict service inclusion from different peers to follow specific topics. For example, the group may accept services and service requests with the topics of Java and Xml only. Hence, the user peer has to show a sense of awareness about the content information served by different groups while requesting services.

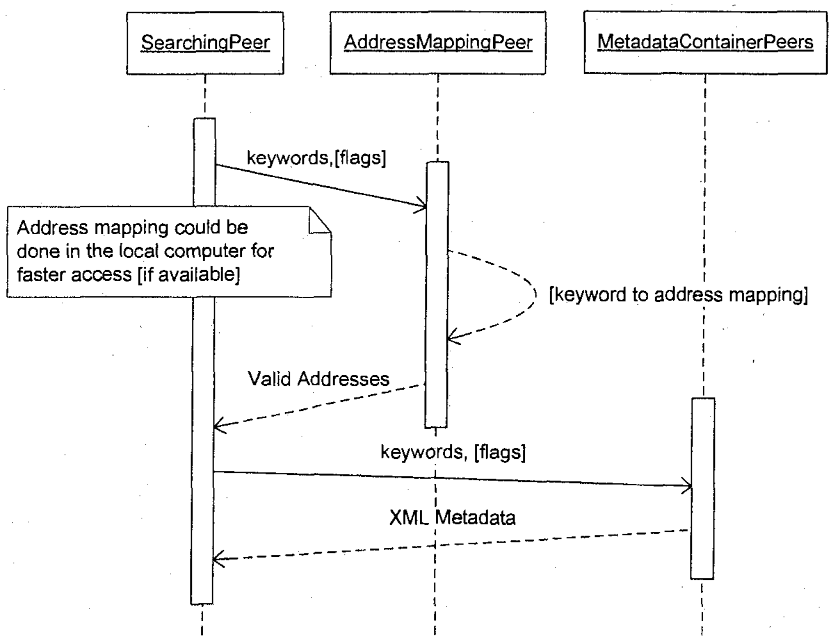

Figure 3.11 A sequence diagram depicting the information flow in the sharing and searching phases.

3.5.3 Keyword Sense Mapping

The address mapping peers employ lexical keyword sense mapping to find relevant subject matters on the search keywords. The process is inspired by current psycholinguistic theories of human lexical memory [12]. English nouns, verbs, adjectives and adverbs are organized into synonym sets, each representing one underlying lexical concept. We are using hypernym relations to find out the link in the synonym sets and hence, the primary focus was on nouns and verbs. As an example of the system, figure 3.12 represents different senses for a particular keyword (e.g. car, automobile). The senses are augmented with the main keywords to find peer addresses. Afterwards, the user peer requests the LOM information from the search service peers of this group using all the senses of the keywords.

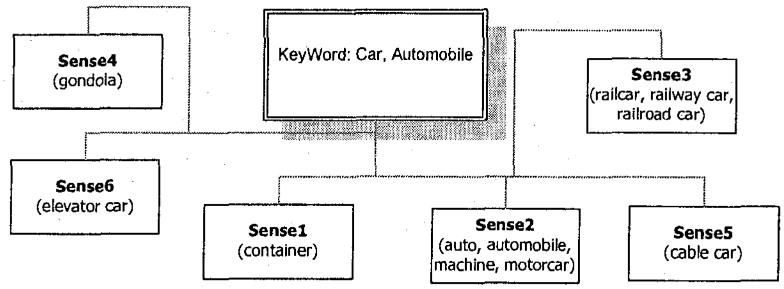

Figure 3.12 Hypernym semantically equivalent words (synsets) for the keywords car/automobile

3.5.4 Searching Peers

With all the software components in hand, searching for LOM information is relatively straight forward. A graphical user interface in the virtual environment takes the query and feeds it to both the search service discovery module and keyword sense mapping module. As described in figure 3.13, a search is initiated using all possible senses of the search keywords and is sent to the search service peers. In turn, the search service peers return XML-LOM data. The information obtained is then grouped using an algorithm that takes the keyword senses into consideration. The information visualization engine then uses these groups and maps them into the 3D virtual environment.

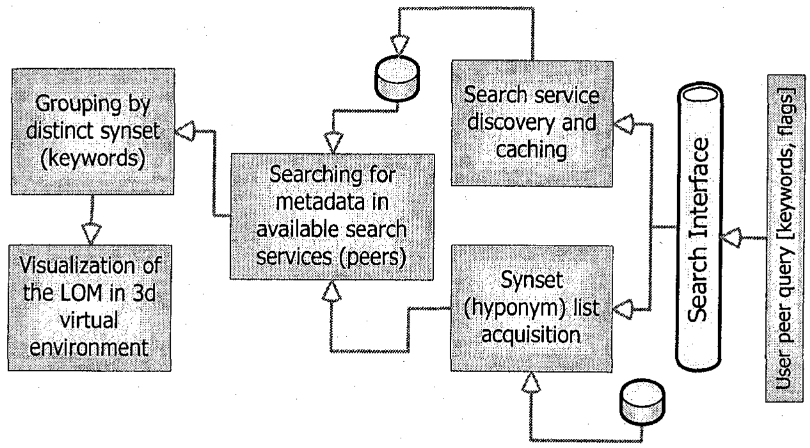

Figure 3.13 Different software components of a peer

To leverage search response time, service peer addresses are cached in the local space. Hence, address discovery is not carried out for successive search requests with keywords having the same senses. Additionally, while navigating in the virtual environment, the learner can bookmark interesting LOM resources (and later can share it by publishing to some other learning groups). This bookmarked information can also be grouped and visualized in the intuitive virtual environment to understand the relations (if any) and have a better perception of the learner's subject matter.

Chapter 4

Implementation

The prototype system EYE & WHY has been implemented using the design concepts described in the previous chapter. This chapter presents the actual implementation process of the prototype. Additionally, we will provide the implementation details of our prototype and gradually describe the Software Architecture, Platform and Deployment issues, and present some sample interfaces.

4.1 System Requirements

EYE&WHY is built with as much open source software as possible. As it is a web based tool, several web technologies are considered. In the following table 4.1 summarizes a list of components that have been investigated and used in order to implement Eye & Why:

Table 4.1 Different components of the Eye & Why prototype

Component name	Description	Required at	OS Licence Type	Publisher
Lwjgl.jar 0.99	Light-weight OpenGL based java game library	Required ▪ Runtime ▪ Build time	BSD license	LWJGL

openAL.jar	3D audio API	Optional ▪ Runtime ▪ Build time	LGPL	OpenAL
js.jar	XSLT or for IBM's Bean Scripting Framework	Optional (runtime only)	CC	
Wordnet database	Lexical database	Required (runtime only)	WordNet 2.1 license	Princeton University
JWordnet	Java standalone object-oriented interface to the WordNet database	Required (runtime only)	BSD	The George Washington University
sphinx4.jar	Speech recognition library	Optional (runtime only)	BSD-style	The CMU Sphinx Group
mysql.jar (3.0.9)	MySQL JDBC Driver (works with MySQL Server 4.0.x)	Optional (runtime only)	GPL	MySQL AB
xerces.jar (1.4.4)	SAX parser	Required (runtime only)	Apache Software License	The Apache XML Project
freetts.jar 1.2.1 cmu_time_awb.jar cmu_us_kal.jar cmudict04.jar cmulex.jar cmutimelex.jar en_us.jar	Speech synthesis API	Optional ▪ Runtime ▪ Build time	BSD-style	Sun Microsystems,Inc and Language Technologies Institute, Carnegie Mellon University
Jsapi.jar	Java Speech API	Optional ▪ Runtime ▪ Build time	BCL -Binary Code License	Sun Microsystems, Inc

The Java application and the Java applet prototypes were developed using the Java 2 Platform, Standard Edition, v 1.4.2 (J2SE) in Eclipse SDK v 3.1. The Eye & Why applet prototype itself is available for download from MCRLab demo section [65] under the BSD license [66]

4.2 Platform and Deployment

The Eye & Why prototype is implemented using a Lightweight OpenGL-based Java Game Library [12]. We have used a P4 desktop PC (2.20GHz, 512MB RAM) with a

NVIDIA GeForce MX/ MX400 graphics card having 32MB VRAM. The operating platform is Microsoft Windows XP Professional, v 5.1.2600 Service Pack 2 Build 2600, total Physical Memory: 1,536 MB. The overall system was first deployed as a Java Web Start based application then later upgraded to a standalone Java Applet that could be accessed in the web browsers. The idea is to use the power of the client's desktop to provide a smooth graphics rendering facility. The later version, unlike the previous Web Start version, does not need to install any additional packages in the client machine in order to launch the desired application.

4.3 Development of Software Architecture

The detailed software architecture is depicted in Figure 4.1. There are several modules in the overall system that performs different functionalities. The Search Interface handles all the search requests of the user. It invokes the Metadata Extractor module that retrieves LOM records from the distributed repositories. The search results are returned from the repositories, which are in XML format. The LOM-XML Parser module parses these results to extract the LOM elements. The parser is implemented using the Java SAX [18] parser. The parsed LOM elements are used by the LOM Clustering Module to cluster the search results into different groups. The 3D Graphics Engine is responsible for all the graphics generation and rendering mechanisms. It maps the different groups of search results to create the 3D world by using templates of primitive graphic objects from the 3D Template Repository. The User Manager authenticates the user's log in information. It also maintains individual user profiles in the Profile Repository for providing a personalized learning environment.

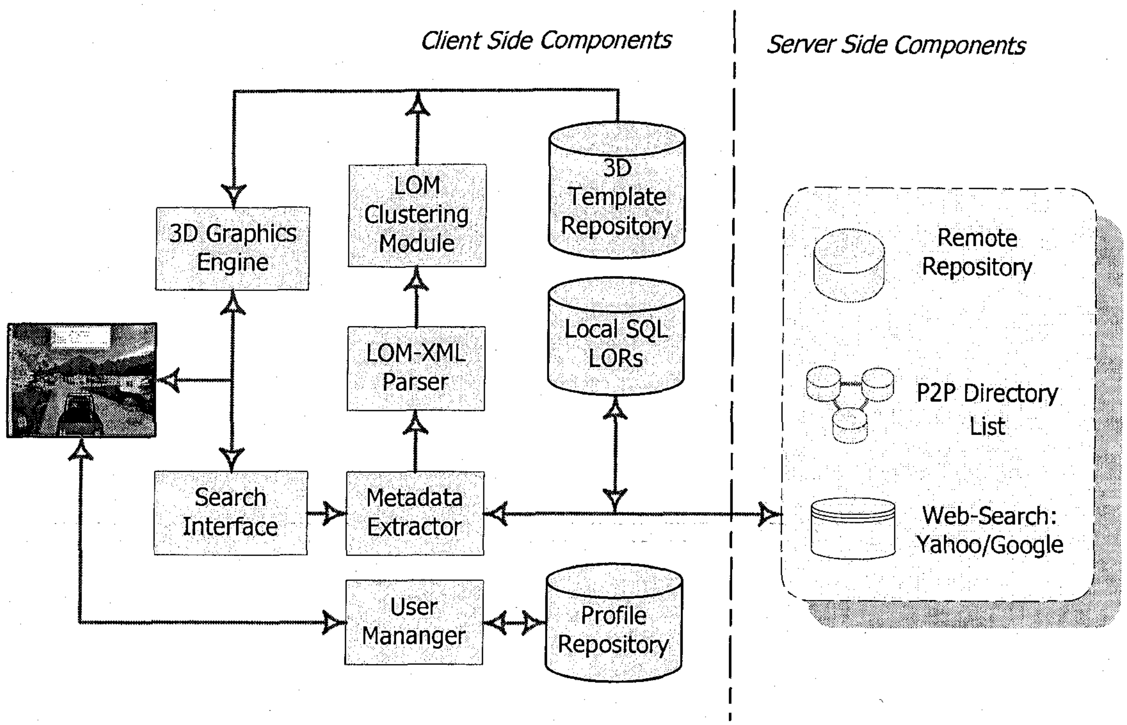

Figure 4.1 Software architecture of the EYE & WHY prototype.

4.4 Example Interfaces

The Highway metaphor is a "car traveling" in a 3D virtual environment with roads, houses, mountains, lakes and trees. The user can choose an avatar car from a wide variety of selections and use it to start the research in an amusing way. The usage of a car metaphor implicitly fosters the navigation process providing a "game sensation" to the user. The navigation is very easy to perceive and to adapt to because the user has the tools, the car avatar, and the data is outside, organized on the streets.

The example interfaces are organized mainly in two different ways. In the beginning, we will present the screen interfaces concerning 3D information visualization. At the end, we will show some essential 2D interfaces, which are mostly related to the interactions with the 3D models and their functional aspects.

4.4.1 3D Visualization

The following, figure 4.2, shows the screen that appears after the user selects another metaphor created dynamically using familiar objects such as traffic signs and roads. In this view, we have the overall road architecture created using the clustering algorithm. Each of the roads has a group sign, which gives access to basic commands to interact with the LOs of that group. The user can activate the group interaction menu by clicking over it to bring the menu as seen in the screen. The user can also navigate through the VE using the dynamic world layout located on the bottom-right corner of the screen.

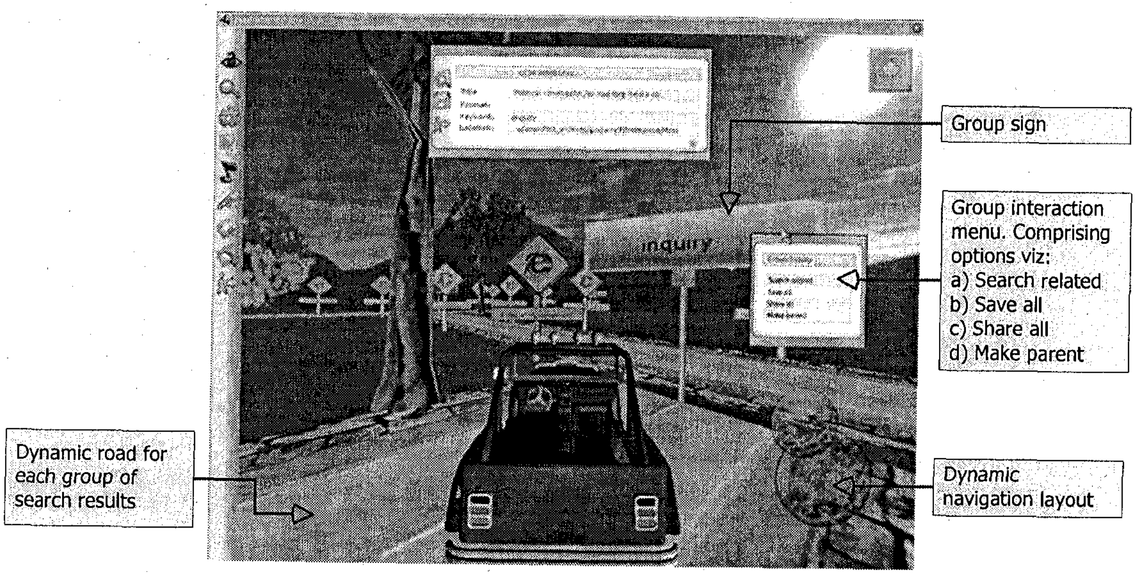

Figure 4.2 Information visualization in dynamically created road architecture.

Figure 4.3 shows a sample screen shot when the search results are rendered in the grid based road layout. The LO organization becomes straight forward with the use of the algorithm, but with some limitations. All the branches of the groups are not mapped instead they are kept for access using the 'Make Parent' feature in the group menu (see figure 4.2). Navigation in the grid based road layout is very easy and more entertaining as it is populated with more 3D objects such as water, houses, billboard trees, etc, as seen on the screen.

When the user navigates in such an environment s/he can remember the layout and information organization with ease. Furthermore, the mouse based navigation layout assists the user to browse through the learning object organization quickly. The learning objects are organized along the roads, where each road is given a group sign to understand the content information represented by the road (please see figure 4.3). The navigation layout contains the shortcut location of these group signs and visualizes them as red circles, which can be interacted with by using the mouse.

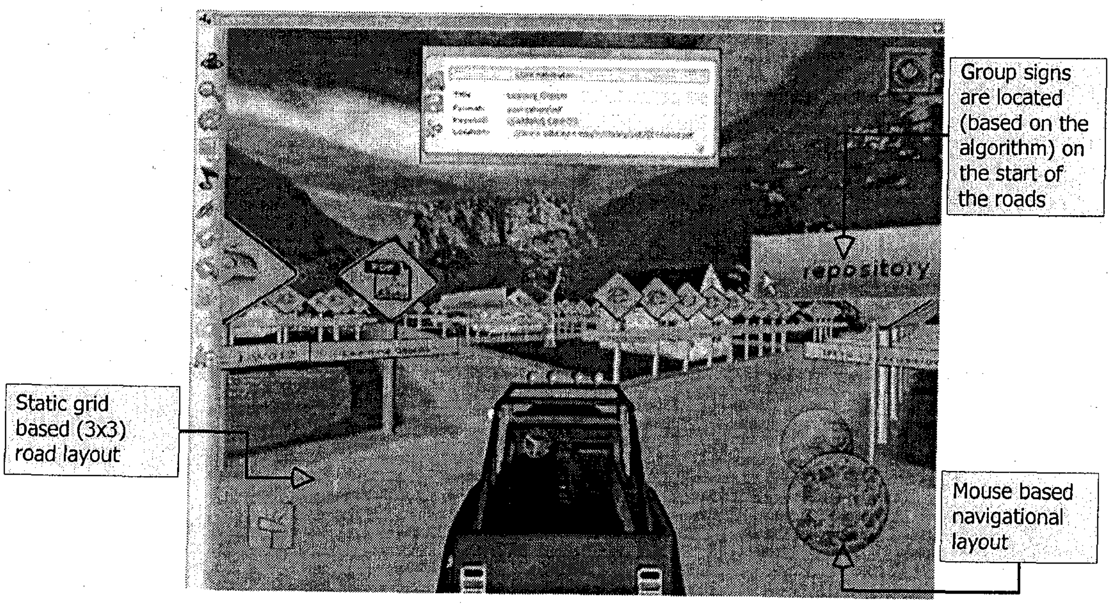

Figure 4.3 Information visualization in a 3x3 Grid based road layout.

The user can randomize the graphical contents and change the look and feel of the VE. Terrain texture, skybox, water texture, trees, and car layouts can be changed using the randomization method. Figure 4.4 shows another look and feel of the 3D interface, where the interior car model is used as the user's avatar in navigating the LOs.

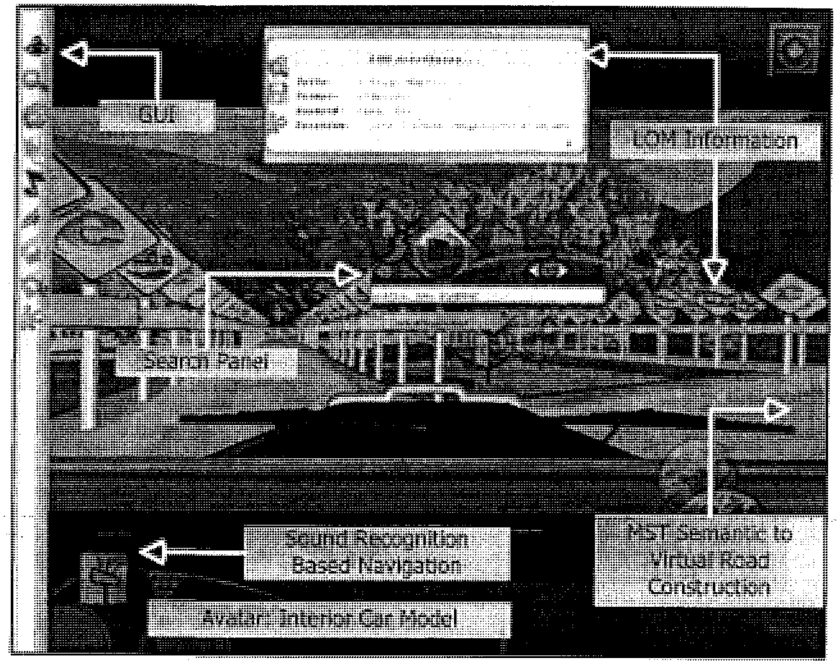

Figure 4.4 A Sample 3D navigational interfaces with an interior car model.

4.4.2 2D Interfaces

a. The Function Bar

The car avatar is controlled through the keyboard arrows by using the left (turn left), right (turn right), up (acceleration) and down (stop) keys for respective navigations. To select and view the learning object metadata (LOM) information the user clicks on the traffic sign and a small window will pop-up containing related information. In order to access the main functional components there is a function bar at the left containing the following commands (please note, tool tips are provided for each icon, see figure 4.5).

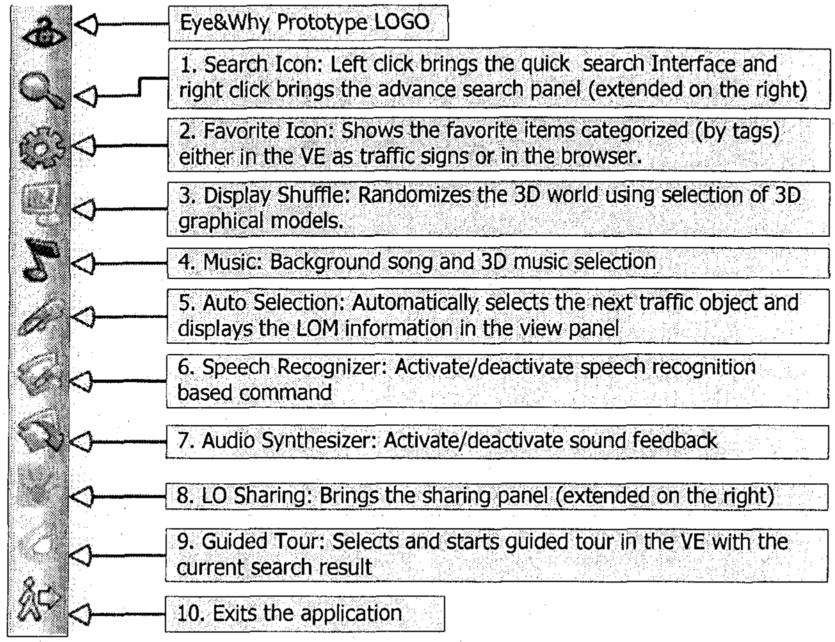

Figure 4.5 Typical shortcut commands located on the function bar.

The search bar commands are listed below in top to bottom order:

1) The magnifying glass icon represents the search action. It will bring the search window as depicted in figure 4.6, where we can specify the keywords to be searched. After submitting his selection criteria, he is provided with the search results displayed in the 3D environment, similar to Figure 4.2, Figure 4.3, or in any other selected metaphor.

2) The wheel icon is the shortcut to access the user's search history. The user can save any search result he has visited by pressing the save icon (figure 4.7) in the pop-up LOM information window.

3) The shortcut containing the display icon is used to change and randomize the theme of the 3D virtual environment. Subsequently, it loads the 3D objects, keeps them in the memory, and recreates the 3D world.

4) The music icon is used to turn ON/OFF the background natural music.

5) Auto selection of the traffic LOM sign (the pen icon) can be used to enable/disable the selection feature, where the nearest traffic sign is selected as the user navigates through the roads.
6) The next icon enables/disables the speech recognition based audio command for navigation as well as interacting with the LOM view panel in the virtual environment.
7) The sound shortcut icon on the function bar is used to enable/disable the audio synthesis voice assistance. It assists the user by saying relevant information dynamically. It triggers when the user interacts with the traffic objects.

b. The Search Box

The graphical search interface is slick in design and portrays quick search interfaces to reach the refined results. Enter one or more keywords (separated by comma) on the search window. Afterwards, press enter to commence the search, or simply click on it to exit. In addition, the search interface supports quick access to advance search options by using short unique modifiers, such as the following:

- *Intitle:* The user can enter this modifier followed by a colon and parts of the title, which will allow him/her to search only in the titles of the LOMs in the appropriate repository.
- *Inttags:* By using the intags operator the search API will conduct the search in the personal directory of the peer groups only in the tag fields specified by the users.
- *Indesc:* This search modifier must be used as the previous two and will allow the user to only search in the description of the search results.
- *Filetype:* The user can direct the search to be conducted for certain file types. To do so, the user can use the file type modifier followed by a colon and one or

more file type specifications (e.g html, image, or video). This modifier can be used along with other modifiers.

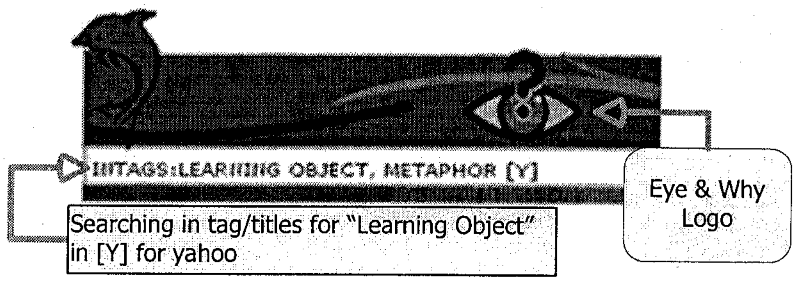

Figure 4.6 Quick search GUI control with a textbox and Eye & Why Logo.

To select a particular multimedia content repository, the user can enter short forms of the repository in the search text box as modifiers. For example, if the user wants to search for the keyword "metaphor" in the repository as well as in the Google web search, then s/he can use: metaphor followed by the repository modifiers [R][G]. Here G stands for Google and R stands for the available learning object repository. Similarly the user can select Y for the Yahoo web search and L to search local favorite search history.

To save the search result automatically in the local search repository (the tags would be the search keywords by default) the user can enter [S] along with other search modifiers. This is particularly useful if the user wants to browse the search result many times.

c. The LOM View Panel

Figure 4.7 shows another zoomed in interface for touch and click interaction with the 3D traffic objects. With the interaction, the LOM view panel is activated and the selected LOM contents are shown on it. The LOM view interface presents a number of shortcuts to reach related functions concerning the LOM.

1. *Play/Browse:* The option opens the LO content in the browser as shown in figure 4.8. Depending on the file type assessment, the player selects appropriate plug-ins in order to play the multimedia content.
2. *Save/Favorite:* Using this option, the user can save the LOM content along with one or more user-defined tags that can later be shared with other peers. Furthermore, the saved LOMs are stored as XML documents and are readily viewable either in the integrated browser or mapped along the roads (similar way the LOs are mapped) in the 3D VE.
3. *Share this:* With this shortcut command the user can share the LOs with other peers. The share preferences and options are opened in the extended window on the right as can be seen in figure 4.8.
4. *Speak Content:* In the LOM view panel the user can use the 'Speak content' option to turn on the dynamic audio synthesis based voice assistance. The audio assistance reads the content of the LOM and encourages the learning process of the user.

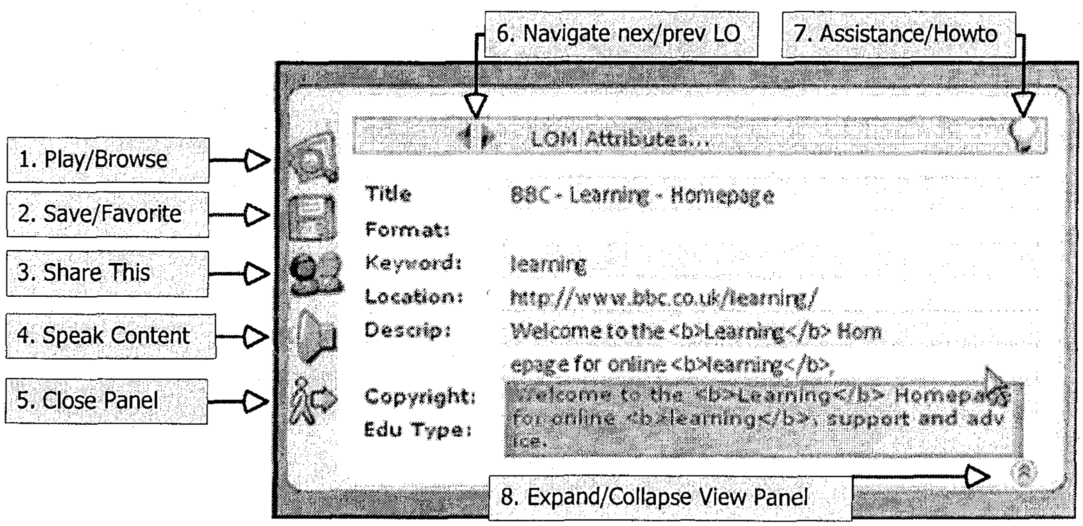

Figure 4.7 An extended view of the LOM information panel

d. Sharing Interface

Figure 4.8 shows a 2D interface when the user selects the advanced search option. The search preferences are opened on the extended right panel on the window. Here, the user is able to search either by specifying multiple keywords or specific LOM elements such as title, format, description, and eventually on a number of other LOM attributes. He can also specify which repository he wishes to include in the search. After submitting his selection criteria, he is provided with the search results displayed in the 3D environment similar to Figure 4.2 (dynamic organization), Figure 4.3 (static grid based organization) or in any other selected metaphor.

The bottom-right portion of Figure 4.8 shows the sharing LO panel interface, which becomes activated when the user selects the share option. The user is able to share the selected learning object(s) either by specifying multiple keyword tags or by proposing a title for the shared LOs. Furthermore, depending on the selection, the LOs can be shared using three different sharing schemes for different learners. For now, only three kinds of schemes have been implemented. They are as follows:

- *Private*: only the owner will be allowed to browse or search the content marked by this cursor. The content will not be visible online.
- *Protected*: only permitted members in a group (created by the user) will be able to access and search the personal LOMs in the user's favorite directory.
- *Public*: the directory content marked by this visibility cursor will be available to all the users in the peer group of which the user is a member.

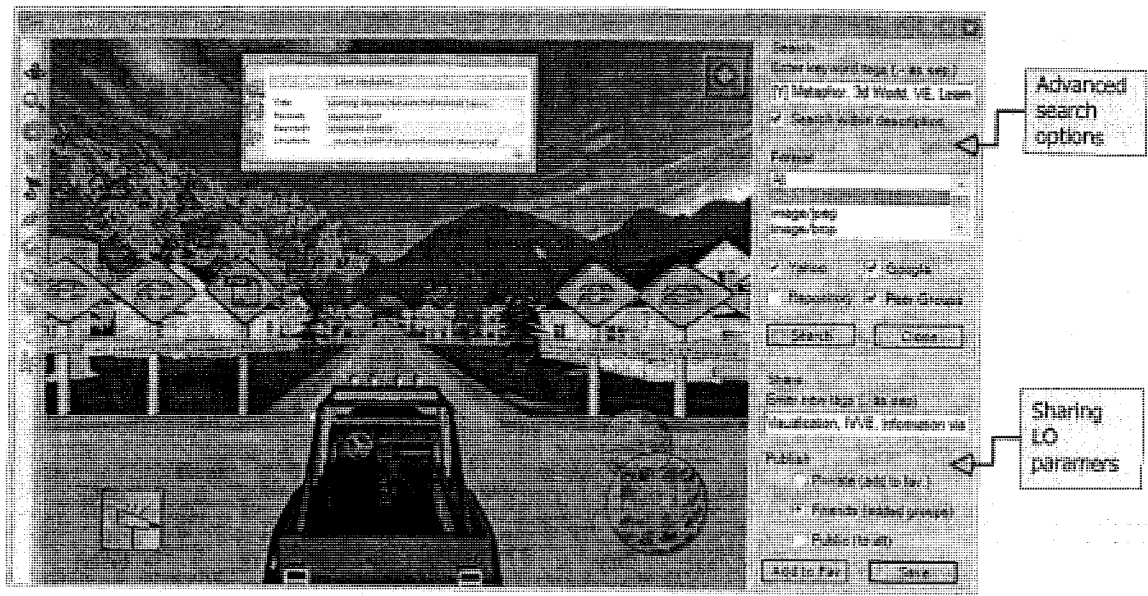

Figure 4.8 An extended panel provides the user options for advance searching and sharing of LOs from within the interface

e. Browser

Figure 4.9 shows another interface for mouse or keyboard based interactions with the traffic LOM objects in the case of an HTML document. Unlike an image, or movie object, the html document is opened in a separate browser. The integrated content browser automatically selects appropriate plug-ins to render the different types of media objects from within the 3D environment.

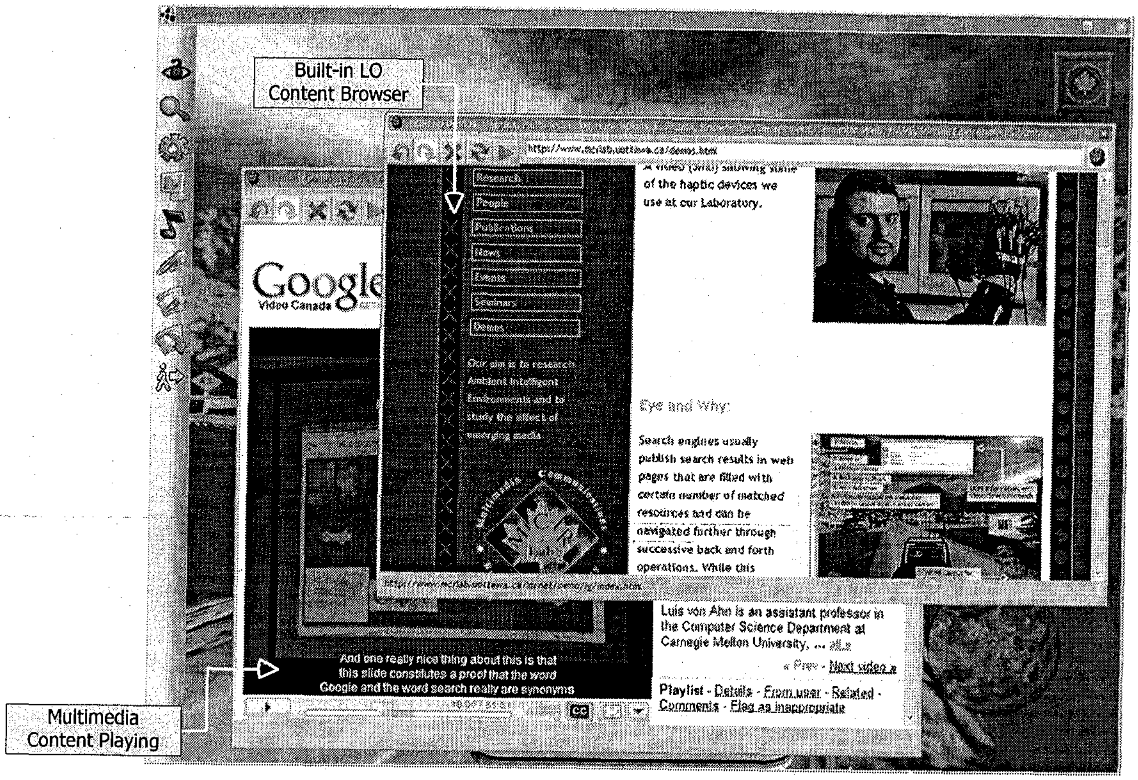

Figure 4.9 The integrated browser supports conventional browsing along with image, audio and video by using additional plug-ins.

There are other navigational interfaces such as the user profile entry interface, admin interface, 3D graphics setting interface, and general search preferences. The sample screen shots of these interfaces are not presented here, but are available in the software prototype of Eye & Why.

Chapter 5

Evaluation and Results

We have performed several quantitative and qualitative measurement studies to evaluate the user's quality of experience with the prototype and to justify the suitability of our proposed approach. The quantitative analysis of the metaphor is performed by evaluating the frame rate, total rendered triangles, searching time, clustering time and mapping time. On the other hand, the qualitative analysis is performed by studying different usability aspects of the proposed system. These are described in detail in the following:

5.1 Quantitative Measurements

Figure 5.1 shows the frame rate with respect to different planned search results. By the planned search results, we are referring to the number of search results to be displayed in the 3D world at one time. Based on this limit, we performed an exhaustive test in order to measure the frame rate (fps) and the respective triangle counts of the system. It is evident from the figure that the frame rate is inversely related to the number of search results. Even when the system displays a high volume of search results (e.g. ~500), it still has a good perceived rendering quality (~14fps).

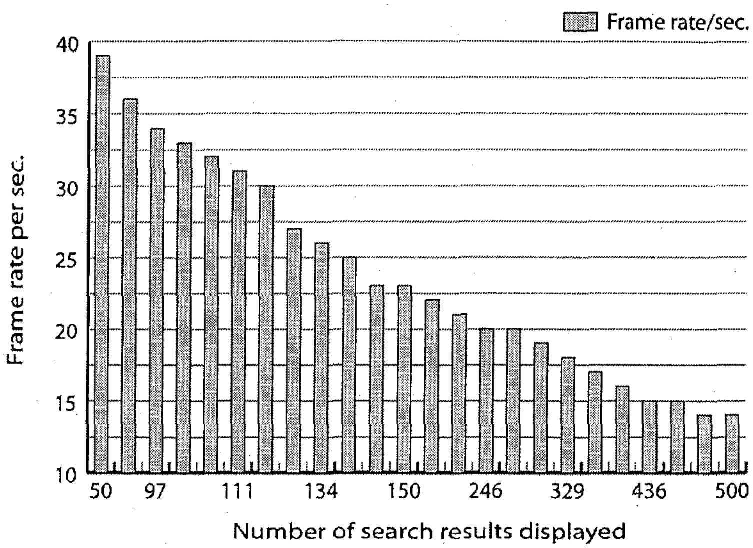

Figure 5.1 Mapped search results vs. frame rate/sec

Figure 5.2 represents the total triangle count of the 3D graphics for the similar range of search results. It is clear from the figure that the triangle count is directly proportional to the number of search results mapped in the 3D world. When the system displays 50 search results, the triangle count is approximately 15200 and the frame rate is around 38.5 fps (see figure 5.1), which shows the high rendering performance of the system.

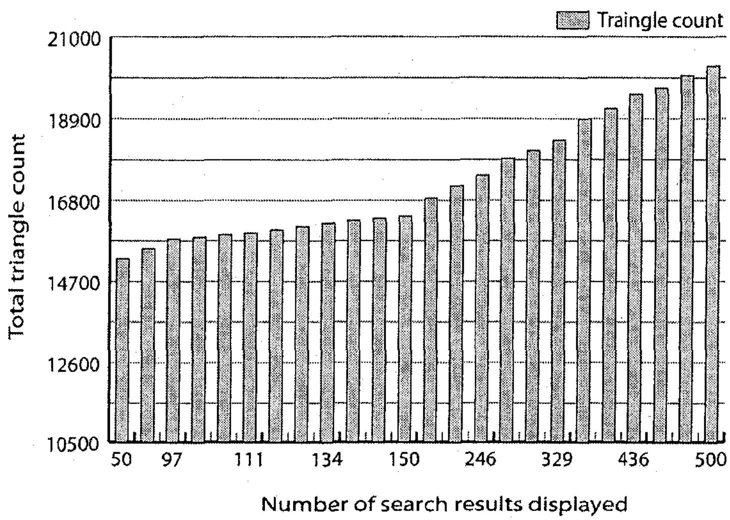

Figure 5.2 Mapped search results vs. total triangle count

Figure 5.3 shows that the selection of the appropriate search repository generally influences the search response time. We have tested the actual search response times of different distributed repositories. The figure shows that searching from the learning object repository is costly in terms of response time. The P2P based directory search is also expensive if the session is broken or is needed to be initialized for each search. Searching from the web generally takes the least amount of time. Based on these search response times, we have selected different search repositories for different groups of users. This is done because certain groups of people are less willing to wait for a longer period of time.

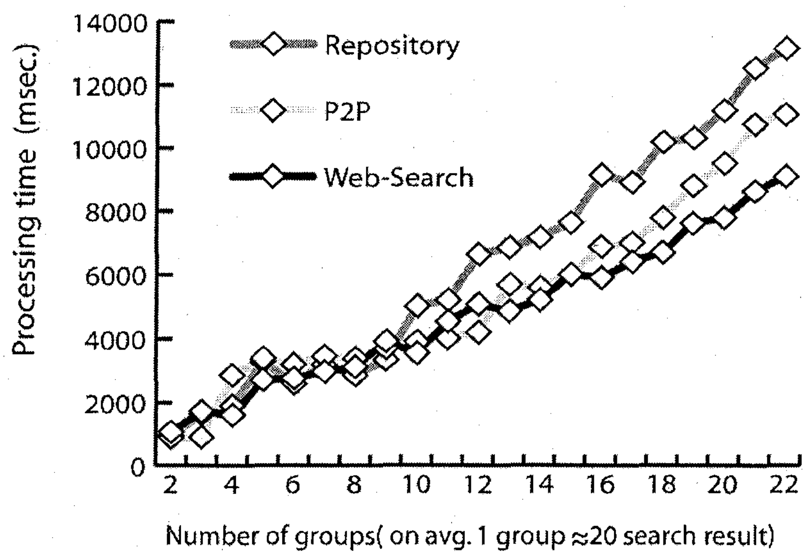

Figure 5.3 Search time comparisons of different search services

Figure 5.4 depicts the search results of the clustering/grouping and mapping times. For grouping/clustering and mapping, with approximately 440 search results (22 groups), the system takes approximately 670 (≈500+170) msec, which is very minimal. Grouping requires polynomial time $O(n^2)$ whereas the mapping (assigning coordinates) time is almost linear.

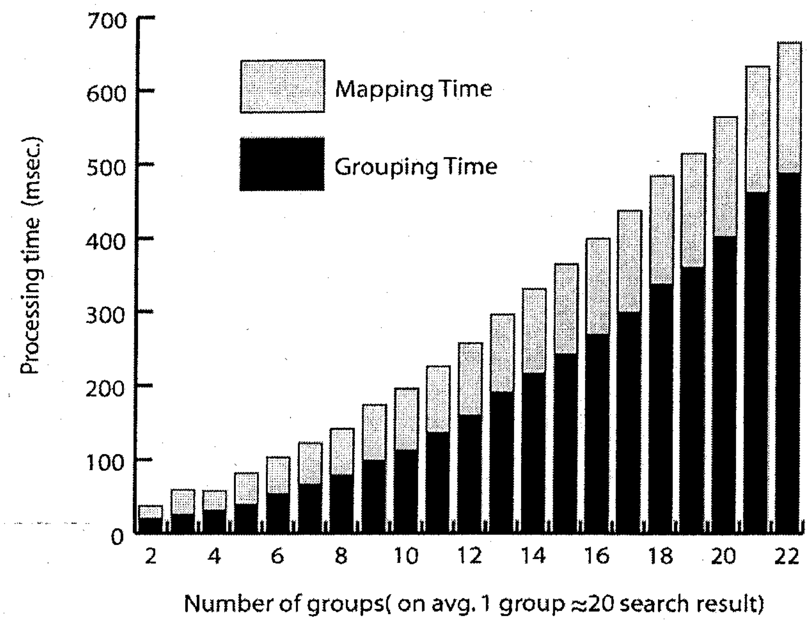

Figure 5.4 Search result grouping and mapping time in the 3D VE

5.2 Qualitative Measurements

We have performed usability tests [22, 23, 24] to qualitatively measure our proposed system. Our usability test consists of over twenty-six volunteers of different age groups and academic backgrounds. The users were requested to use the 3D environment to complete certain tasks. Based on their navigational experience they were asked to answer several questions. The answers to the questions are in the range of 1-5 (the higher the rating, the greater the satisfaction) on a Likert scale [25]. The questions were grouped into five different classes (Q1-ease of use, Q2- information clustering/grouping perception, Q3-visual quality, Q4-navigational comfort, and Q5-search response time), and their answers were summarized in order to better understand and categorize the performance of the different user groups. Figure 5.5 shows the users' responses in percentages. The responses show the suitability of the proposed 3D metaphor.

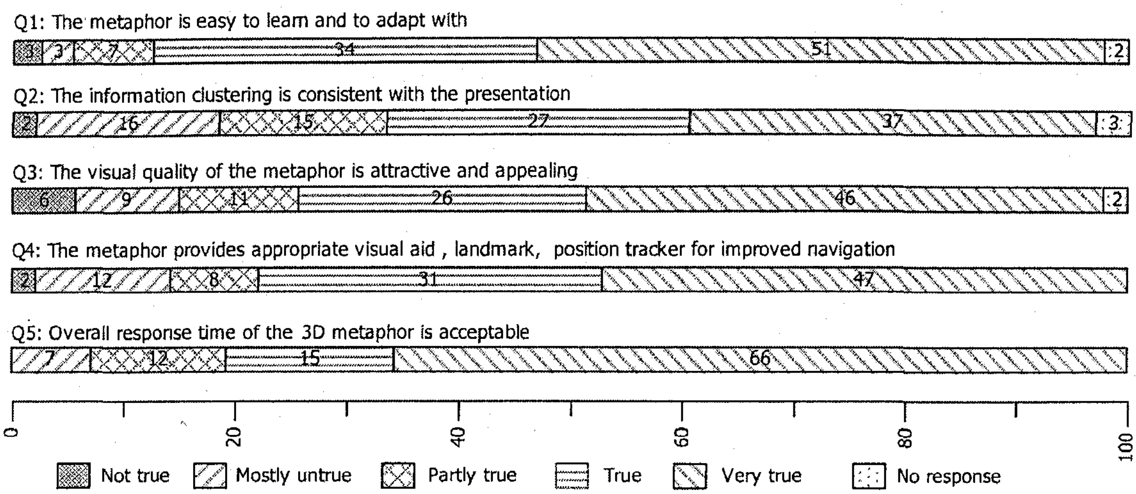

Figure 5.5 User response percentage on the evaluation of the 3D metaphor

Table 5.1 summarizes the overall performance score of the users. The higher mean values of *Ease of Use, Navigation*, and *Search Response* represent a very satisfactory user response, while the moderate mean values of *Information Clustering* and *Visual Quality* show relatively good user satisfaction.

Table 5.1 User satisfaction on the overall evaluation in the Likert scale

	Ease of Use	**Information Clustering**	**Visual Quality**	**Navigation**	**Search Response**
Mean	4.3	3.84	3.97	4.1	4.4
Std. Dev.	0.42	0.20	0.16	0.44	0.22

Figure 5.6 summarizes the evaluation to show the user satisfaction based on their 3D application/gaming experience. The users who have prior 3D gaming experience could easily use and navigate the system. They are, however, critical of the visual quality and information presentation parameters. The users who have no previous 3D gaming experience found the visual aspect very appealing. However, such observations do not seem to hold in all respect. The overall satisfaction score, which is almost identical for all the groups, signifies this assumption.

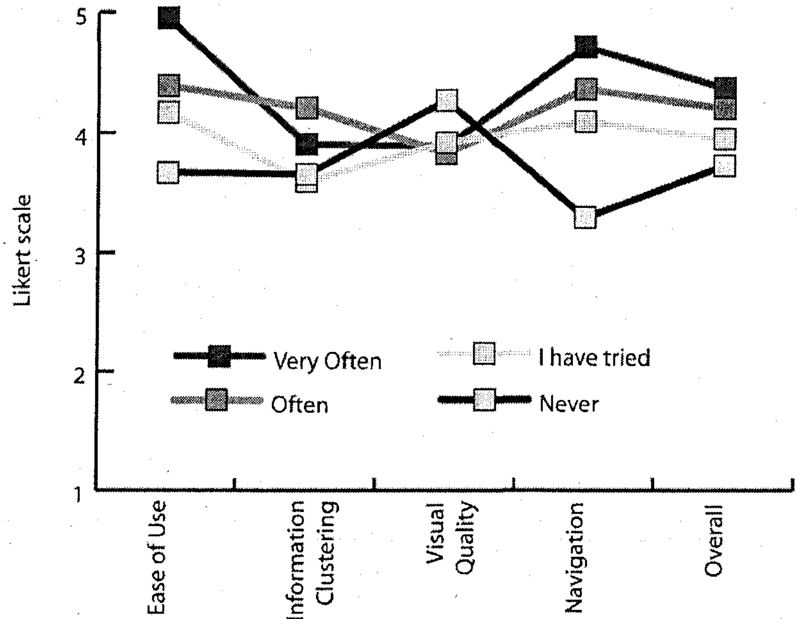

Figure 5.6 User satisfaction based on the 3D application/gaming experience

In our study we also attempted to evaluate the acceptability of the system by the users of two different age groups (group-1: ages 9-17, group-2: ages 18+). Compared to the older group, the younger group seemed to be more attracted to the game-like search interface and liked to navigate and interact with the 3D world even when they were not assigned any particular tasks. The older group was satisfied with the search response time while the younger group was more cautious about it. Figure 5.7 summarizes this observation.

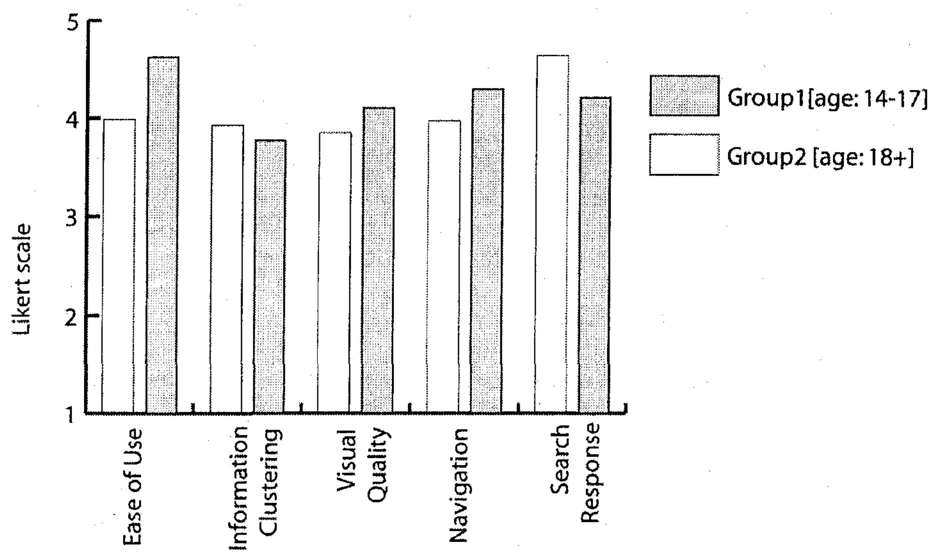

Figure 5.7 Comparison between responses of users from two different age groups.

Chapter 6

Conclusion and Future Work

6.1 Conclusion

In this thesis, we presented a new way of visualizing search results in a 3D virtual gaming environment. The spatial landscape of the 3D environment is proven to be useful in order to represent more information at a time. The interactive, visually rich and 3D graphics enabled information visualization scheme allows the user to explore the semantic LO organization, discover patterns, browse content, and share the experience with other users. The semantic organization of the information lets the learners gain a quick overview of the searched knowledge and give access to explore related learning content very easily.

Gaming by default has its own attractions to the learners, especially to the youth. Hence, the use of a car gaming metaphor in our system is entertaining and engages the learners. It also provides intuitiveness in the search and exploration operations that are performed while navigating the 3D world. We incorporated IEEE LOM standards as the base data model for identifying and searching learning objects from distributed repositories. This enabled us to extend our search operations to cover more repositories as they become available. Also, the standard element names brought forth the possibility to add new visual metaphors without changing the data extraction layer. Finally, we showed some test statistics covering different quantitative measurement aspects of our system.

There are some limitations in our prototype tool. There is no means to update the tagged metadata associated with the displayed LO, except for viewing them. Such updates require authorization since the LORs are maintained by different communities. However, we could try to do the same for the LOR that we implemented. This may facilitate filling the metadata tag values that would otherwise remain empty. Another limitation is that there is no semantic arrangement of the 3D data objects in the virtual environment. This is due to the fact that no such semantic relationships descriptions are currently maintained among the LOs. We want to address some of these issues in the future release of the prototype.

One of the possible extensions of the system would be the exploration of haptic devices in view of facilitating interaction with the 3D objects in the virtual environment. This new improved way of interaction would enable the system to produce forced feedback from the environment thereby making the user more involved in the searching process. Also, we are exploring the possibilities of including collaborative navigational features in the proposed system.

Furthermore, we are also planning to investigate more 3D information visualization metaphors and conduct extensive usability tests. However, we believe that our proposed visualization techniques will remain as a motivation for further research in this area.

I sincerely hope, with the effort and ideas presented in this information visualization prototype research, it will open up new opportunities for future researchers, which will bring new innovative information visualization paradigms through intuitive scopes and openings.

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