3-2000

Three-Dimensional Data Visualization of Electronic Military Intelligence Using the Project Broadsword System

Michael L. Goeringer

THREE-DIMENSIONAL DATA VISUALIZATION OF ELECTRONIC MILITARY INTELLIGENCE USING THE PROJECT BROADSWORD SYSTEM

THESIS

Michael L. Goeringer, Lieutenant, USAF

AFIT/GCS/ENG/00M-08

DEPARTMENT OF THE AIR FORCE
AIR UNIVERSITY

AIR FORCE INSTITUTE OF TECHNOLOGY

Wright-Patterson Air Force Base, Ohio

AFIT/GCS/ENG/00M-08

THREE-DIMENSIONAL DATA VISUALIZATION OF ELECTRONIC MILITARY INTELLIGENCE USING THE PROJECT BROADSWORD SYSTEM

THESIS

Presented to the Faculty

Department of Systems and Engineering Management

Graduate School of Engineering and Management

Air Force Institute of Technology

Air University

Air Education and Training Command

In Partial Fulfillment of the Requirements for the

Degree of Master of Science in Engineering and Environmental Management

Michael L. Goeringer, B.S.

Lieutenant, USAF

March 2000

AFIT/GCS/ENG/00M-08

THREE-DIMENSIONAL DATA VISUALIZATION OF ELECTRONIC MILITARY INTELLIGENCE USING THE PROJECT BROADSWORD SYSTEM

Michael L. Goeringer, B.S.,
Lieutenant, USAF

Approved:

Lt. Col. Timothy M. Jacobs	7 Mar 2000 date
Dr. John J. Salerno	2 Mar 00 date
Maj. Michael L. Talbert	8 Mar 2000 date

Acknowledgments

The research presented here was only possible through the trust, support and faith of many individuals. First and foremost I would like to thank my wife Nicole and our three children Sasha, Phillip and Tyler. Their understanding and support was paramount in keeping my research focused and on track. The sacrifices they made are beyond words. Thank you...I love you very much!

Special thanks goes to Dr. John Salerno and the entire Project Broadsword team. By allowing me to conduct my research at the Air Force Research Laboratory/Rome Research Site, Dr. Salerno provided me with an opportunity that few students get the chance to even consider. I would also like to thank Mr. Michael Wessing and his support staff for encouraging my work and handling the temporary duty and travel related issues.

I would like to thank Lieutenant Colonel Timothy Jacobs for his guidance. His trust and faith in my abilities is greatly appreciated. I would like to thank Major Mike Talbert for not only having an interest in my work but also taking the time to be part of my committee. Finally, I would like to thank Mr. David Buick and Mr. Rodney Forbes for some serious diversions that helped me keep things in perspective.

Table of Contents

Page

Acknowledgements i

Table of Contents ii

List of Figures v

List of Tables vi

List of Color Plates vii

Abstract viii

1. Introduction 1

   1.1 Overview 1
   1.2 Background 3
   1.3 Problem Statement 3
   1.4 Research Objectives 4
   1.5 Assumptions 4
   1.6 Scope and Limitations 5
   1.7 Research Summary 5
   1.8 Document Summary 6

2. Intelligence and Data Visualization: Relevant Issues 7

   2.1 Overview 7
   2.2 The Need for Intelligence 7
   2.3 The Project Broadsword Solution 8
   2.4 Data Visualization 13
      2.4.1 Color 15
      2.4.2 Vision 16
   2.5 Conclusion 18

3. Methodology 20

   3.1 Data Exploration 20
   3.2 Software Development Process 20
   3.3 Visualization Considerations 21

3.4 Data Navigation 22
3.5 Scenario Generation 22

4. Development Environment 24

4.1 Environment 24
4.2 Target Environment 24
4.3 Project Broadsword Code Base 25
4.4 Model Approach 25
4.5 Evaluation of Hardware Platforms 26
4.6 Software Development Languages 26
4.7 Automated Tools 26
4.8 Graphics Rendering 27
4.9 External Support 27
4.10 Commercial Off the Shelf Products 28

5. Design and Implementation 30

5.1 Environment 30
5.2 Three-dimensional Visualization 31
5.2.1 Three-dimensional Objects 31
5.2.2 Multilevel Glyphs 33
5.2.2.1 Level One Glyph 34
5.2.2.2 Level Two Glyph 39
5.2.3 Level Of Detail 40
5.3 Navigation 44
5.3.1 Graphics Navigation 45
5.3.2 Textural Navigation 46
5.4 Multimedia 50
5.5 VRML Plugin Verification 50
5.6 Conclusion 50

6. Findings 51

6.1 Introduction 51
6.2 Experiment Setup 51
6.3 Experiment Results 52
6.3.1 Visual Presentation 52
6.3.2 Visual Navigation 55
6.3.3 Textual Data Navigation 56
6.4 Conclusion 58

7. Conclusions and Recommendations 59

7.1 Introduction 59
7.2 Conclusions 59

7.2.1 Implementation Consideration 60
7.3 Further Research 62

Color Plates 65

Bibliography 77

Vita 78

List of Figures

Figure	Page
2.1 Textual Results	10
2.2 Timeline Results	11
2.3 Geospatial Map Results	12
2.4 Preattentive Processing	18
3.1 Experiment Scenario	23
5.1 Symbolic Glyphs	32
5.2 Multilevel Glyphs	34
5.3 Cylinder Shaped Level One Glyphs	35
5.4 Cube Shaped Level One Glyphs	36
5.5 Transparency as Designed	37
5.6 Transparency in Operational Environment	37
5.7 Redesigned Level One Glyph	39
5.8 Abstract Level Two Glyph	40
5.9 Model Based Level Two Glyph	41
5.10 Low Level of Detail Glyphs	41
5.11 Low Level Of Detail Glyphs on a VRML Landscape Map	42
5.12 Proximity Sensor Activation Rendering	43
5.13 Products Represented by Gray Glyph	44
5.14 VRML Environment with Frames	47
5.15 Pop-up Dialog Box	48
5.16 Text Handling	49
6.1 Glyph Representation	54
6.2 Two-dimensional Geospatial Map	54
6.3 Product Exploitation with BGONE	57
7.1 Current Results Display	61
7.2 BGONE Enhanced Results	62

List of Tables

Table Page

5.1 Intelligence Data Mapping 31

5.2 VRML Navigation 45

List of Color Plates

Plate	Page
Plate 1: Geospatial Map Results	65
Plate 2: Preattentive Processing	66
Plate 3: Symbolic Glyphs	66
Plate 4: Multilevel Glyphs	67
Plate 5: Cylinder Shaped Level One Glyphs	67
Plate 6: Cube Shaped Level One Glyphs	68
Plate 7: Transparency as Designed	68
Plate 8: Transparency in Operational Environment	69
Plate 9: Redesigned Level One Glyph	69
Plate 10: Abstract Level Two Glyph	70
Plate 11: Model Based Level Two Glyph	70
Plate 12: Low Level of Detail Glyphs	71
Plate 13: Low Level Of Detail Glyphs on a VRML Landscape Map	71
Plate 14: Proximity Sensor Activation Rendering	71
Plate 15: Products Represented by Gray Glyph	72
Plate 16: VRML Environment with Frames	73
Plate 17: Text Handling	74
Plate 18: Glyph Representation	75
Plate 19: Two-dimensional Geospatial Map	75
Plate 20: Current Results Display	76
Plate 21: BGONE Enhanced Results	76

AFIT/GCS/ENG/00M-08

Abstract

Today's military electronic infrastructure solves many problems while creating others. Using computers, battlefield and global awareness is brought to bear through the near real-time linking of sensor platforms from around the globe. These intelligence networks produce vast amounts of data that must be parsed, interpreted, digested and stored by information gathering systems. As the amount of intelligence data continues to increase, these text-based systems become cumbersome and inadequate. To ensure vital information is not overlooked or discovered too late, other forms of intelligence product management and data navigation need to be investigated.

This thesis explores procedures for enhancing the capabilities of Project Broadsword, an intelligence data retrieval system, using three-dimensional data visualization. Employing a stand-alone representative environment, this research develops methods and techniques for overcoming problems encountered when visualizing large quantities of data. Textual handling through graphical triggers is also addressed.

The results of this research demonstrate the effects of utilizing three-dimensional visual cues to organize, perceive, and navigate vast amounts of intelligence products and their associated metadata. Conclusions drawn from this research directly affect the next major release of the Project Broadsword system, currently under development.

THREE-DIMENSIONAL DATA VISUALIZATION OF ELECTRONIC MILITARY INTELLIGENCE USING THE PROJECT BROADSWORD SYSTEM

1. Introduction

1.1 Overview

Information is power. This notation has been the crux of successful political and military actions throughout recorded history. Measures of this power range from the influence of shamans and priests who were well versed in the ways of the natural world to General Schwartzkoff with his sophisticated network of surveillance platforms during the Gulf War.

Today's military decision-makers utilize data and information under the concept of Command, Control, Communications, Computers and Intelligence (C^4I). The concept of "Command" encompasses all levels of authority from the commander-in-chief to the airman in charge of a security detail. Each level requires the key individual to receive and assess known situational information, build options, and then execute his/her final decision. According to the Department of Defense's Dictionary of Military and Associated Terms, "Control" is defined as

> *That authority exercised by a commander over part of the activities of subordinate organizations or other organizations not normally under his command, which encompasses the responsibility for implementing orders or directives. All or part of this authority may be transferred or delegated.*

In this context, "Control" lends itself to the means by which information and command functions are passed. "Communication" depicts the means by which full-duplex information is moved. In essence this can be anything from runners and carrier pigeons to fiber optic network lines. Today's decision-makers no longer rely on pulp media as their sole source of data and information. With the introduction of the first computer by John V. Atanasoff in 1939, the need for and use of "Computers" has grown rapidly. Through this electronic realm, we are able to collect, manage, cross-reference, validate, meld, and examine intelligence even as the amount of data rises exponentially. Finally, "Intelligence" is the collection, analysis, presentation, and utilization of information on an area or subject of interest.

As identified by Lee Paschall, former Director, Defense Communications Agency, the line between information needs and information overdose is a blurry one that is difficult to define (1). Numerous Department of Defense programs and research efforts have been put in place to try and calculate the needs of the decision-makers while understanding that human factors play a vital part in the equation.

This research examines the "I" in C^4I, with respect to the needs, productivity, and natural ability of the intelligence analyst, through interaction with an intelligence data dissemination effort sponsored by the Air Force Research Laboratory (AFRL), Rome Research Site. Known as Project Broadsword, this web technology-based production level program is enhanced utilizing data visualization techniques. Conclusions are drawn about whether the added visual cues increase the intelligence analyst's technical productivity while maintaining an easy to adapt and use computer interface.

1.2 Background

In 1994 the Secretary of the Air Force, Dr. Sheila Widnall, and Chief of Staff, General Ronald R. Fogleman, directed the Air Force Scientific Advisory Board (SAB) to identify those technologies that will guarantee the air and space superiority of the United States in the 21st Century (2). To that end, a study was conducted in 1995 that identified those areas that are crucial for the United States to continue its dominance of air and space. The final report emphasized the importance of a global awareness capability for the warfighter. To meet this challenge head-on, Project Broadsword was created at the AFRL, Rome Research Site Information Directorate in New York State.

The main thrust of Project Broadsword is to allow the intelligence analyst seamless access to vast amounts of heterogeneous data. Achieving this goal requires varied layers of information dissemination and presentation through all levels of command. To efficiently solve such real-world problems is one of the major challenges facing the Air Force today. As stated in New World Vistas, "The problems of the next decade are to identify the relevant databases, to devise methods for collecting, analyzing, and correlating them, and to construct the needed communication and distribution architectures." (3)

1.3 Problem Statement

Since the advent of the digital computer in 1939 the amount of data and information available to an intelligence analyst has grown exponentially. Digital transfer of intelligence provides knowledge faster, in bulk, and allows for more precise tactical decisions. Today's military intelligence products, which can be found in text, multimedia, and image form, are navigated and exploited through textual interfaces. As the amount of intelligence data continues to increase, these interfaces become cumbersome and inadequate. In order to ensure vital information is not overlooked or discovered too late, other forms of product management and data navigation need to be explored. Addressing the SAB's Global Awareness agenda, Project Broadsword has developed a universal textual interface for data source management and has begun to explore the potential benefits of data visualization using a two-dimensional approach.

1.4 Research Objectives

The primary purpose of this research effort is to create a representative environment to examine ways by which Project Broadsword can offer management of intelligence products through data visualization. Based on verbal request of those attending the 1999 spring Project Broadsword user conference, this research is directed towards visualization in the three-dimensional realm. Key areas of interest include product representation utilizing three-dimensional glyphs as well as suitable and effective navigational approaches. To fulfill this objective, three-dimensional visual cues must offer the analyst an efficient and effective way of organizing, understanding, and navigating vast amounts of intelligence products and their associated metadata. The Project Broadsword verification and validation team holds the principle role of determining the suitability and productiveness of this approach.

1.5 Assumptions

If the results of this thesis are to be integrated into future Project Broadsword baselines, a level of backwards compatibility must be maintained to the version 3.0 release. Additionally, all work is constrained to the environment supplied within the Project Broadsword development and integration vault. This is to fulfill functional requirements and maintain primary security certification.

1.6 Scope and Limitations

This research effort explores an effective and efficient three-dimensional visual representation of user requested products when utilizing the Project Broadsword interface. This research narrows its scope to a limited user base and provides a proof-of-concept environment only. No attempt has been made to produce a production quality entity or provide tailored features to a particular Project Broadsword user class.

1.7 Research Summary

This research explores data visualization techniques that enhance an analyst's exploitation capability when employing the Project Broadsword system. Using a stand-alone representative environment, this research develops methods and techniques for overcoming problems encountered when visualizing large quantities of data. Textual handling through graphical triggers is also addressed. The results of this research demonstrate the effects of utilizing three-dimensional visual cues to organize, perceive, and navigate vast amounts of intelligence products and their associated metadata.

1.8 Document Summary

The remainder of this document is divided into six chapters. Chapter 2 discusses relevant issues in intelligence and data visualization. This chapter also explores the Project Broadsword solution to seamless intelligence exploitation from dissimilar heterogeneous data sources. Chapter 3 presents the research process and design methodology. Chapter 4 describes the research development environment. Chapter 5 outlines design and implementation decisions made based on data visualization, data navigation, and software development. Chapter 6 contains findings and reviews the observations made during this research. Finally, Chapter 7 summarizes this research, identifying specific contributions and proposed recommendations for future work.

2. Intelligence and Data Visualization: Relevant Issues

2.1 Overview

The exploitation of military intelligence using data visualization is a relatively new technique that few implementations have developed and put to practical use. This chapter begins by providing a cursory review of the need for military intelligence. It then introduces Project Broadsword, a software-based data retrieval system that is able to access multiple intelligence product domains through a single user interface. Finally, elements of data visualization that directly effect this research effort are presented.

2.2 The Need for Intelligence

The basic function of intelligence is to provide the requisite support for timely, sound decisions of all matters both in and out of a military conflict. As stated by William E. Colby, "The purpose of intelligence is to help you act so that you can have a better rather than a worse future. And if you act intelligently, and cause a change in that future, then of course the prediction turns out to be wrong—for the right reason, and you've really capitalized on what intelligence is all about." (4)

Intelligence is performed in a cycle that consists of collection, production, and dissemination of information. With this in mind, the tasking laid before the analysts is to understand and adapt to the operational environment. Information about the environment must be collected, analyzed, and finally molded into a comprehensible output for use by a decision-maker. The importance of this process cannot be overstated. As emphasized by General Ronald R. Fogleman, the ability to collect information, rapidly correlate it, and then quickly disseminate it to the users and commanders changes the nature of warfare (1). As we approach the 21st century, we teeter on the ability to locate, track, and catalog anything on the face of the Earth in near real time. This capability brings with it an ever-increasing demand on the part of the analyst to understand and ingest more data at a faster rate. When dealing with these vast amounts of data, we must control the flow such that only the important or key elements are brought forth and presented. Thus, only what is immediately important is driven to the attention of the analyst. Based on these concerns, intelligence exploitation systems are continually exploring advanced data presentation techniques to maintain equilibrium between our need to get more information faster and our ability to handle it.

2.3 The Project Broadsword Solution

Project Broadsword is an Air Force Research Laboratory effort sponsored by the Joint Intelligence Virtual Architecture (JIVA), the National Imagery and Mapping Agency (NIMA) and the Air Staff. In performance of their duties, the intelligence analyst has four types of information to collect and exploit - imagery, video, text, and audio. The mission of Project Broadsword is to make retrieval of these product types as seamless as possible. In order to accomplish this feat, a set of tools and services are employed which allow an analyst to search and retrieve information from a collection of heterogeneous data sources. These sources include, but are not limited to, the Military Intelligence Database (MIDB), the Image Product Library/Image Product Archive (IPL/IPA) and the Automated Message Handling System (AMHS).

Project Broadsword is made up of two elements: the client and the Gatekeeper. The client provides universal access to all available intelligence data sources via the Gatekeeper by way of standard Internet protocols. This approach allows the analyst to use a common web browser for system access. The Gatekeeper, a robust thin layer of software, performs a variety of internal functions, most notably the ability to simultaneously query multiple dissimilar intelligence databases while returning uniform results. These results are available in a multitude of formats, to include text listings, a chronological timeline, and a two-dimensional visual display.

Results are presented in one of three ways. First, all results may be returned as textual descriptions as seen in Figure 2.1, with accompanying thumbnail images (where applicable) similar to today's modern commercial Internet search engines. Figure 2.1 shows a product with a thumbnail image and the data elements under which it was cataloged. These data elements, known as metadata, consist of descriptions that, either individually or when combined, uniquely identify a product. Figure 2.1 displays only a small sample of the possible metadata elements available for a product.

If textual descriptions are not desired, a timeline may be chosen, as seen in Figure 2.2, which displays all products in chronological order of creation. This method organizes products by date and allows a larger number of products to be displayed in the same amount of screen space. The results are limited to thumbnail images coupled with a hypertext link to their associated metadata. Selecting a hypertext link generates a window containing the selected product metadata, similar to Figure 2.1. Figure 2.3 shows the third presentation method, a two-dimensional

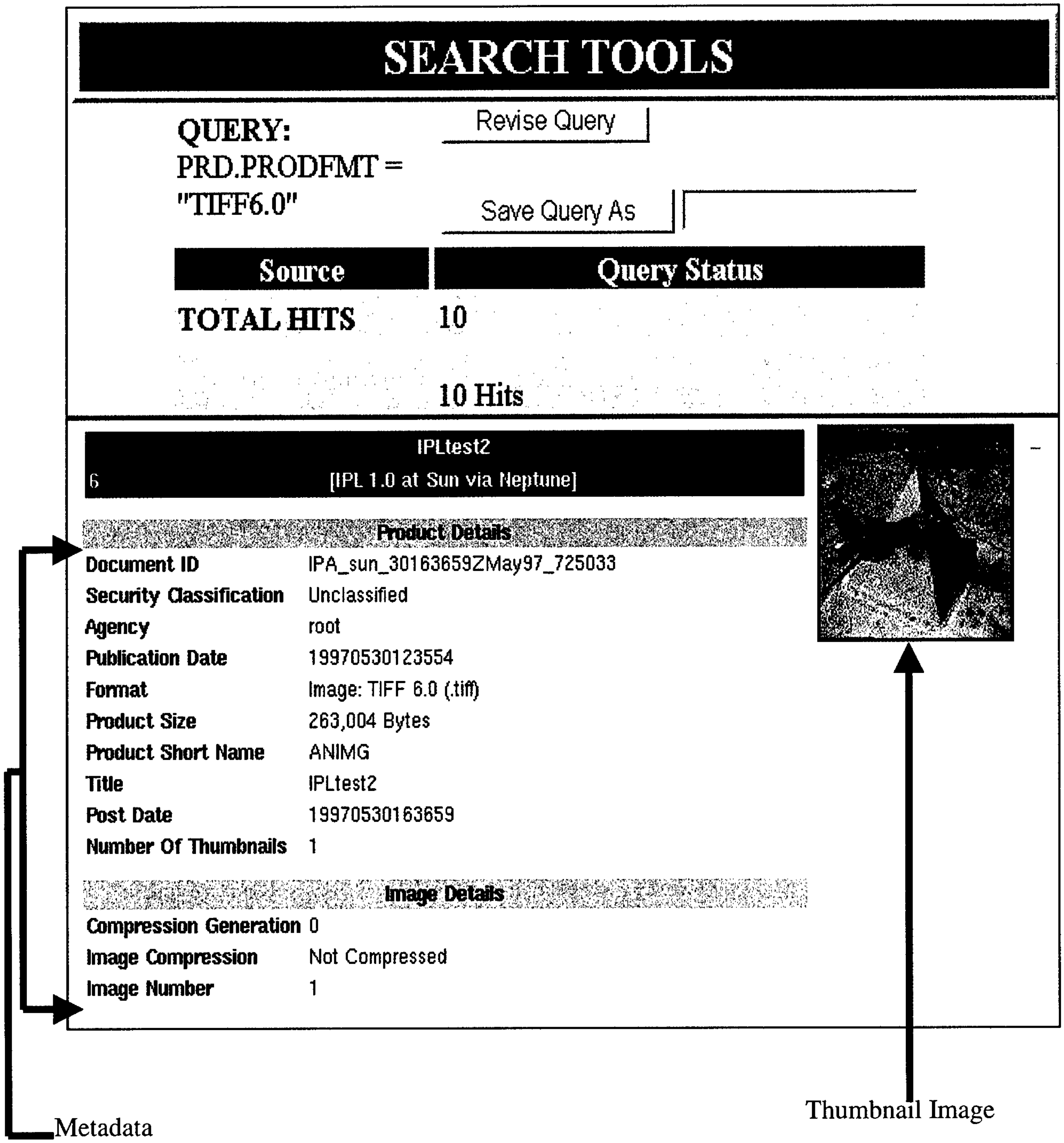


Figure 2.1: Textual Results

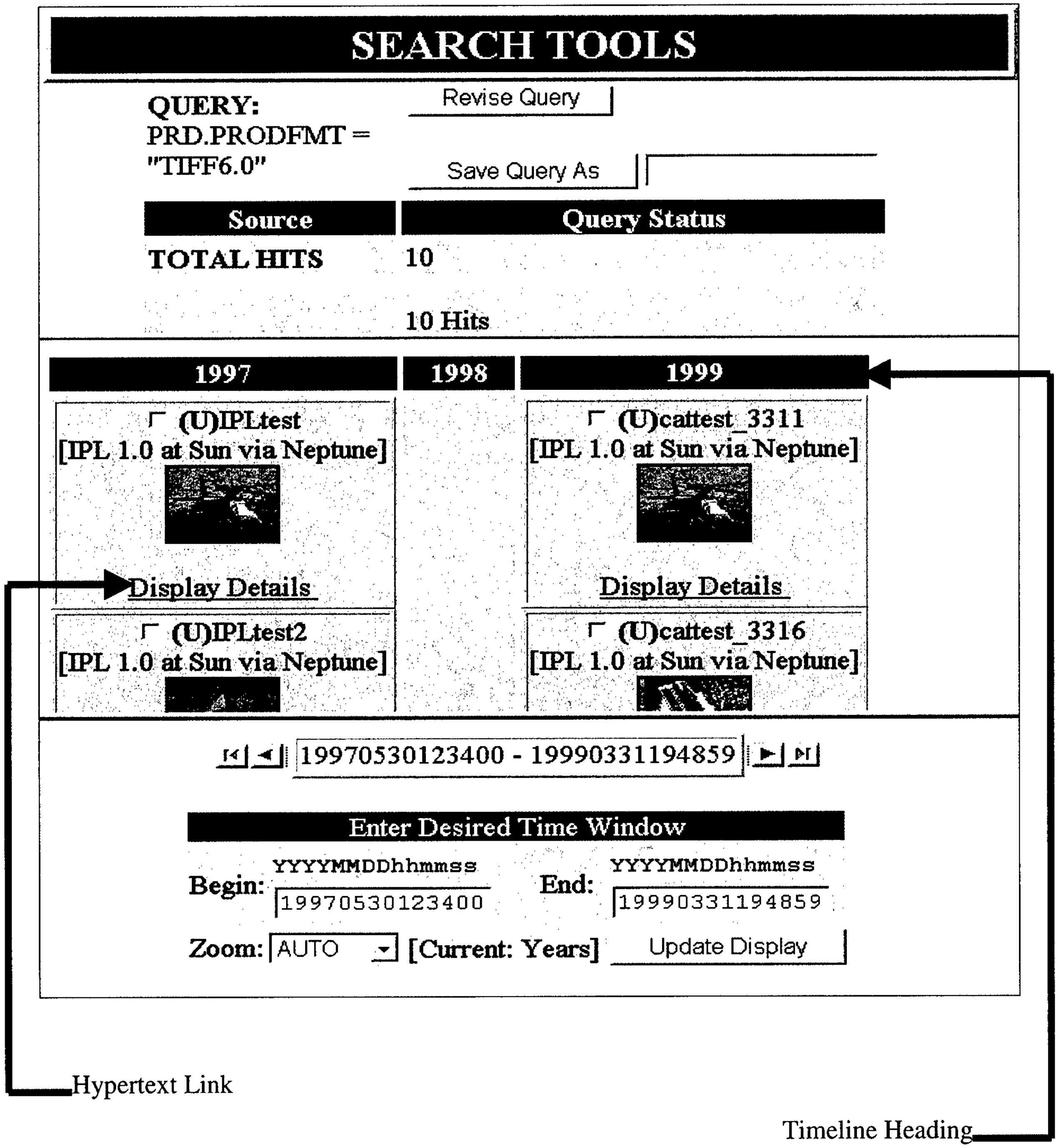


Figure 2.2: Timeline Results

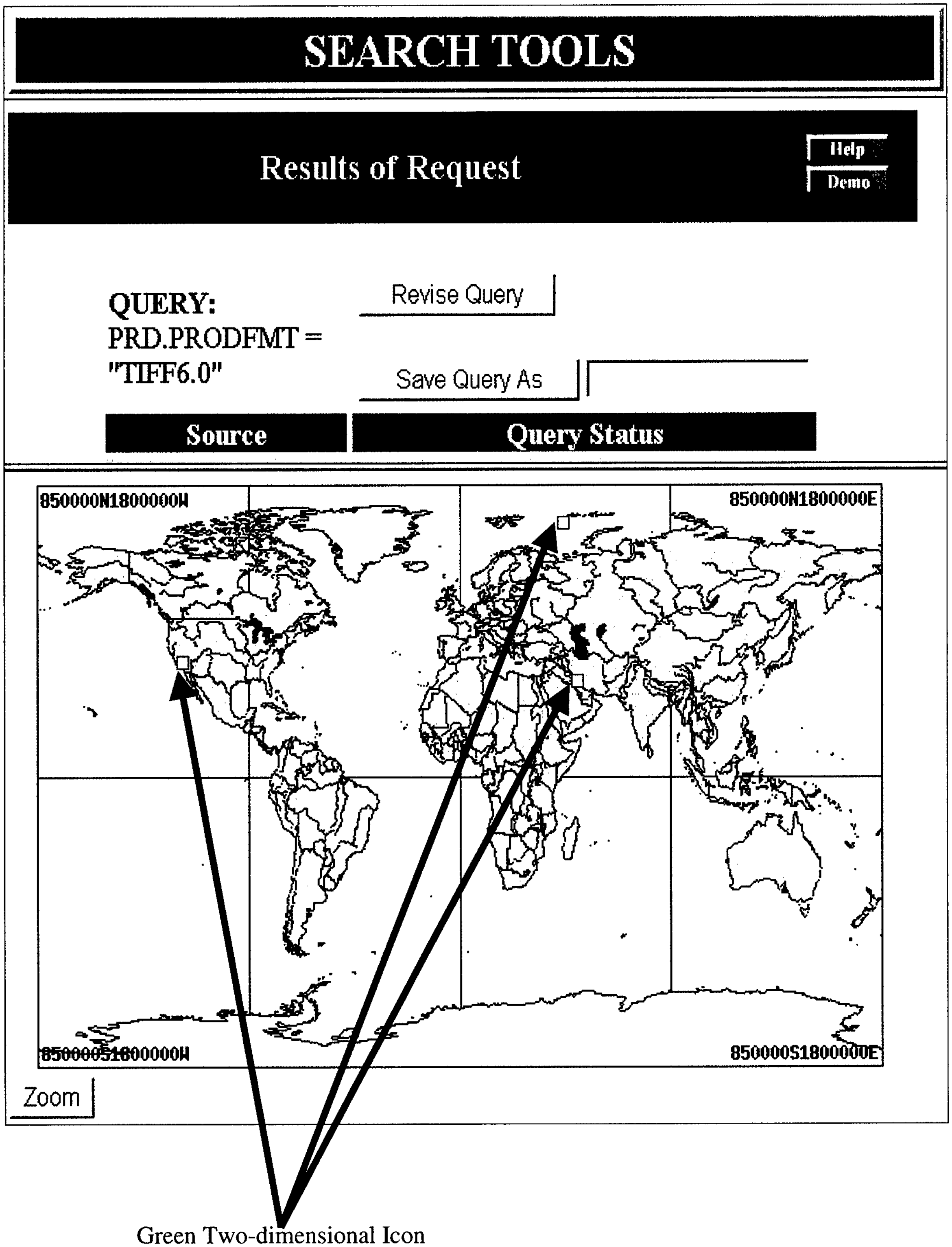


Figure 2.3: Geospatial Map Results (Color Plate 1)

geospatial map that graphically depicts the geographic location of each product by use of a green square icon. This icon represents all products that were found at a single location. The three icons in Figure 2.3 represent at least 3 products. They may also represent three hundred products or more.

To take full advantage of Project Broadsword's potential, data visualization techniques must be further refined and exploited. The current two-dimensional map offers a data visualization capability using geospatial coordinates as its base. As can be seen in Figure 2.3, this does not provide any meaningful information beyond data clustering. Since a single icon can represent an unlimited number of products, each is a hypertext link, that when selected, results in a textual output as seen in Figure 2.1. Being forced to return to a textual format immediately after results are displayed negates the true essence of utilizing data visualization in the first place.

2.4 Data Visualization

The increasing number of data sources and information repositories coupled with the availability of fast digital network access through the Internet and more secure global networks has created an enormous demand for querying, accessing, retrieving and understanding of information. One approach to aid in the organization of these tasks involves data visualization. The effective use of visualization addresses the challenge of discovering and exploiting information that may have otherwise been overlooked or neglected.

Data visualization enhances decision-making through spatial exploitation of diverse data products. Technological advances in computing have widened the data visualization spectrum to a point where the greatest challenge is no longer the available technology but rather retaining the intimate involvement and understanding of the end-user. Traditional text interfaces, which navigate with a mouse or keyboard, allow us to work *on* a computer, interacting with the system and not the data. Data visualization, on the other hand, enables us to work *with* the computer by enabling interaction with the data. This approach allows the system to be an extension of our visual and cognitive system, creating a seemingly free-flow convergence of user and data.

The quest for the perfect data visualization implementation is a moving target and presents some major challenges. The first task is to locate and retrieve the relevant data. In our world of dynamically changing and diverse heterogeneous data sources, this in itself is a major undertaking. Though not generally a visualization function, data retrieval is a required step toward a successful visual product.

Next is the challenge of understanding the data at a level that is appropriate and comfortable for the user. Consider the different levels of military command, each having their own intelligence requirements, yet accessing the same data sources. Identical data elements may have a varying degree of importance at each level and therefore require a different priority in the visual realm. Maintaining a high level of human involvement and participation in the data processing and analysis requirements through visual interaction supports this association. The intimate involvement and understanding of data analysis significantly aids in the prevention of erroneous abstract conclusions by ensuring the meaning and intent of the data is portrayed in context of the task at hand, and not simply interpreted blindly. For example, the sudden grounding of several Minuteman III Payload Transporters (used to transport missile guidance components) may seem suspicious by an analyst who does not understand Intercontinental Ballistic Missiles (ICBM) inspection requirements. Effectively communicating the proper meaning of the information is paramount. Portraying a perfectly crafted visualization is meaningless if the intended audience does not understand or misinterprets it.

A further challenge of information visualization is the available hardware interfaces and software display formats. The goal is to maximize the information content within our physical constraints while accommodating and capitalizing on the natural capability of the user. From a hardware perspective this is simply an issue of resolution and rendering performance. For the user, complications such as visual acuity and level of understanding must be considered.

2.4.1 Color

Based on research performed by the Department of Computer Science at the University of British Columbia, an important factor to consider when building visual models is the correct use of color (5). Color is a popular and effective attribute used to map a dataset into a visual plane. Previous studies attest to the fact that choosing a correct color, or number of colors, is an important step towards a successful visualization. Research on the design of military systems suggests that the general guideline for computer-generated images is no more than five to seven colors at a time (5). Additionally, recent work at the IBM Thomas J. Watson Research Center has focused on a rule-based visualization tool that considers how a user perceives visual features such as hue, luminance, height, and so forth (6, 7). This work emphasizes the understanding of data visualization; however, it has not addressed how color aids in a more accurate identification of individual data elements.

The use of color is a powerful medium element that capitalizes on each individual's hard-wired perceptual capability. Color perception is deeply wired into the human psyche and as a result our perception of color is fast, accurate, automatic, and effortless. A well-constructed image will use color to reduce the amount of thought process required to understand the information being presented. This thought process, defines those elements required for more complex recognition, such as reading text or attaching meaning to an object. Thinking is a relatively slow process that requires mental resources and is error-prone. Misreading a word or sentence is relatively common whereas mistaking a red apple for blue is not. Even those who are colorblind easily acknowledge subtle changes in color. Based on these founding principles, color tends to be the primary focus of data visualizations.

In three-dimensional space, color is an effective tool for the control of spatial perception (8). In a natural scene, mountains off in the distance usually appear blue-violet and indistinct. Known as aerial perspective, this visual effect is produced by white sunlight hitting the atmosphere and refracting on its shorter wavelength (8). Since the eye automatically interprets blue-violet and loss of detail as a sign of distance, it can be creatively used to add a feeling of depth to a flat display. To emphasize closeness, warm colors such as red, yellow, and orange are used.

2.4.2 Vision

Effective graphics development requires a general understanding of vision and the distinction between "attentive" and "preattentive" processing (8). At the instance a scene is first viewed, there is more information presented than can be cognitively processed. To overcome this, we instinctively decompose the image into more manageable pieces and then examine each piece individually. This divide and conquer strategy is called *attentive processing* and is accomplished by moving the eyes such that the current area of interest forms an image on the fovea, the highest acuity area of the retina. Attentive processing can be thought of as a spotlight, which the viewer moves across the scene. Once formed, the highlighted segments are processed for further meaning, such as understanding an object's representation, and are no longer simply patches of color. In this attentive processing stage, the viewer is still dimly aware of the sensations outside of the spotlighted area but has no idea of their meaning. While focusing on the local area the viewer still maintains a sense of awareness of the rest of the world.

To effectively perform attentive processing the user must effectively break the image into useful segments and then decide which area to examine first. *Preattentive processing* provides this function by relying on raw sensory information, such as color, which has no immediate inherent meaning. As the user organizes and links different colors encountered, natural image segmentation takes place. This instinctiveness allows a similar color in geographically separate areas to reinforce commonality. Figure 2.4 illustrates how a designer can use color to push a user's view in a desired direction (8). Notice how the red squares on the right immediately draw attention from the dark blue squares and involuntarily force you to link them into a single line. The lighter blue squares on the left differ only in brightness and therefore the effect is not as strong. Both of these examples demonstrate how a clever

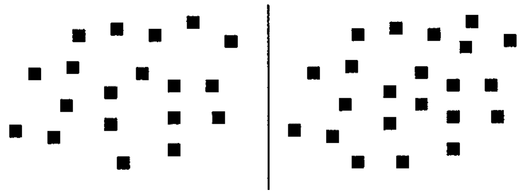


Figure 2.4: Preattentive Processing (Color Plate 2)

designer can use preattentive processing to draw a user's eye to a desired location, and further, control to some extent, the movement of the eye around an image.

The importance of optimizing preattentive processing and minimizing thinking is widely acknowledged in visualization literature. Cleaveland noted that in "elementary graphical-perception tasks" the preattentive perception of basic graphical elements underlies data visualization (9). Abarbanel suggests that visualization can be defined as the substitution of "preconscious visual competencies" for "conscious thinking"(10). Woods indicated that "If the mental activities required to locate base data units are not automatic, but require mental effort or capacity, they may disrupt or divert...the main line of reasoning" (11).

2.5 Conclusion

Intelligence plays a vital role in the decision making process both in and out of a military conflict. Reaching these decisions is no small task. Navigating the sea of information through our vast data repositories is a large undertaking. Confronting this intelligence problem is Project Broadsword. While making great strides in the area of data management, Project Broadsword is also investigating more advanced data exploitation methods through visual cues. The field of data visualization, though constrained by technology and human factors, is an expanse of possibilities waiting to be explored. Exploration of the visual realm leads immediately to the use of color. Association through color is an inherent human trait that is very fast, efficient, and effortless. This research embraces that fact and exploits it.

3. Methodology

3.1 Data Exploration

This research provides an effective representative environment for exploitation of stored military intelligence. The philosophy of design is to provide the intelligence analyst with enhanced visual cues and the spatial freedom to explore, analyze, and evaluate products from a chosen geographical area of interest in three-dimensional space. The Project Broadsword Test and Evaluation team conducted intelligence product exploitation tests with and without the use of data visualization techniques. Their subjective comparisons between data visualization and a text-only approach lay the groundwork for the findings in Chapter 6 and the conclusions and recommendations in Chapter 7.

3.2 Software Development Process

The nature of the Project Broadsword data visualization problem lends itself nicely to the construction of a partial implementation, or prototyping. Within prototyping there are two schools of thought, the *throwaway* approach and the *evolutionary* approach (12). The *throwaway* approach is concerned with the construction of software in order to learn more about the problem or its solution. Once this is understood, the prototype is completely discarded. The evolutionary approach also examines the problem or its solution; however, once the requisite knowledge has been gained, the prototype is readapted and used again. This process repeats itself until the prototype eventually becomes the actual system.

The intelligence community is beginning to explore how the use of data visualization can satisfy its users' needs. Responding to this trend, Project

Broadsword is emphasizing the "look and feel" of a final data visualization design, not its underlying implementation. This research provides the means by which an analyst can explore and adapt to new data visualization ideas and concepts. For this reason, I have chosen *throwaway* prototyping as the software development process.

3.3 Visualization Considerations

Applying methods of good data visualization techniques can be difficult. Although a significant amount of background work goes into producing "good" data visualizations, a large part of this thesis relies on visual experimentation and the associated human response. Regardless of technical orientation, each Project Broadsword tester's feedback is partially subjective and based on their personal tastes and prior data visualization experience. Final analysis of this research and the associated conclusions must take this subjectivity into account. This research uses technically sound approaches to explore appealing graphical representations. Technically perfect data visualizations will not be utilized if they do not appeal to the user.

As stated in Section 2.4.1, color is a major factor in the success or failure of data visualizations. For this reason, color is heavily examined throughout this research. Evaluating the effects of different colors at varying levels of resolution and intensity account for a significant amount of effort.

Transparency is a unique graphics capability that, when used effectively, allows for the interior of a three-dimensional object to be used as additional data presentation space. This research explores the additional capabilities provided by this method of object creation.

3.4 Data Navigation

Intelligence products are constructed with more data elements than can be comfortably mapped to the visual realm. Therefore, a successful visualization is dependent on the environment and its ability to handle this overload. When viewed from this perspective, data visualization takes a back seat to navigation and is handled accordingly throughout this research.

3.5 Scenario Generation

To validate the results of this research, a scenario was constructed which simulates real-world intelligence product exploitation. This scenario, seen in Figure 3.1, exercises the current Project Broadsword textual and two-dimensional product retrieval functions. The scenario is then exercised using the newly developed three-dimensional data visualization methods.

For each experiment, testers are provided with the result formats and tasks as outlined in Figure 3.1. Providing the results eliminates the need for testers to perform the actual searches and ensures each tester has an identical display at the start of each test. Following each test, feedback is generated through tester interviews. Each tester subjectively rates the experience for ease of use, suitability to task and perceived performance. Findings and conclusions based on a comparison of test results are found in Chapters 6 and 7.

The scenario in figure 3.1, used for testing purposes, is constructed of intelligence products from three intelligence sources (the Military Intelligence Database (MIDB), the Image Product Library/Image Product Archive (IPL/IPA) and the Automated Message Handling System (AMHS)) and contains all four product types; i.e. imagery, video, text and audio.

Broadsword Geospatially Oriented Navigational Environment

Experiment Scenario

Instructions: Given a set of one hundred and seventeen intelligence products and three result formats, complete the three tasks in any order. Utilize the accompanying color identification map for product-to-glyph color associations.

Result Formats:
1. Text-only
2. Two-dimensional map with icons
3. Three-dimensional map with glyphs

Task #1: Locate the total number of textual products available.

Task #2: Retrieve all imagery products that have IPL as a data source.

Task #3: Identify all F-15E aircraft imagery products.

Intelligence Product-to-Glyph Color Identification Mapping

Color		***Product Type***
Green	→	Imagery
Purple	→	Textual
Red	→	Video
Yellow	→	Audio
Gray	→	Multiple Products

Figure 3.1: Experiment Scenario

4. Development Environment

4.1 Environment

To confront the growing stream of intelligence data, as stated in Section 1.3, while meeting the challenges of data management as outlined in Section 1.4, this research effort created an environment to explore proof-of-concept data visualization capabilities tailored to the Project Broadsword intelligence data retrieval and exploitation system. This environment, the Broadsword Geospatially Oriented Navigational Environment (BGONE), was constructed in accordance with the Project Broadsword System Security Requirements and Analysis document. This document provides the vehicle for listing, and establishing compliance with, the minimum technical and nontechnical requirements for the Project Broadsword System in processing U.S. intelligence in the System High mode (classified mode) of operation. Additionally, it provides an analysis of Project Broadsword's safeguards intended to satisfy system security requirements where applicable.

Due to the sensitive nature of Project Broadsword's mission, BGONE is constrained to coding languages and techniques authorized by the Project Broadsword program office. These constraints constricted BGONE's evolution by significantly reducing the number of possible development paths.

4.2 Target Environment

Although BGONE is a stand-alone environment, its implementation mirrors the functional design of Project Broadsword. A review of available documentation and operational parameters revealed that Project Broadsword is deeply committed to the cross platform belief. It utilizes only those processes and techniques to interact with the system from virtually any platform. Additionally, the system is carefully tailored to include only those programming languages that support seamless operation through an Internet Protocol network. These languages include the Hypertext Markup Language (HTML), JavaScript, the Common Gateway Interface (CGI) and the Virtual Reality Modeling Language (VRML). Through strict adherence to these developmental policies, users are able to perform their duties by simply utilizing a standard World Wide Web (WWW) browser such as Internet Explorer or Netscape Navigator. To ensure accurate results, BGONE conforms to this operating environment paradigm.

4.3 Project Broadsword Code Base

Project Broadsword is currently undergoing a major code rewrite. Of key importance to this research is the map server and its associated data handling functions. As these are being re-coded from the ground up, their completion times exceed that allotted for this study. To support this research without having a fully functional Project Broadsword map server, BGONE was created as a stand-alone entity. The new map server relies heavily on VRML and JavaScript code; therefore these languages make up BGONE's core code base.

4.4 Model Approach

BGONE provides exploration of intelligence data handling concepts through the use and manipulation of three-dimensional VRML models. BGONE's primary focus is the representation of the data, and not the terrain over which it is displayed. Therefore, three-dimensional maps are externally generated and imported as needed. The Project Broadsword development team provided map models as needed.

4.5 Evaluation of Hardware Platforms

Multiple hardware platforms are available within the Project Broadsword development lab. These platforms include SUN, Silicon Graphics, and x86 based machines of varying speeds and capabilities. Based on suitability to task, ease of use, and support for VRML, the x86 architecture was chosen as the development platform. Although SUN systems are prevalent in the lab, UNIX based platforms do not yet fully support the VRML language.

4.6 Software Development Languages

BGONE was developed using JavaScript, HTML, and VRML. These languages were pre-determined by the Project Broadsword project office so no evaluation of alternate tools was performed. VRML was chosen as the only available three-dimensional graphics language that adheres to Project Broadsword's strict security, integrity and IP requirements. VRML provides a robust graphics-rendering library but lacks functionality in the area of data navigation. JavaScript and HTML fill the void by providing effective data selection and interaction.

BGONE is primarily based on the 1997 International Organization for Standardization (ISO)/International Electrotechnical Commission (IEC) document 14772, Virtual Reality Modeling Language (13). All VRML code is constructed using this document as a guide. Additionally, the JavaScript and HTML support code are integrated using established industry practices.

4.7 Automated Tools

To facilitate the development of BGONE, I employed the use of Spazz3D by Virtock Technologies, a powerful VRML object generation tool. Spazz3D provides key functions which include:

- A GUI based interface to accommodate simple geometry creation by a visual drag-and-drop method
- Software wizards that aid complex tasks such as creating animations and moving cameras.
- OpenGL support for enhanced graphics rendering
- Easily implemented directional lights, point lights, and spot lights

While Spazz3D provided the bulk of objects used in BGONE, assembling the environment and employing data navigation methods required coding by hand. This was accomplished with PC Editor, a simple multi-windowed ASCII text editor.

4.8 Graphics Rendering

BGONE graphical rendering is accomplished using OpenGL. Developed by Silicon Graphics Incorporated in 1992, OpenGL is the most widely adopted graphics standard in use today and is supported on virtually all platforms. This fact coupled with its ability to produce visually consistent displays, regardless of operating system or windowing system, maintains Project Broadswords' goal of universal functionality and presentation across heterogeneous platforms. When OpenGL compliant hardware is unavailable or not configured, software emulation is seamlessly enabled.

4.9 External Support

BGONE, developed with interpretive based languages, requires a JavaScript enabled WWW browser with an associative VRML plug-in to function properly. Since no web browser supports VRML code directly, a helper program or plug-in is required. Although the code in BGONE is based on VRML97, JavaScript 1.2, and

HTML 3.2 standards, each browser supports a particular standard with varying degrees of success. Due to their lack of compliance and poor documentation on the part of VRML, JavaScript and HTML; the success or failure of a specific design can only be validated following completion. The testing of the various combinations of web browsers and plugins played a crucial role in BGONE development and is explained in section 4.10.

4.10 Commercial Off The Shelf Products

Project Broadsword prides itself in leveraging off of existing technologies. Due to its web design, it relies on commercially based WWW browsers and VRML plugins. There are three major players with respect to browsers: Internet Explorer, Netscape, and Opera. Internet Explorer is a Microsoft standard browser and is available for the x86 Windows and Sun Solaris based architectures. Netscape caters to virtually every architecture. Opera is a x86-based browser that is under development. Of these three, Netscape is the primary browser used by the Project Broadsword development team as it has the most support. Based on this fact, Netscape was also chosen as the web viewer for BGONE.

As inferred in section 4.9, Netscape does not support a VRML environment directly. It requires an external plugin to perform this function. Three VRML plugins were considered for use: Cosmo, Blaxxun Contact 3D and Cortona. Cosmo has been a leader in VRML technology in the past but development has been halted and it is no longer supported. Blaxxun Contact 3D and Cortona are currently the only two actively supported VRML plugins. Both take advantage of OpenGL accelerated hardware while providing adequate navigational functions. The only true differentiation is the amount of real estate used by the on-screen VRML controls. Blaxxun Contact 3D excels in this area; utilizing a relatively small footprint and thus was chosen as the BGONE companion to Netscape.

5. Design and Implementation

5.1 Environment

The Broadsword Geospatially Oriented Navigational Environment (BGONE) is a stand-alone software environment that provides an effective representative atmosphere for exploitation of stored military intelligence. Modeled for Project Broadsword, BGONE is a stand-alone environment that provides an effective representative atmosphere for exploitation of stored military intelligence. BGONE design and implementation is based on design concepts of the new Project Broadsword 3.x map server. It also complies with policies and procedures congruent with mandated security requirements outlined in Section 4.2.

BGONE provides a one-to-one mapping of intelligence data product metadata elements, such as product type, to a specific visual attribute like color. Mapping is provided by pre-selected user input and is a function of the environment architecture. Project Broadsword prides itself in offering the user a plethora of configurable options when using the system. Likewise, the integration of concepts and techniques developed in BGONE are intended to be user configurable via the Project Broadsword user preference interface. Hence, each individual user can select which visual attribute maps to which data element to satisfy their specific needs.

The most important contribution of BGONE is the ability to map intelligence data, not decide what the ideal mapping should be. For the purposes of this research, Table 5.1 depicts the mapping of color to product type, i.e. imagery, video, text or sound. Additionally, the use of the color gray designates that multiple products are present but not shown. Use of this particular mapping along with others will be further discussed throughout this chapter.

Table 5.1: Intelligence Data Mapping

Product Type	Visual Attribute - Color
Imagery	Green
Textual	Purple
Video	Red
Audio	Yellow

5.2 Three-dimensional Visualization

User feedback obtained through informal interviews revealed a need for an environment where intelligence products could be exploited through visual means. Leveraging off of the old adage that "a picture is worth a thousand words", user's expressed the desire for a mechanism that provided increased understanding of a given set of intelligence products within a narrow window of time. Specifically implicated was the additional possibilities generated by the use of the third dimension. Adding this additional dimension significantly increases the amount of usable virtual real estate for data presentation.

Responding to user feedback, this research did not pursue two-dimensional data visualization. Instead, BGONE moves directly from a textual to a three-dimensional representation. This transition poses technical obstacles that are a non-issue in two dimensions. These obstacles include occlusion as objects are placed directly in front of each other, user perspective at a given instance in time, and data navigation.

5.2.1 Three-dimensional Objects

Managing representative objects in data visualization begins with the creation of the objects themselves. To accommodate BGONE development a glyph-based visualization approach was employed. A glyph is an icon or graphical object that is affected by its input data and certain properties such as x, y, z locations in three-dimensional space, color, opacity, orientation, shape and size.

Glyphs differ from standard graphical objects because they provide a direct one-to-one mapping between a selected data element and a glyph attribute. For example, an intelligence product type can be directly mapped to the color attribute. Using the mapping of table 5.1, figure 5.1 symbolizes four imagery products. Since figure 5.1 displays four unique shapes, a second data element, such as the branch of military service that produced the imagery, could be mapped to the shape attribute. This second mapping would increase the usefulness of the data visualization by

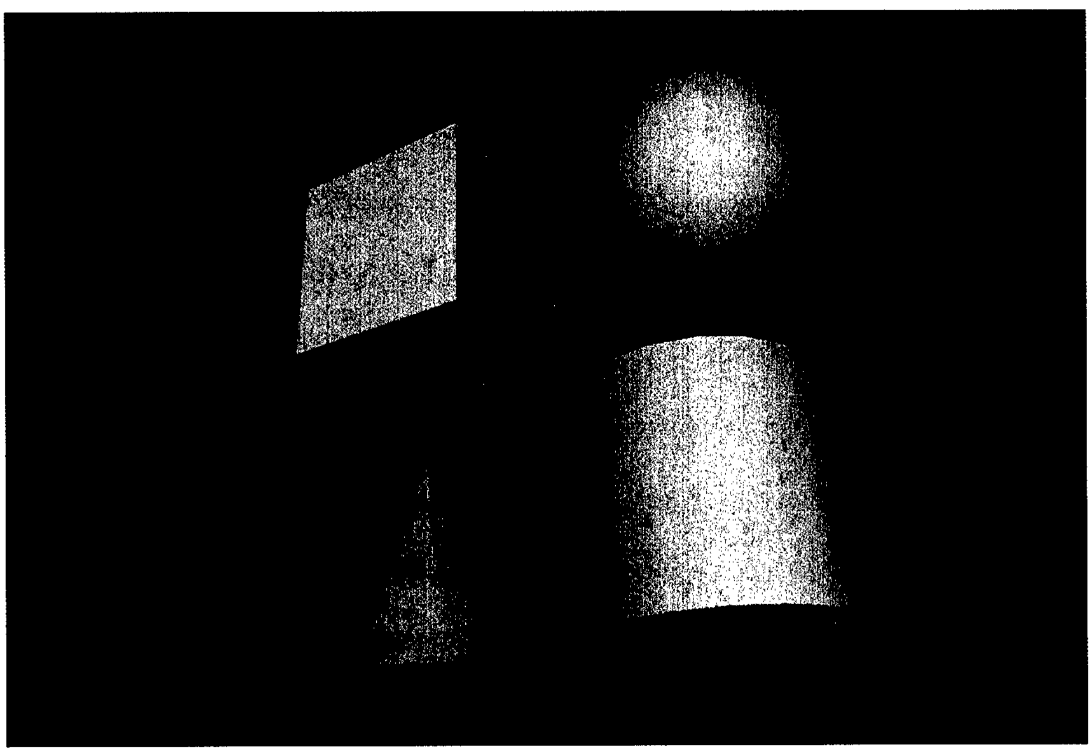


Figure 5.1: Symbolic Glyphs (Color Plate 3)

helping the analyst visually segregate the search space by product and image creation source. As more 'intelligence data element to glyph attribute' mappings are performed, the given search space is further populated with more graphically represented product details. Each added representation increases the analysts' ability to quickly select specific products of interests without immediate textual intervention.

For BGONE, initial prototype glyphs were created using Spazz-3D, which is described in section 4.10 Automated Tools. Using Spazz-3D it was possible to quickly create glyphs, such as those seen in figure 5.1, for immediate examination.

5.2.2 Multilevel Glyphs

Users specifically requested three-dimensional data visualization. Their request was motivated by the knowledge that using the third dimension allows for the use of depth, which provides more usable space for data presentation. To ensure maximum screen space usage, glyphs were created at two levels of data resolution; level one and level two. A level one glyph, often referred to as the outer glyph, is the primary glyph and provides identification of individual products such as imagery. Each level one glyph represents one intelligence product. A level two glyph, often referred to as the inner glyph, is the secondary glyph and provides specific information about that particular product. Figure 5.2 shows representation of two products. Based on this example, the green level one glyphs symbolize two imagery products. The level two glyph, which can be seen inside the level one glyph, can now further the analysts' understanding of the product through a one-to-one matching of product element to glyph attribute. Here a cube may represent ground-based imagery while the cone may represent air-based imagery. Additionally, the color of the inner glyph offers another mapping level such as product origin. As shown, this glyph in a glyph visual approach helps maximize the useable space taken up by each product representation. Although this does not effect the number of products displayed, it does increase the amount of information portrayed.

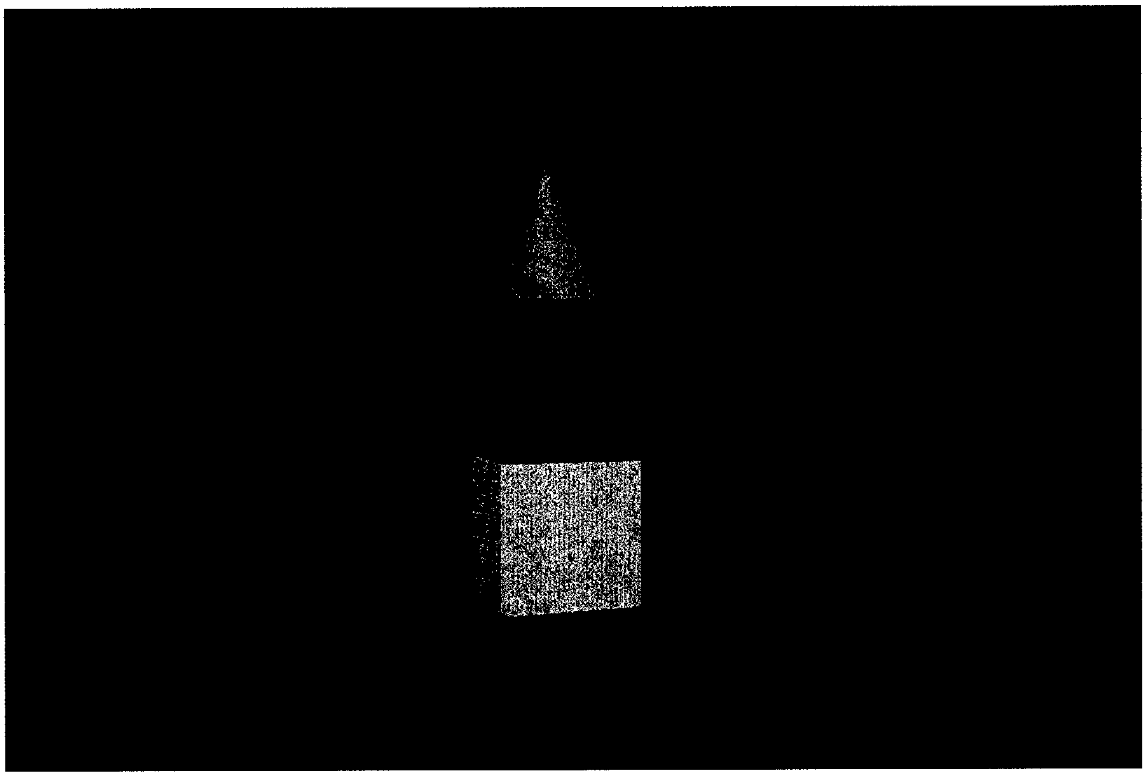


Figure 5.2: Multilevel Glyphs (Color Plate 4)

5.2.2.1 Level One Glyph

To allow the analyst to identify each intelligence product, a level one glyph represents one product in its entirety. The first area of interest dealt with the shape used when displaying this glyph. The use of shape as a data-mapping attribute required careful examination. Initially, each of the four product types was mapped to one of the geometric shapes shown in figure 5.1. Preliminary testing indicated that the vertical stacking of these glyphs in relatively small concentrations (20 products or less) resulted in an acceptable representation. However, when the number of products displayed increased, the virtual landscape began to take on a cluttered appearance. After developing several models and consulting with the Project Broadsword program office, it was decided to maintain a uniform shape for all outer glyphs.

Four common geometric shapes were candidates for the level one glyph: the cube, the sphere, the cone and the cylinder. Each was evaluated for its appearance after being vertically stacked and placed side-by-side. Based on the subjective observation that they do not stack well and wasted the most space per object, the cone and sphere were eliminated as contenders. As can be seen in figures 5.3 and 5.4, the two remaining choices offer a uniform eye appealing presentation. The final decision

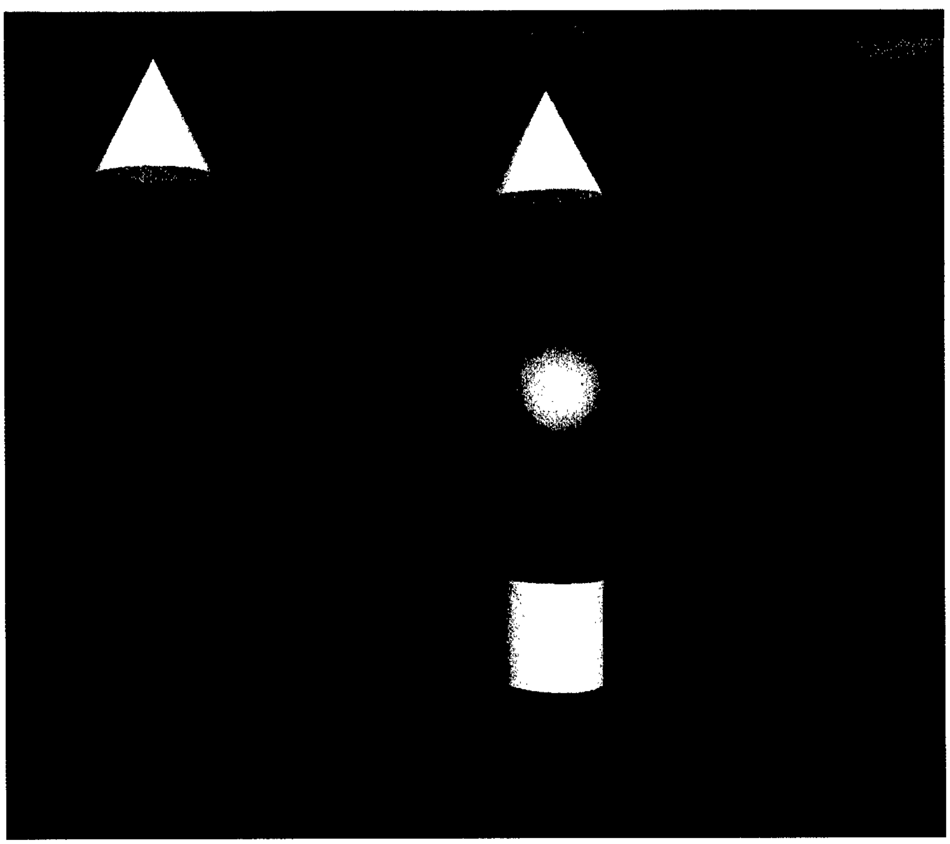


Figure 5.3: Cylinder Shaped Level One Glyphs (Color Plate 5)

to use a cube-based glyph was made to reduce the number of polygons required to generate each glyph.

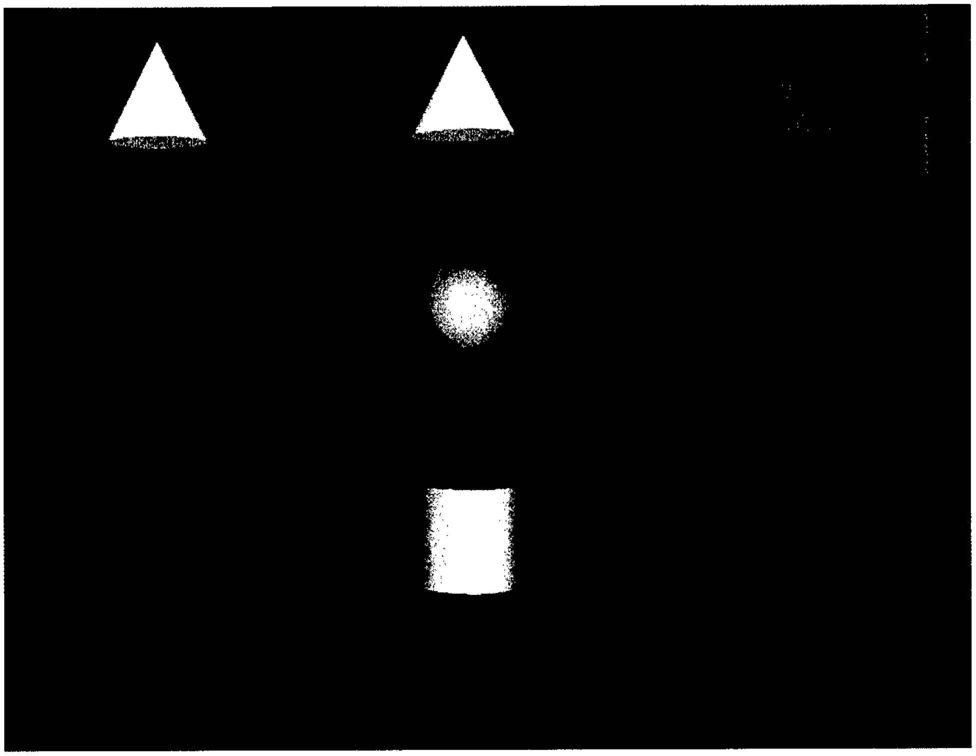


Figure 5.4: Cube Shaped Level One Glyphs (Color Plate 6)

With the cube selected as the level one glyph, attention was turned to the use of color. As explained in section 2.4.1, color is a very effective data visualization tool. For the purpose of this research, the color of the outer glyph represents a specific product type. Table 5.1 provides the color mapping used.

Exploiting the inner glyph only succeeds if the outer glyph provides visual access to its interior. One approach is to use transparency. Transparency provides interior access while maintaining the outer glyphs shape and color integrity. This technique also allows a user to see other products in the distance without changing perspective. Figures 5.5 and 5.6 examine varying levels of transparency and the

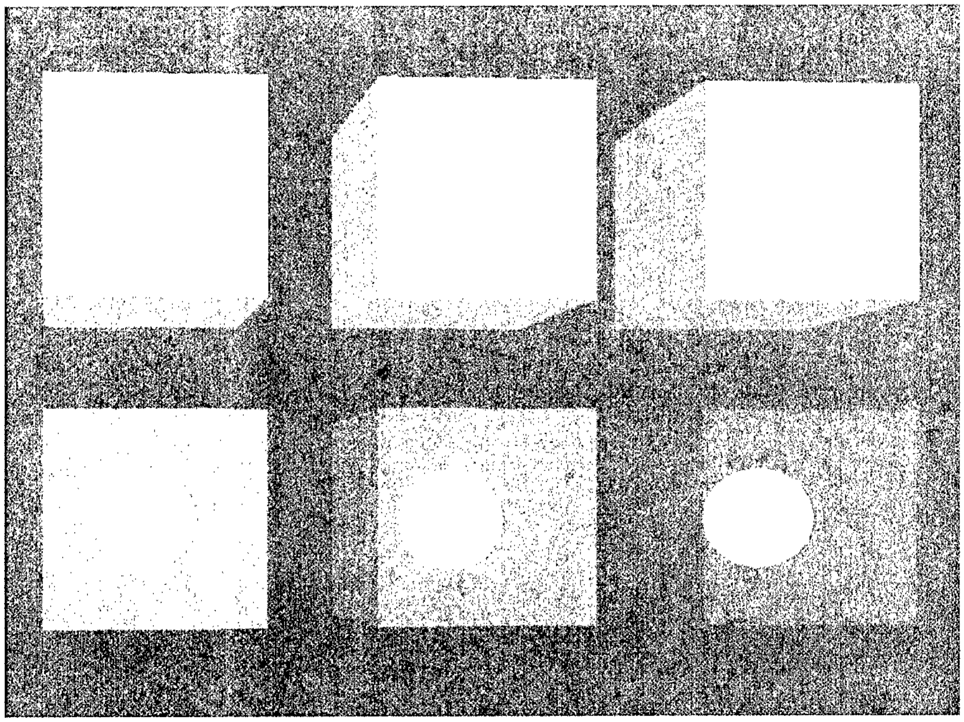


Figure 5.5: Transparency as Designed (Color Plate 7)

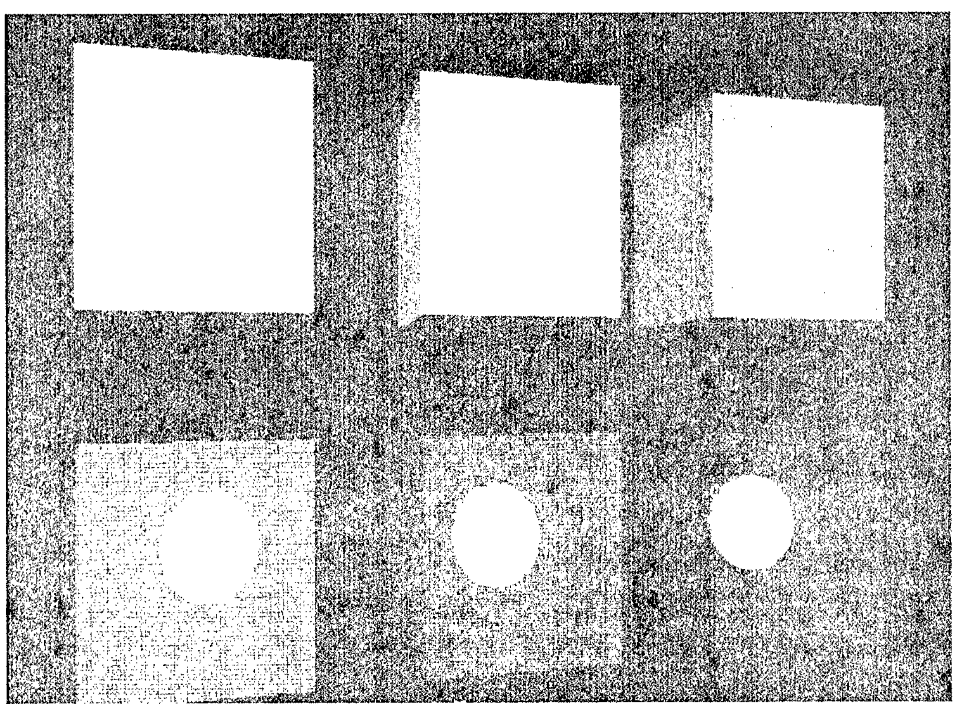


Figure 5.6: Transparency in Operational Environment (Color Plate 8)

ability to distinguish the inner glyph while maintaining the outer glyph. Figure 5.5 displays transparency as viewed with the Spazz-3D, a VRML object generation tool. Using Netscape and its associated VRML plugin Blaxxun Contact 3D, as required by Project Broadsword, resulted in figure 5.6. Examining these two figures highlights two major inconsistencies. First, figure 5.5 demonstrates six levels of transparency as designed. Notice that at each level, both the inner and outer glyph is discernable. Figure 5.6 shows the same six glyphs, as viewed in an operational environment. It is clearly evident that as the level of transparency increases the visibility of the outer glyph diminishes until it is no longer discernable.

Another adverse inconsistency is the textural appearance of the outer glyph. The original design, figure 5.5, was intended to provide a smooth fog like effect, not a coarse texture. The coarseness displayed in the top row of figure 5.6 is easily mistaken as intended texture. Although mapping intelligence data to texture may lead to more data represented, this was not the intent and it visually detracts from the inner glyph. This detraction reduces the inner glyphs ability to effectively provide data visualization mappings by making it difficult to see, thus reducing its utility. Being in three-dimensional space, the coarseness also reduces the ability to see objects directly behind the glyph being viewed.

The diminished visual quality, as is evident by the lack of definition and coarseness in figure 5.6, severely impacted the decision to pursue transparency. The dismal results of transparency further emphasized the lack of VRML compatibility from one VRML interpreter to another.

A second, more successful approach to outer glyph creation is shown in figure 5.7. The outer glyph is constructed of twelve smaller three-dimensional boxes that

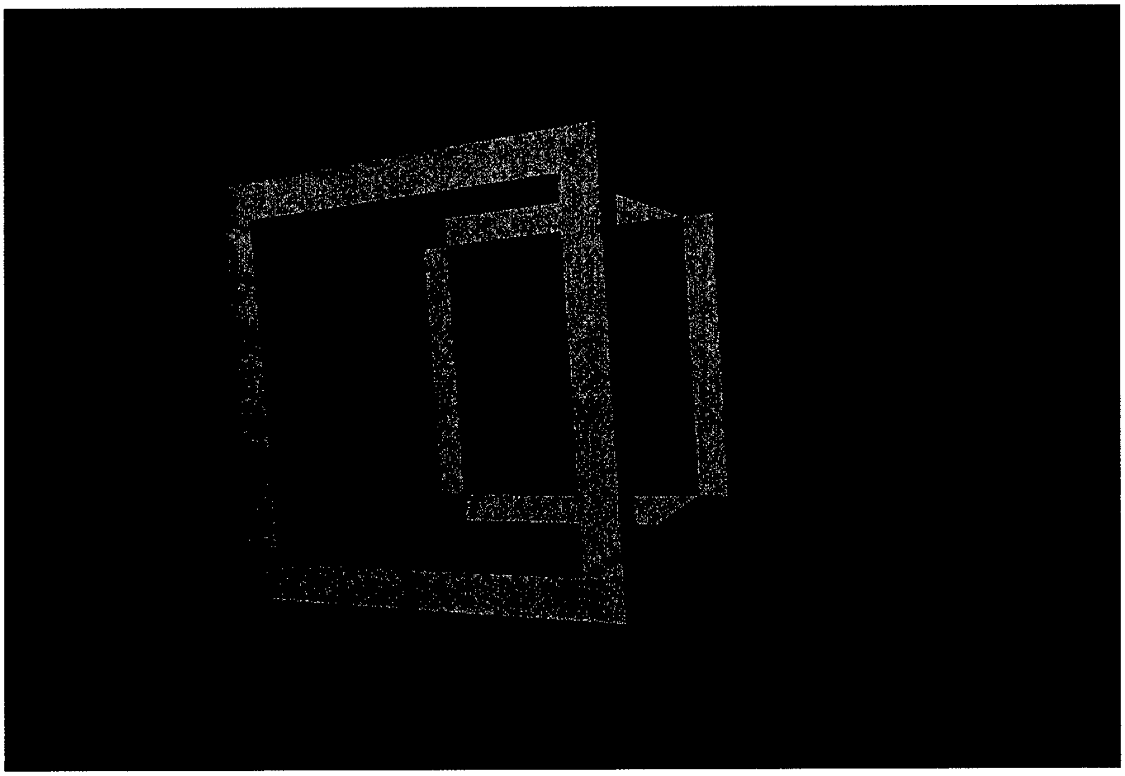


Figure 5.7: Redesigned Level One Glyph (Color Plate 9)

are arranged to form the original cube. This layout maintains a uniform color mapped cube while providing easy visual access to its interior. An added feature of this scheme is that the transparent interior does not alter the appearance or color of the inner glyph.

5.2.2.2 Level Two Glyph

Level two glyph development initially progressed as a mirror of level one. Results of this are shown in figure 5.8. As shown here with the outer green cube symbolizing an image product, the inner glyph attributes of shape and color are

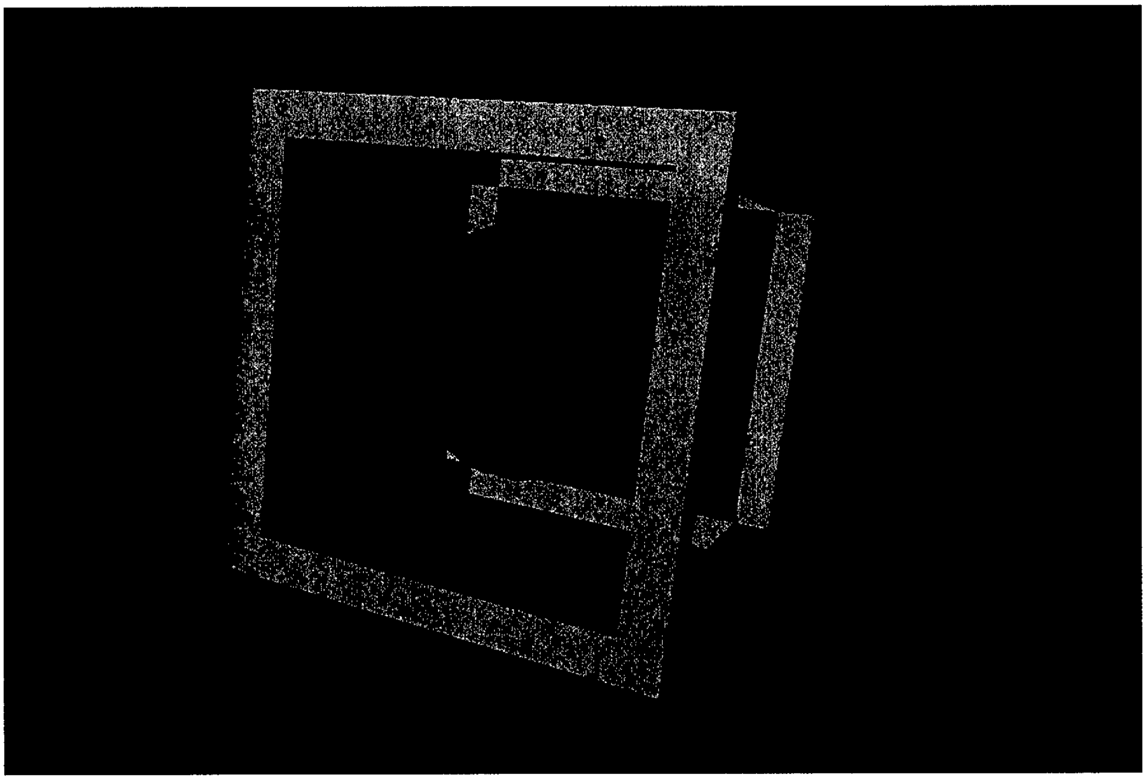


Figure 5.8: Abstract Level Two Glyph (Color Plate 10)

available for mapping two additional product elements. Collaborative meetings with the Project Broadsword program office revealed a desire for a more gradual introduction of data visualization with a smaller learning curve. Figure 5.8 requires the user to have a previous knowledge of the inner glyph mappings. A more intuitive approach is to integrate a VRML model of the product type being represented. This is demonstrated in figure 5.9 with an imagery product of an aircraft.

5.2.3 Level Of Detail

To minimize visual clutter when viewing a large number of products from a distance, a Level Of Detail (LOD) scheme was employed in two stages. First, low LOD models were created to give analysts a visual understanding of the level one glyph without requiring knowledge of the level two glyph. These models, as seen in

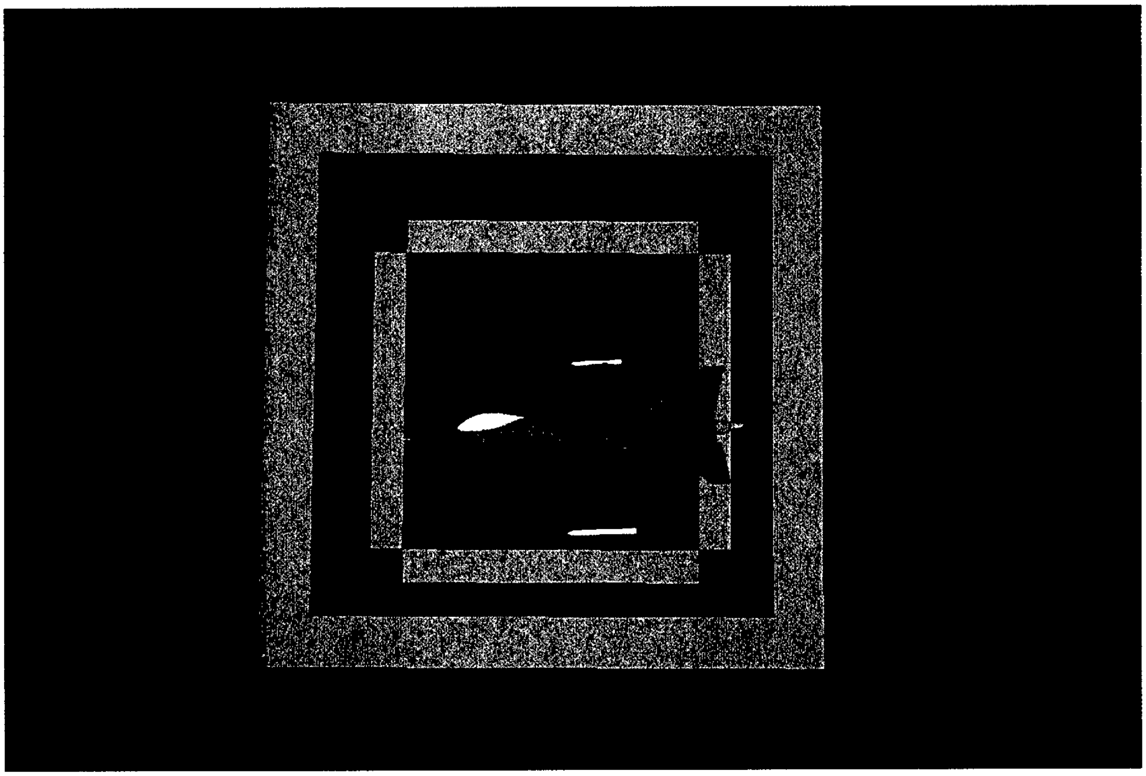


Figure 5.9: Model Based Level Two Glyph (Color Plate 11)

figure 5.10, render only the outer glyph. Masking the inner glyph permits the outer glyph to be rendered as a solid cube. A solid cube provides more surface area for the color attribute, as compared to figure 5.7, allowing the viewer to more easily identify

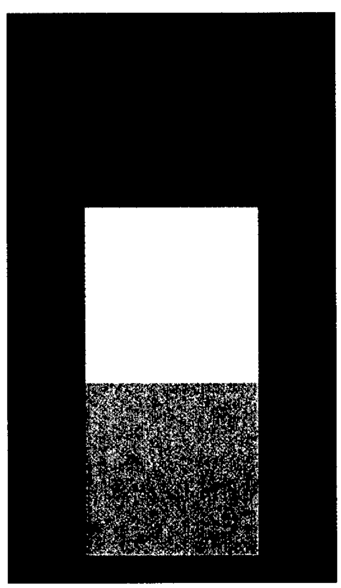


Figure 5.10: Low Level Of Detail Glyphs (Color Plate 12)

a specific glyph from a distance. When viewing data in a three-dimensional landscape, the ability of the user to see all rendered elements is crucial.

Users select a key product element to be mapped to the color of a level one glyph. Their selection allows them to quickly locate products of interest based on the task at hand. For example, an analyst may be directed to analyze all available imagery over a specific geographic area. If the inquiry returns a mix of products, low LOD models with a color attribute of green will be readily evident. As seen in figure 5.11, low LOD models used with a VRML landscape map provide immediate feedback without the distraction of individual level two models.

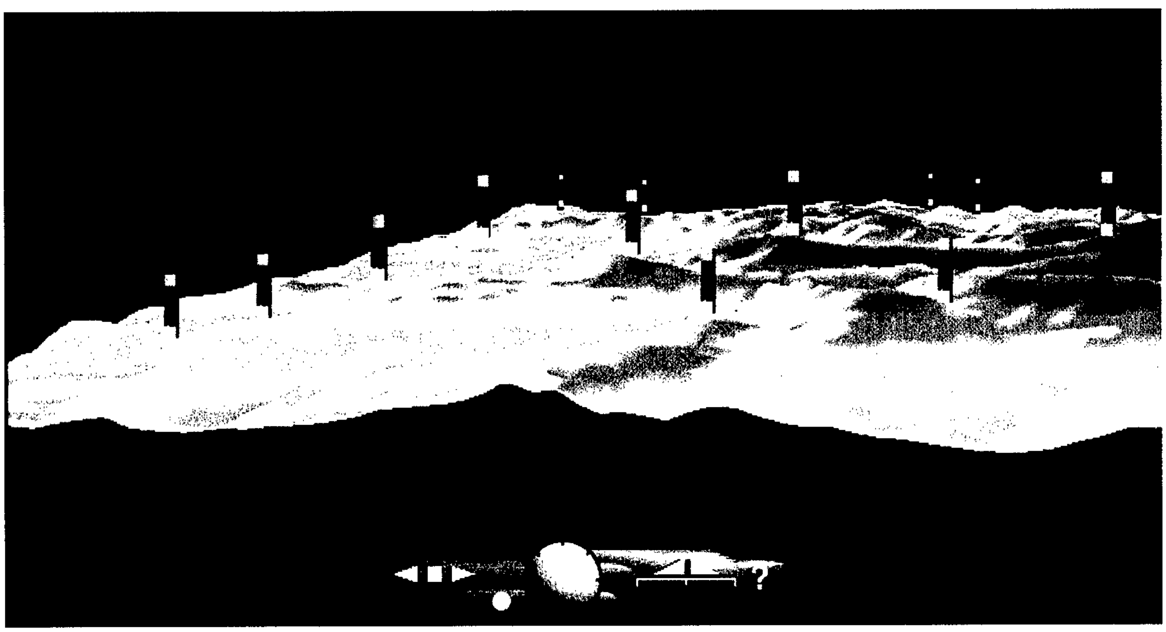


Figure 5.11: Low Level Of Detail Glyphs on a VRML Landscape Map (Color Plate 13)

Low LOD models minimize visual clutter by using proximity sensors. As an analyst moves closer to glyphs of interest, the models change to that seen in figure 5.12, revealing additional information about the products. When the analyst is finished in one location and moves towards another, the first glyphs revert to their original form as shown in figure 5.10.

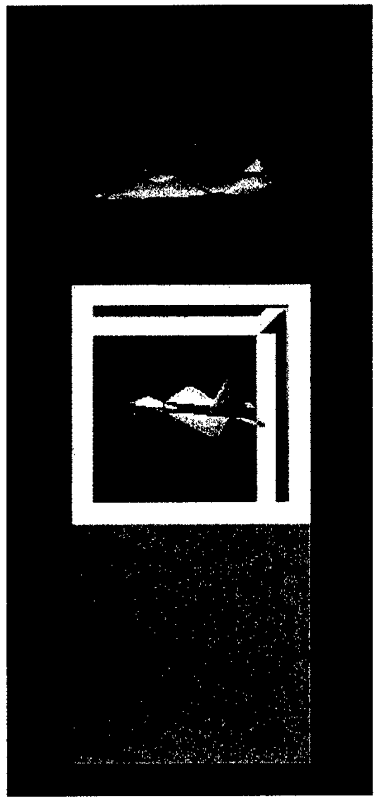


Figure 5.12: Proximity Sensor Activation Rendering (Color Plate 14)

Level Of Detail is also concerned with the number of products displayed at a given time. Even with three dimensions, display space is a limited commodity and must be managed accordingly. Project Broadsword testers frequently perform searches that result in over eight hundred products. To accommodate such a large number, the gray glyph at the bottom of Figure 5.12 was introduced to signify that multiple products are present but not visible.

For this research, Figure 5.10 or Figure 5.12 provides an understanding of seven products; textual, imagery, and five that require additional actions to explore.

A gray glyph is explored by selecting it with the mouse and clicking a mouse button. A second web browser window is then generated, as seen in figure 5.13, which displays the products found at that location.

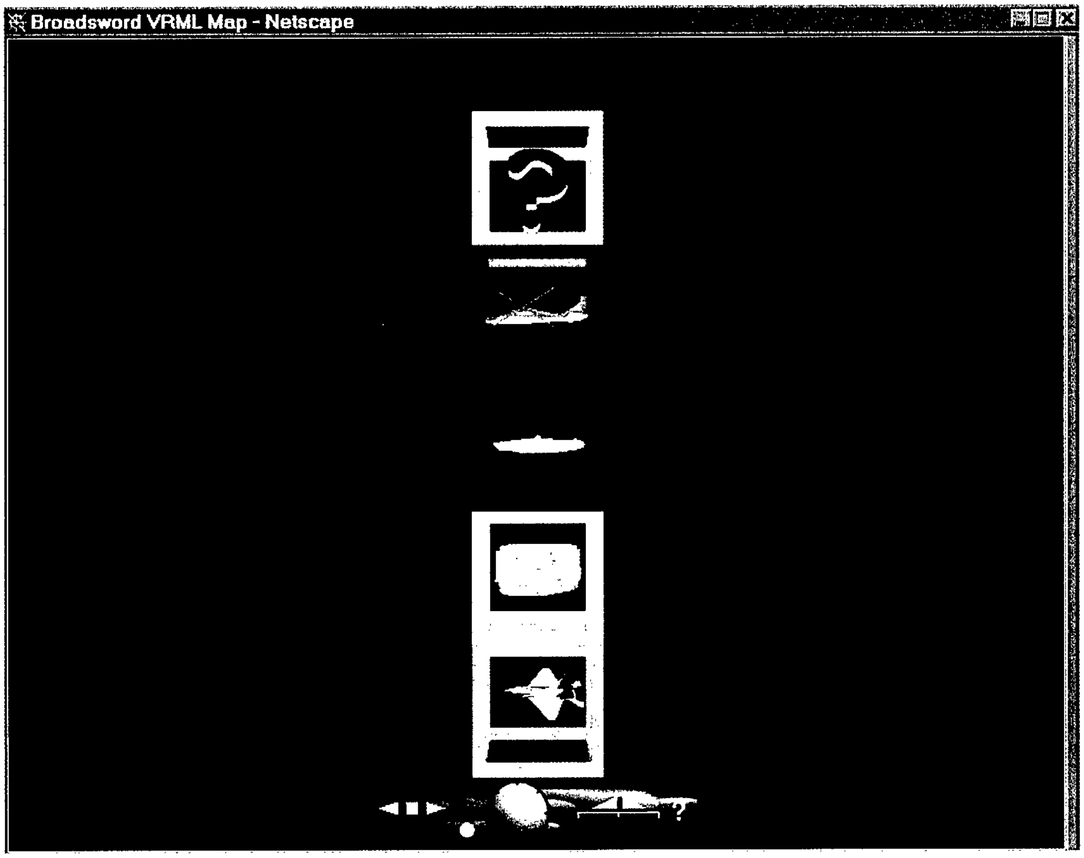


Figure 5.13: Products Represented by Gray Glyph (Color Plate 15)

5.3 Navigation

When dealing with a two-dimensional plane, navigation is primarily concerned with how the eye traverses the scene. This is controlled through effective use and placement of lines, shapes and color. Entering the third dimension introduces an expanded domain in which the user must physically navigate the data.

Individual intelligence products provide a large amount of data and therefore a one-to-one matching of each data element to a visual cue is unrealistic. Key product metadata elements are therefore used for visual rendering leaving the remainder for textual displays. This allows for quick visual selection of a desired product. This separation in data and metadata necessitates the need for two types of navigation: visual environment navigation and data navigation.

5.3.1 Graphics Navigation

Visual environment navigation is provided through Blaxxun 3D as discussed in section 4.10. Table 5.2 provides a cursory navigation overview. Particular keyboard and mouse actions for each of the stated movements can be found in the Blaxxun 3D help menu.

Table 5.2: VRML Navigation

Walk	Allows the user to move through the scene in an X and Z direction
Slide	Allows the user to move through the scene in an X and Y direction
Examine	Allows an entire scene to be rotated around its own X axis
Rotate	Allows an entire scene to be rotated around its own X and Z axis
Fly	Allows the user to move through the scene in an X, Y, and Z direction.
Pan	Allows the entire scene to be rotated around the users X and Y axis

Additional movement through the use of coded Viewpoints is also provided. Viewpoints allow an analyst to quickly move to an area of interest with a click of the mouse or a limited sequence of keystrokes. A segment of Viewpoint code is shown here:

```
DEF ViewPoint1 Viewpoint {
    description "ViewPoint1"
    jump TRUE
    fieldOfView 0.79
    position  0.0 0.0 0.0
}
```

This segment defines an X, Y, Z position relative to the current coordinate system and a field of view, in radians, indicating the spread angle of the viewpoint's viewing-volume frustum. Additionally, the *jump* being set to *TRUE* ensures the new viewpoint becomes the current user view.

The Blaxxun 3D controls coupled with Viewpoints allow a user to gracefully move through BGONE, observing the various products and data elements presented. However, navigation of the visual environment provides only a partial solution. Text handling must also be integrated.

5.3.2 Textual Navigation

Once a desired product is visually selected for exploitation, the user must have effective text handling techniques to benefit from the initial data visualization. As seen in figure 5.14, integrating a text box with a VRML environment is conducive to the use of frames. Project Broadsword already utilizes frames so their inclusion was seamless.

Text handling through the use of frames allows the analyst to maintain the visual results while examining the textual details. This is an improvement over a pure text approach, but more advanced methods through dialog boxes were explored.

Natively, the VRML language provides a function termed *TouchSensor* that enables animation based on mouse interactions. For example, placing a mouse cursor

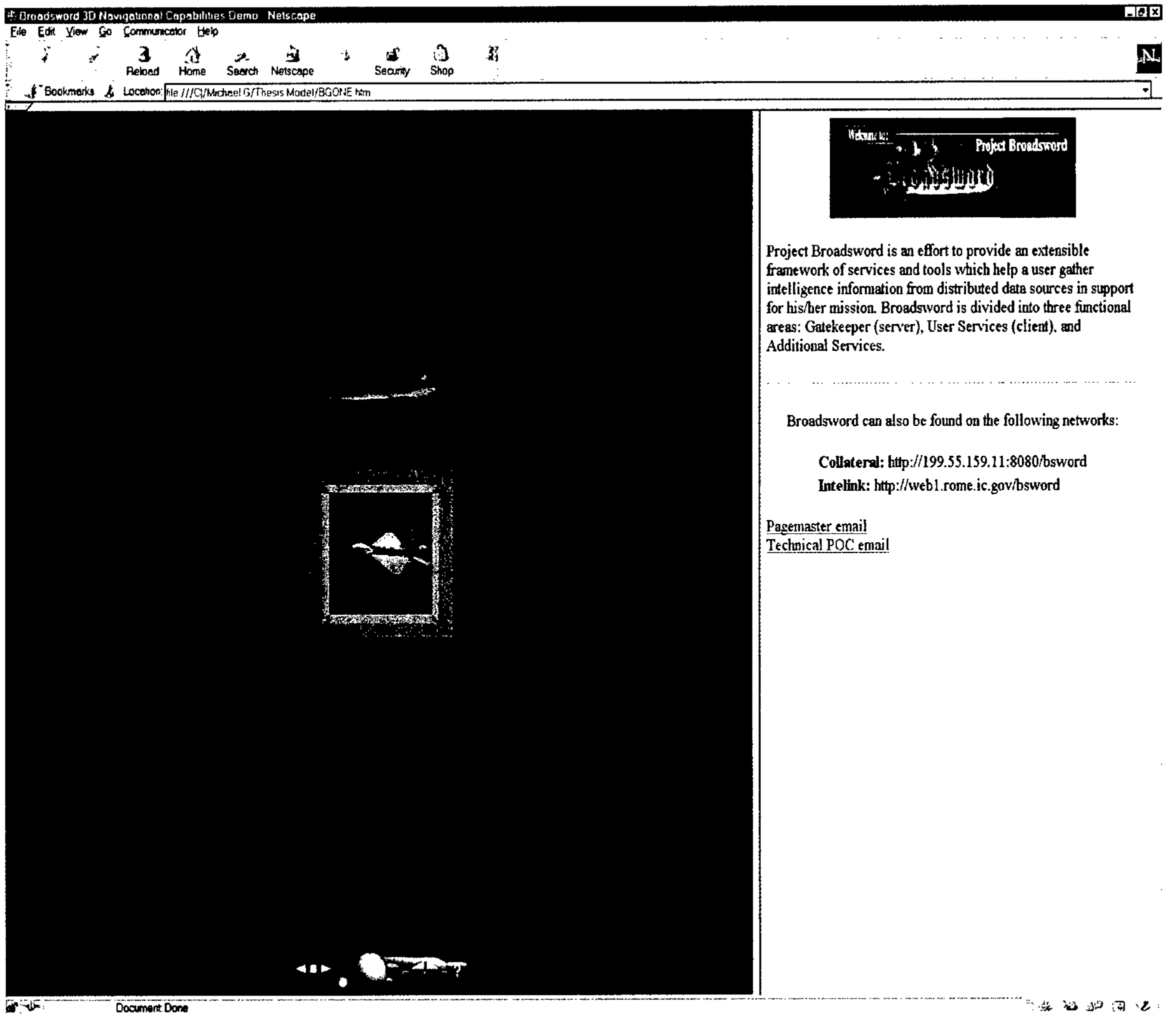


Figure 5.14: VRML Environment with Frames (Color Plate 16)

over a sphere and pressing the left mouse button can cause the sphere to spin on its axis. This interaction is an ideal candidate for the support of pop-up dialog boxes containing intelligence product data. Examination and experimentation with these touchsensors revealed VRML is not capable of providing context-sensitive dialog boxes. A supporting language, such as JavaScript, was required. JavaScript is well situated for browser-based text handling tasks. However, being designed to co-habitat with HTML, it does not readily support the VRML environment.

For this research, methods were created for the control and generation of data elements when interacting with glyphs. These new methods combined the animation functions of VRML with the text handling capabilities of JavaScript. The resulting functionality enables BGONE to meet the needs of Project Broadsword by providing quick and efficient access to data elements not mapped to a glyph attributes.

These new methods provide context-sensitive dialog boxes and data handling, through three VRML interactions: *isActive*, *isPressed* and *isOver*. Figure 5.15 shows

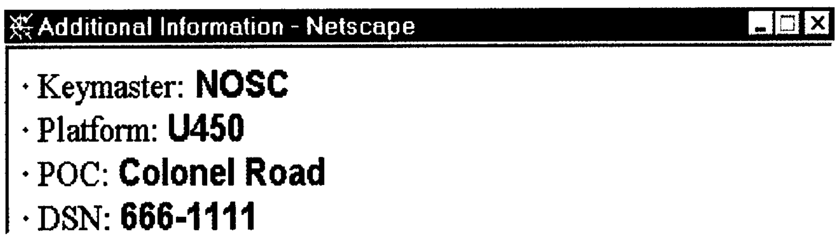
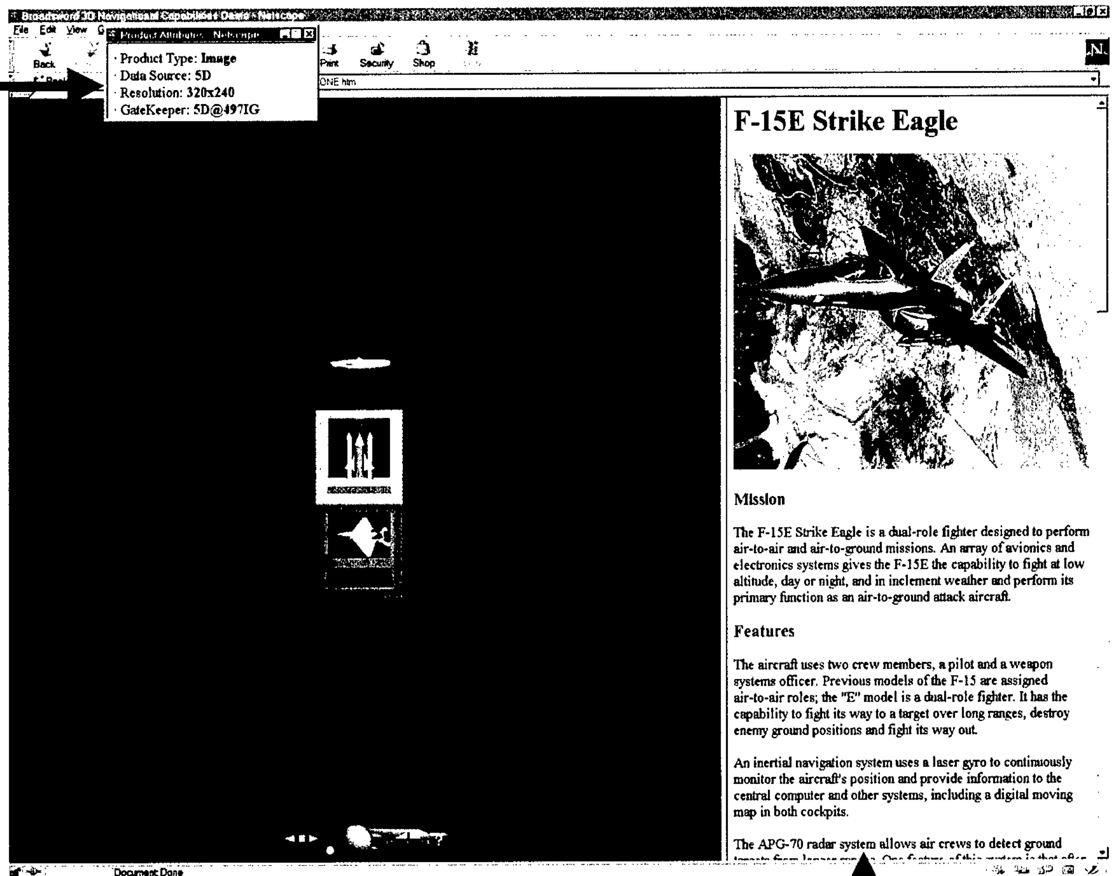


Figure 5.15: Pop-up Dialog Box

a resulting window when the *isActive* method is called. This method opens a dialog box whenever a mouse button is pressed and held while over a glyph. When the mouse button is released the dialog box closes. Figure 5.16 demonstrates the *isPressed* method that generates the associate data, in this case an F-15E, in the right frame of the browser window. This is accomplished by placing the mouse cursor over a glyph and single clicking the mouse. Figure 5.16 also shows activation of the *isOver* method. This method opens a dialog box whenever the mouse cursor is moved over a glyph. The box remains open until the cursor is moved completely off of the glyph. The automatic opening and closing of the dialog box provides a very quick glance capability as the mouse cursor is moved from one product to the next.



Dialog box generated by the *isOver* method

Data placed in frame via the *isPressed* method.

Figure 5.16: Text Handling (Color Plate 17)

5.4 Multimedia

To expand the data exploitation capabilities within BGONE, multimedia concepts were explored. Specifically targeted was the integration of streaming video. To enhance exploitation of this medium, the inner glyph was cast as a cube with the video stream texture mapped onto it. Video support is provided through the use of the Real Audio player plugin. Playing of the video is triggered by activation of a touchsensor.

5.5 VRML Plugin Verification

Operation of BGONE requires a VRML plugin be present. Detection software was created to prevent program execution if a plugin is not installed. This new code identifies which browser is being used and then checks for known x86 based VRML plugins. These include Blaxxun 3D, Contact, Cosmo Player, Microsoft VRML 2.0 Viewer, Viscape Universal and Worldview. If a plugin is detected the user notices no difference during startup. If not, an informational message is displayed.

5.6 Conclusion

This chapter focuses on the design approach and obstacles encountered during the implementation of BGONE. It was clearly evident early on in the research that design tradeoffs would have to be made in order to mirror the security and integrity mandates placed on Project Broadsword. The creation of new, never before seen, data handling methods gives BGONE a unique operating base on which to explore further data visualization and text handling capabilities.

6. Findings

6.1 Introduction

The primary objective of this thesis is to show that three-dimensional data visualization can provide an analyst a more efficient and effective way of organizing, understanding and navigating vast amounts of intelligence products. This visualization approach is specifically tailored to Project Broadsword, an intelligence data retrieval system, being developed at the Air Force Research Laboratory/Rome Research Site in Rome, New York. The creation of the Broadsword Geospatial Oriented Navigational Environment (BGONE), a stand-alone representative environment of Project Broadsword, provided a tightly controlled test environment through which the Project Broadsword verification and validation team could compare their current intelligence exploitation methods to those provided by BGONE. The findings presented here are based on results while employing the test scenario outlined in Section 3.5. For the remainder of this chapter, the Project Broadsword verification and validation team will be referred to as 'testers'.

6.2 Experiment Setup

Intelligence products used in this research were obtained from unclassified sources located inside the Project Broadsword development, testing and integration vault. Three sources were utilized; the Military Intelligence Database (MIDB), the Automated Message Handling System (AMHS), and the Image Product Library/Image Product Archive (IPL/IPA). These sources provided products from all four types; audio, video, imagery, and text documents.

Following the guidelines presented in Section 3.5, testers performed each task three times. First, each scenario was completed using the live Project Broadsword system in 'text results only' mode. Next, the scenario was accomplished with the system in 'geospatial map results' mode. Finally, the scenario was exercised using BGONE.

6.3 Experiment Results

Experiment results are based on the combined responses received during tester interviews upon completion of each scenario. Each tester completed a single experiment cycle (the scenario exercised in each of the three configurations as described above) once.

6.3.1 Visual Presentation

People have a natural acceptance and appeal for visual stimuli. As discussed in Chapter 2, the average individual can recognize and comprehend a complete graphical image much faster than reading a single line of text. BGONE taps into this acceptance by providing an environment where cognitive functions are stimulated through visual depictions of intelligence products. Embracing this phenomenon, testers found themselves naturally drawn to the scenario results provided by BGONE. Although not a technical measure, they found the rich color and sense of depth caused by using three-dimensional objects pleasing to the eye. Compared to the existing two-dimensional approach, testers felt that BGONE portrayed an enhanced realism that allowed them to categorize and explore geographically based intelligence data more quickly. The most prominent factor to this perceived speedup was the testers' ability to more easily comprehend the overall clustering of products within the area of interest. Testers also commented that the ability to alter one's viewpoint without redrawing the scene, as is currently done in the two-dimensional geospatial map, allowed for a more fluid transition when directing attention from one product to the next. In response to the added visual intensity of utilizing three-dimensional space, testers overwhelmingly conveyed that its use enhanced the data exploitation experience. Their observations were based on the fact that the increase in the number of products able to be viewed at a single time is a vast improvement over the current two-dimensional map and textual based display. The ability to view a large number of products in a given instance of time increases efficiency by reducing the amount of time and user intervention required to browse through all products of interest.

Besides visual acceptance, testers examined whether BGONE increased understanding of the total number of products available when compared to the two-dimensional map. Testers found that BGONE increased product results knowledge by enabling a better understanding of the number of products located at a given location. This is accomplished in two ways. First, each individual product is represented and displayed as a single glyph. However, when the number of products available at single location exceeds a user-specified parameter or the available scene space is depleted, a gray glyph takes on the representation of multiple products. For example, with a gray glyph set to represent five products, Figure 6.1 displays seven available products.

The two-dimensional map, seen in Figure 6.2, uses a single green square to represent all products at a given location. There is no mechanism to enable the user to gain an understanding of the number or types of products available. This

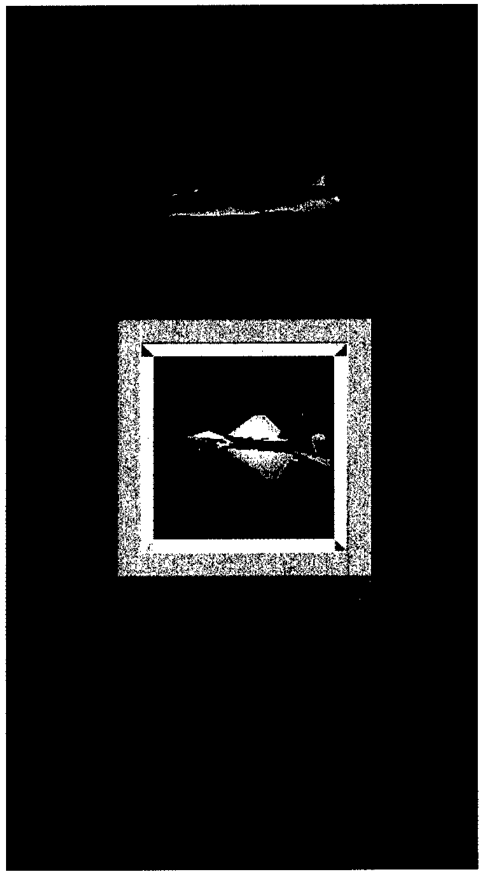


Figure 6.1: Glyph Representation (Color Plate 18)

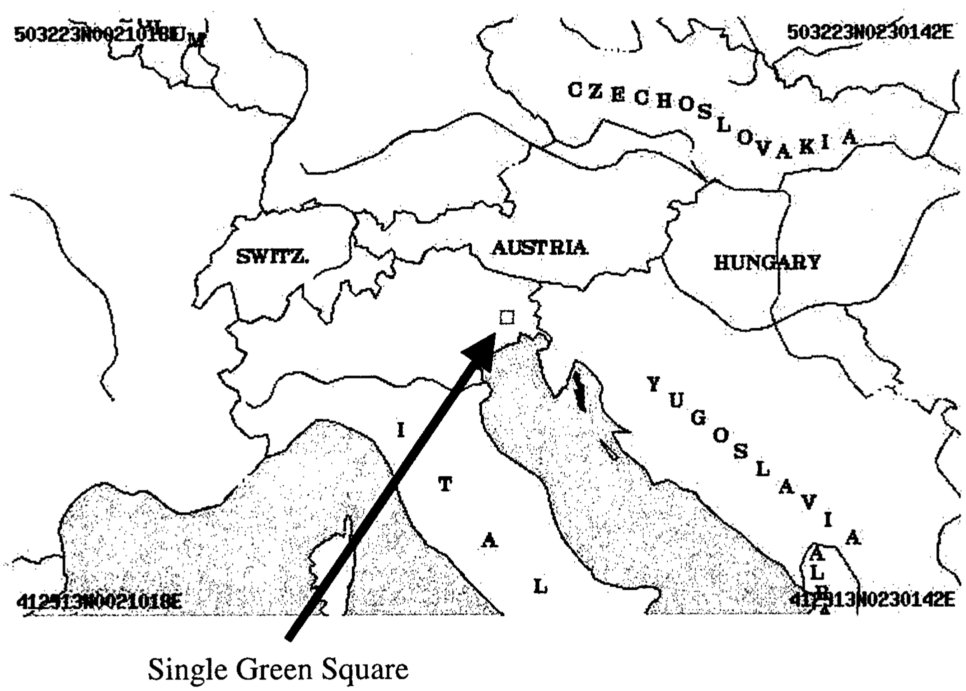


Figure 6.2: Two-dimensional Geospatial Map (Color Plate 19)

understanding requires the icons to first be explored. Exploring an icon requires the opening of a new window and returning to a text based format. Testers found this method of operation to be counter productive.

Beyond the number of products, testers preferred the BGONE method of mapping product types to the color of the outer glyph. When performing scenario task one, the ability to quickly identify textual products by the color purple made for light work. Presented with the two-dimensional map, task one required the exploration of every icon coupled with a text based visual search for products marked as 'text'. Using BGONE, gray glyphs also had to be explored; however, they did not require textual searching. Overall each tester performed task one in approximately fifty percent less time when utilizing BGONE.

6.3.2 Visual Navigation

Three-dimensional data visualization over a geospatial map may require a user to physically navigate the virtual space. Since task one, locating the total number of textual products, only required identification of the outer glyph, it could be accomplished using only low level of detail glyphs (as described in Section 5.2.3). Glyphs can be selected at any visible distance, therefore, no movement within the virtual world was required. Task two, retrieving all imagery products that have an IPL source, forced testers to move about the virtual landscape tripping proximity sensor to reveal the inner model. Testers found this movement difficult and time consuming. The most common problem was loosing track of their current virtual location. Additionally, maintaining the correct visual perspective required careful movements to prevent disorientation. When compared with the textual and two-dimensional map based approach, performing task two with BGONE took approximately four times longer to complete. Prior to this experiment, most users had little to no experience navigating in a three-dimensional environment.

6.3.3 Textual Data Navigation

Task three, accounting for all F15-E imagery products, built on the requirements of task two by adding the additional need to locate more data than can be visually displayed. Testers had the same navigational experiences as described in Section 6.3.2, however, once there they had to contend with locating the correct information. When fulfilling task three using the textual and two-dimensional map approach, testers searched through a laundry list of products to locate the required F-15E imagery. As shown in Figure 6.3, using frames and automatic pop-up dialog boxes, as described in Chapter 5, BGONE enabled testers to more efficiently locate the needed information. This is made possible because a dialog box provides a quick-look capability for key elements of information. Figure 6.3, therefore, enables us to quickly view the product type, resolution of the image, the data source, and the originating gatekeeper without having to sift through all the data available. Although the testers highly praised the text handling of BGONE, getting to that point in the experiment caused task three to take five times longer to complete versus using the textual or two-dimensional map methods.

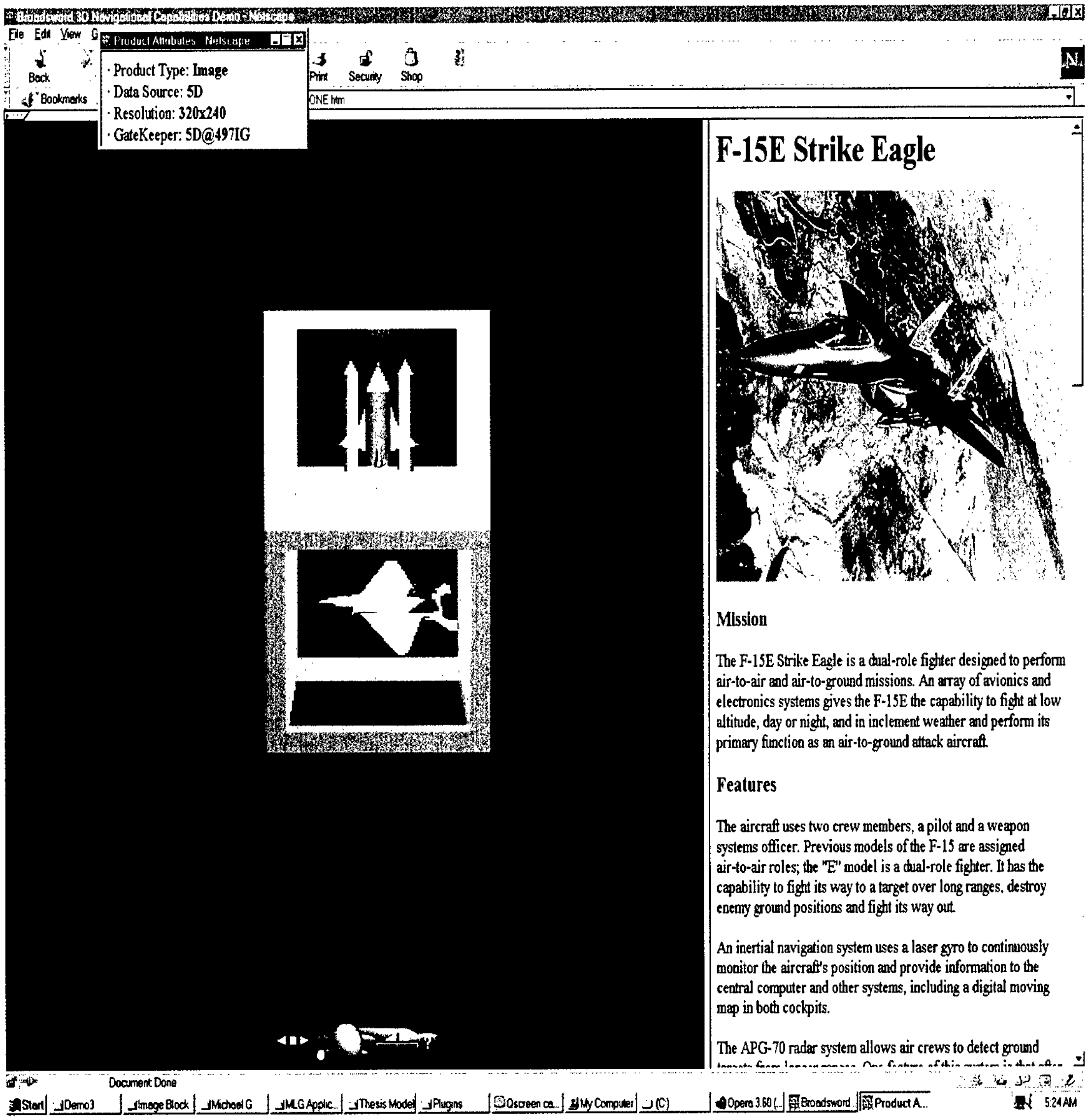


Figure 6.3: Product Exploitation with BGONE

6.4 Conclusion

These findings paint a mixed picture, depending on which issues you place the most emphasis. Data visualization in three-dimensional space appears to bring new opportunities with challenges to match. Despite the challenges, testers found BGONE to be a solid basis for which to test and examine Project Broadsword data visualization issues. Conclusions and recommendations for further research based on these findings are presented in Chapter 7.

7. Conclusions and Recommendations

7.1 Introduction

This research set out to explore how data visualization techniques could enhance an intelligence analyst's exploitation capability. Specifically targeted were Project Broadsword and its unique ability to access and disseminate data from heterogeneous sources worldwide. To investigate data visualization concepts in controlled experiments required construction of a representative modeled environment. This environment, known as the Broadsword Geospatially Oriented Navigational Environment (BGONE), supplied the framework and tools to simulate how an adept user in the field would respond and navigate a geospatially disperse field of data.

This chapter discusses implementation considerations based on the findings in Chapter 6. Unique contributions to the field, developed as a result of this research, are also covered. Finally, recommendations for future research are presented.

7.2 Conclusions

The experiments run in BGONE offered a wealth of information. The most notable being that the primary concern with data visualization in a three-dimensional space is not the visuals, but rather the navigation required moving from one product to the next. Given that our dataset is geospatially placed on a worldwide scale, the amount of virtual terrain that must be traversed may be quite large. Using only standard two-dimensional input devices, a mouse and keyboard, most testers who had to travel more than a few virtual meters found the experience quite frustrating.

The intelligence data products used for this research contain a large number of data elements. This large quantity is more than purely visual methods can effectively display. The addition of pop-up dialog boxes effectively aided testers in the completion of experiment tasks requiring exploitation of specific data elements held by a product. Unlike the two-dimensional map method, testers were able to quickly move from one product to the next without returning to a text-based laundry list of products.

This research focused around the display of representative geometric objects in three-dimensional space. Data visualization is a powerful tool that becomes exponentially more complicated to develop and control when a user must physically interact with the data they are viewing. Those who have little to no experience with three-dimensional environments may find this type of data visualization uncomfortable to work with. As discussed in section 6.3.2, testers had a difficult time navigating within BGONE. Had this not been a research experiment, most agreed they would have reverted to a text based data exploitation method to "get the job done quickly". The use and implementation of knowledge and techniques developed from this study must therefore complement, not replace, current intelligence exploitation methods. As with any updated technology or method of doing business, people need time to conquer the learning curve before benefits can more accurately be assessed.

7.2.1 Implementation Consideration

The Project Broadsword program office, encouraged strongly by the user community, is looking to expand into the three-dimensional realm when using data visualization methods. Although they wish to give the users what they want, I feel that jumping headfirst into such an undertaking is a mistake. At this time, the maturity level of the technology and standard computer input tools supplied to each analyst are not yet sufficient. Rather than a full implementation of three-dimensional data visualization, as presented, a gradual integration of this technology should be explored. One possible technique involves coupling results from the current two-dimensional geospatial map with BGONE enabled exploitation. When an analyst is presented with results, as seen in Figure 7.1, rather than the green icon leading to a

Figure 7.1: Current Results Display (Color Plate 20)

text-based format, a new window such as Figure 7.2 could be displayed. This new window shows all products available at the chosen location of interest. With the results map left in an unmodified window, the analysts can visually explore the locality without losing global perspective. Applying the concept of Figure 7.2, the new data navigational techniques allow for quick exploitation of products of interest without physical movement within the three-dimensional space. This provides improved intelligence exploitation techniques, as discussed in Section 7.2, while alleviating the discomfort testers felt while traversing a VRML map. This research set out to develop new data exploitation methods and techniques for the plethora of digital intelligence products. Implementing the data navigation techniques, as described in Section 5.3.2, required the creation of new methods that allow automatic pop-up dialog box generation in a VRML environment. This capability, never before seen in this format, is crucial for the effective use of data

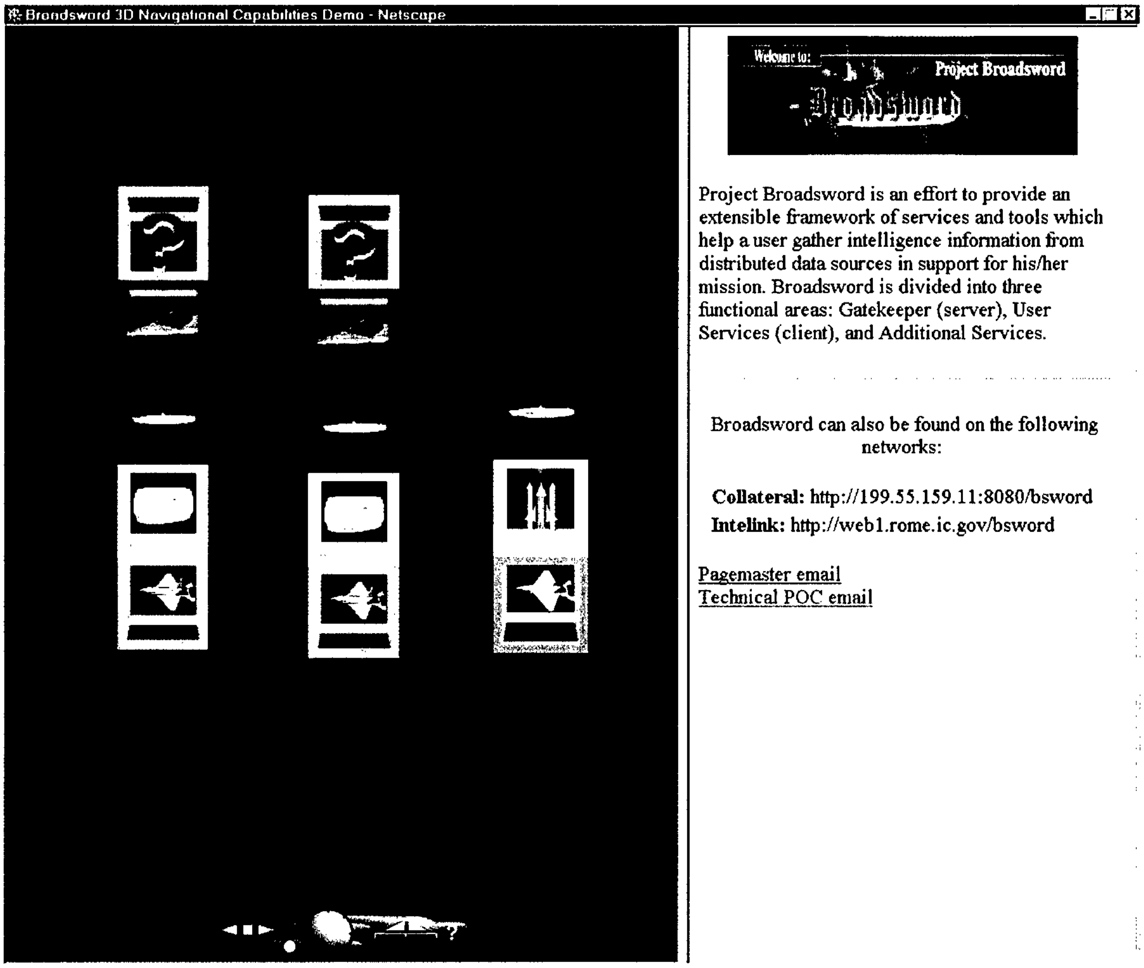


Figure 7.2: BGONE Enhanced Results (Color Plate 21)

visualization when the amount of data to be exploited exceeds the handling capabilities of the graphics. The application of these techniques can and should be applied to other data visualization problems where a large amount of information is present. These other problems include data exploration in a two-dimensional environment, which highlight the fact that the creative handling of data in two-dimensional visual space has not yet been exhausted.

7.3 Further Research

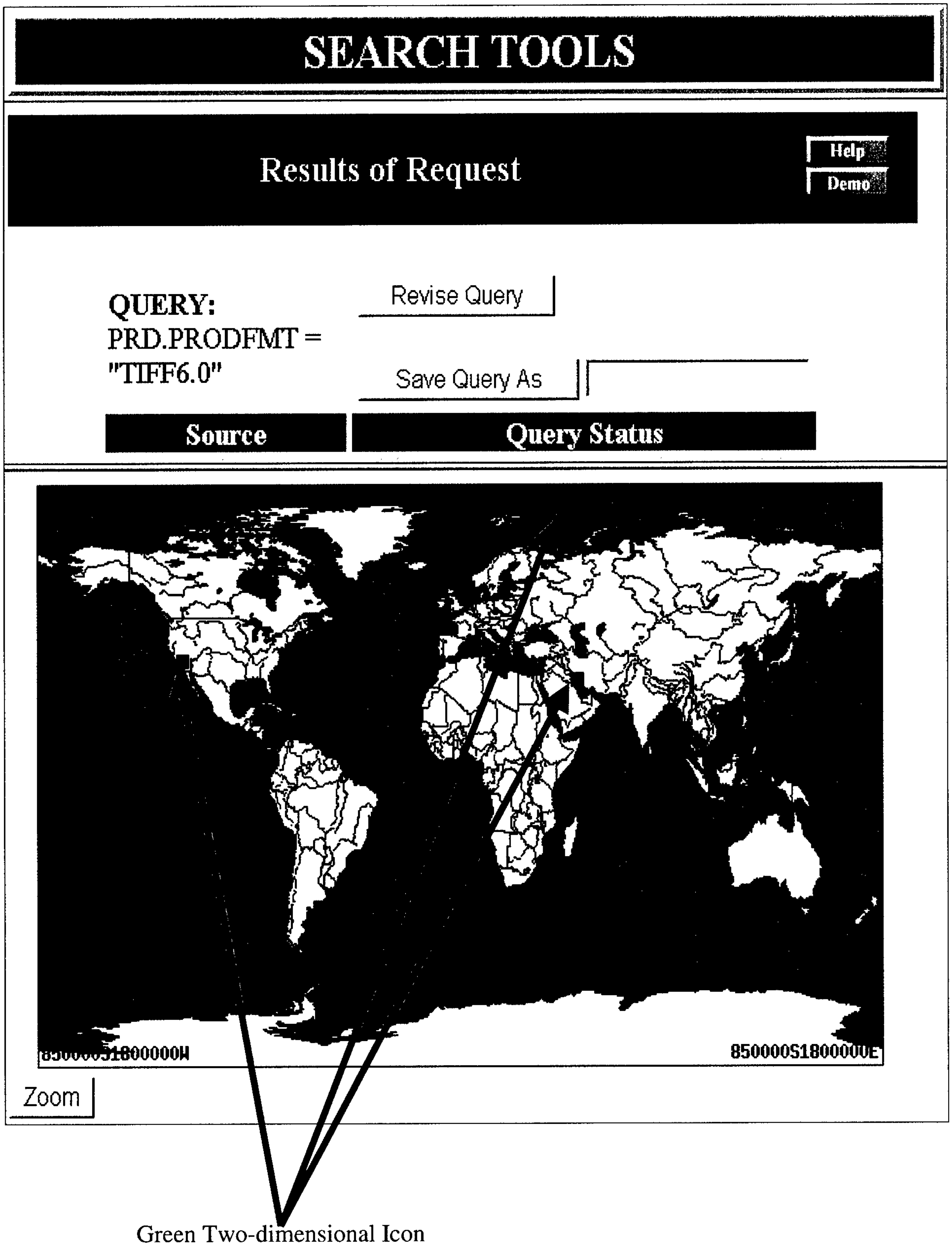
This thesis set out to demonstrate the benefits of exploiting intelligence products using data visualization employed in three-dimensional space. However, research revealed that more work is needed before successful implementation in this area. Numerous areas of study need to be pursued, to include correlation of a products' representative size to the users' view level, virtual reality device usage, and enhanced multimedia capabilities.

Under the current architecture, proper scaling between a glyph or an icon with respect to its location on the geospatial map is not performed. As a user moves about the map or zooms in and out, the icon size does not change with respect to the users' view. For example, at one level of resolution a single result's icon can encompass fifty square nautical miles of area, while in another the same results icon may cover only one square mile. Although the glyph size does change with respect to a users' view, the geospatial location over which it is located is not defined in exact detail since this information is not passed to the graphics renderer. The design process currently arbitrarily sets glyph and icon sizes. A method for properly controlling and varying the size of the glyph or icon with respect to the actual data location as the analyst changes worldview perspective needs to be addressed.

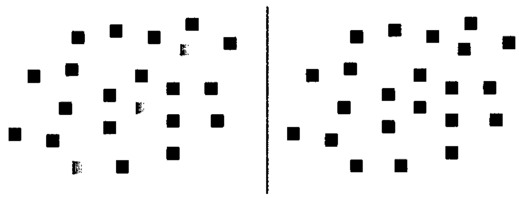
Since most analysts are constrained physically by two dimensional control devices, effective ways of breaking out of this confinement need to be explored. Using virtual reality devices, such as a space ball or head tracker, would allow additional freedom and ease of movement. Inclusion of these devices may effectively eliminate the movement difficulties outlined in Section 6.3.2.

This research has only brushed the surface of what can be achieved with multimedia. As network bandwidth and computer processing increases, the possibilities for video streaming (both live and archived) and other technologies hold many promises for future enhancements.

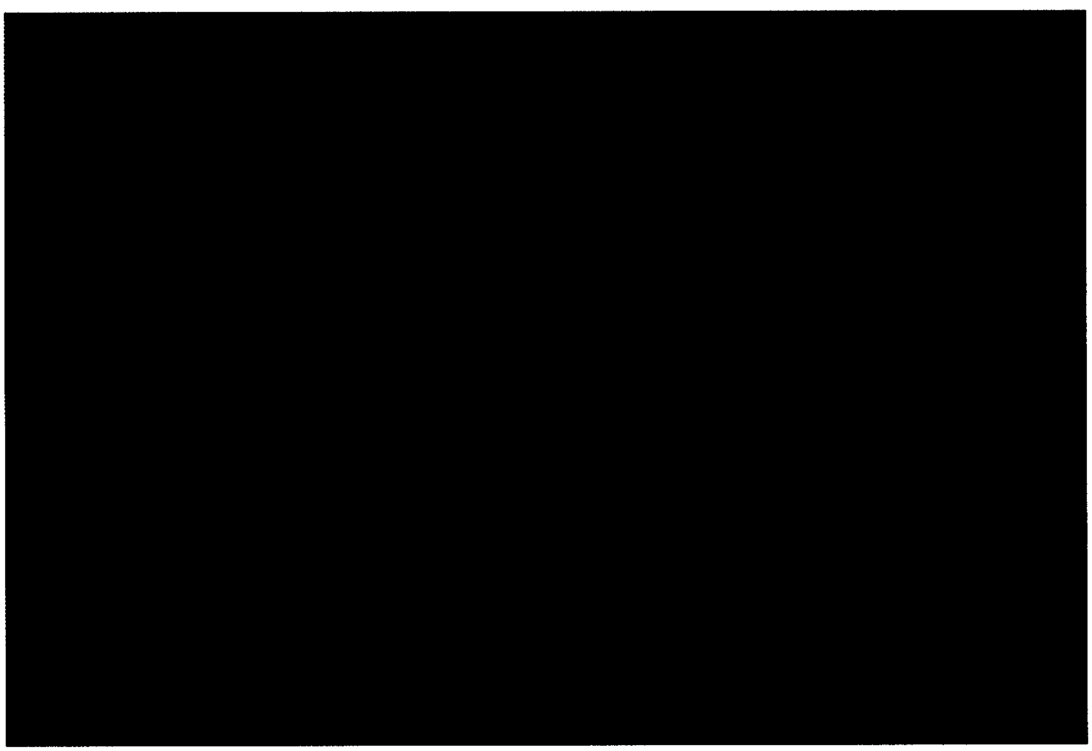
Color Plates



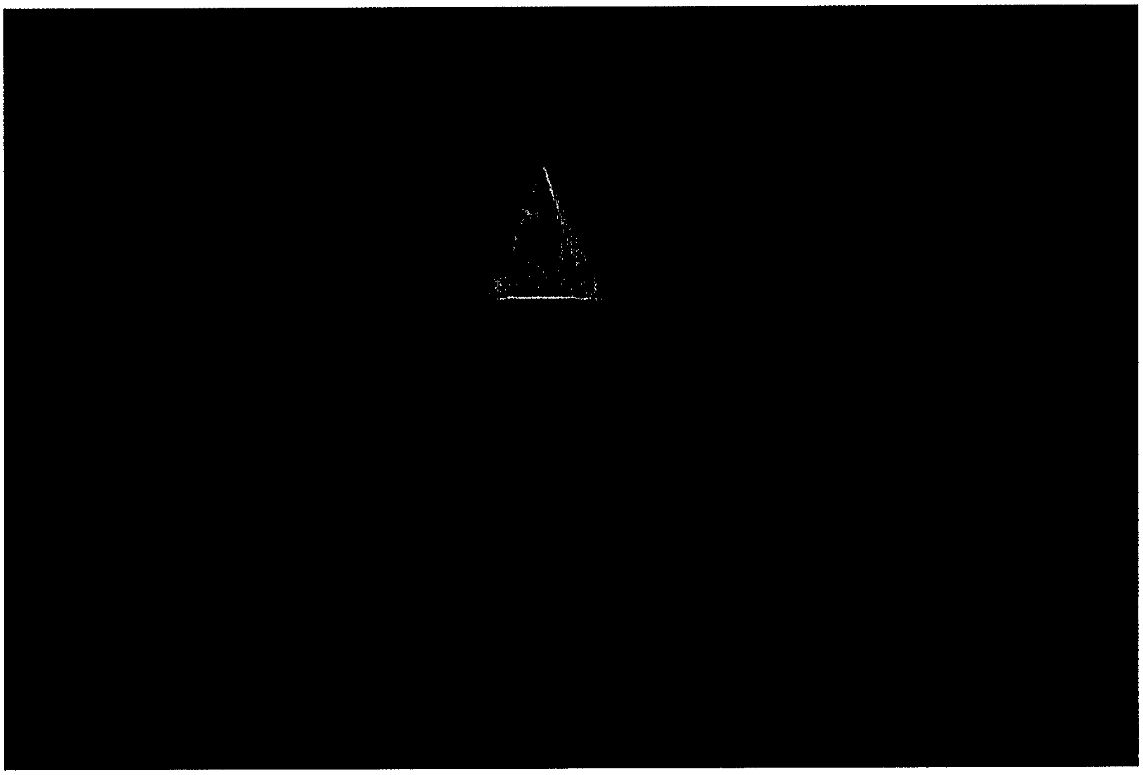
Color Plate 1: Geospatial Map Results



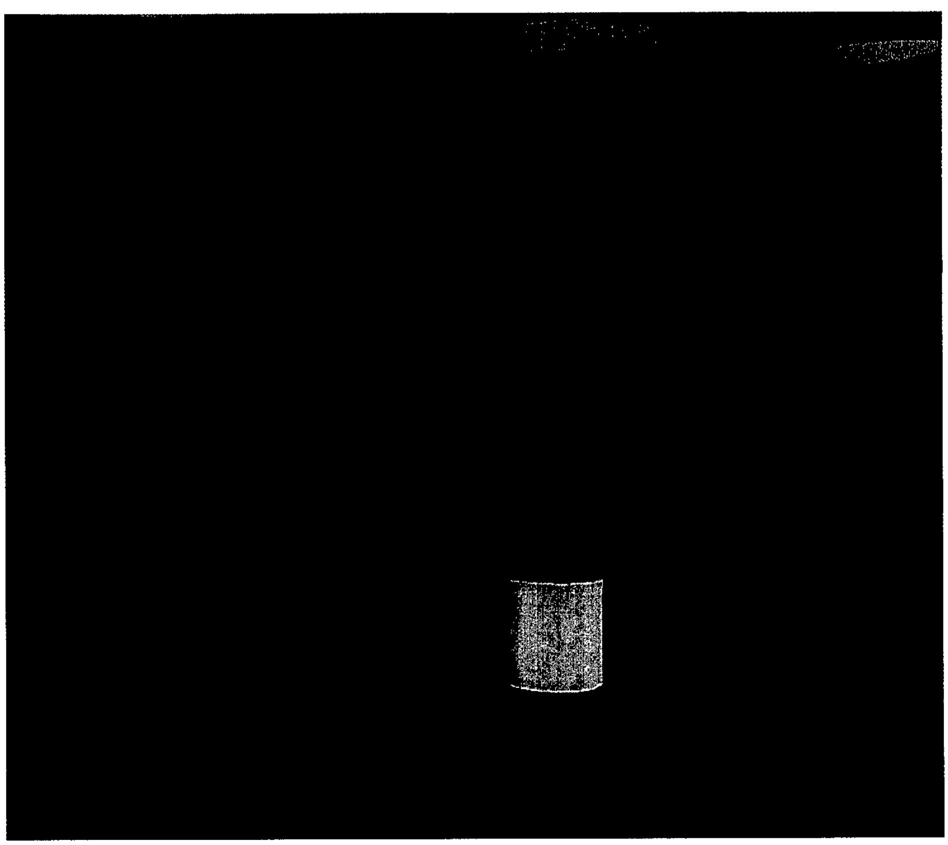
Color Plate 2: Preattentive Processing



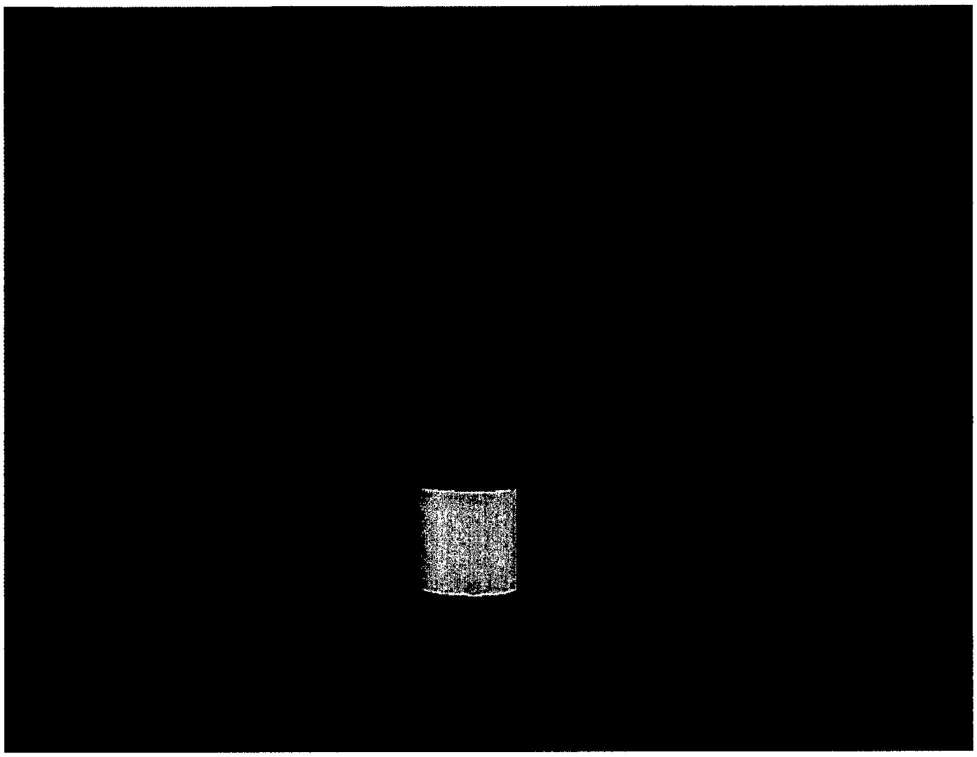
Color Plate 3: Symbolic Glyphs



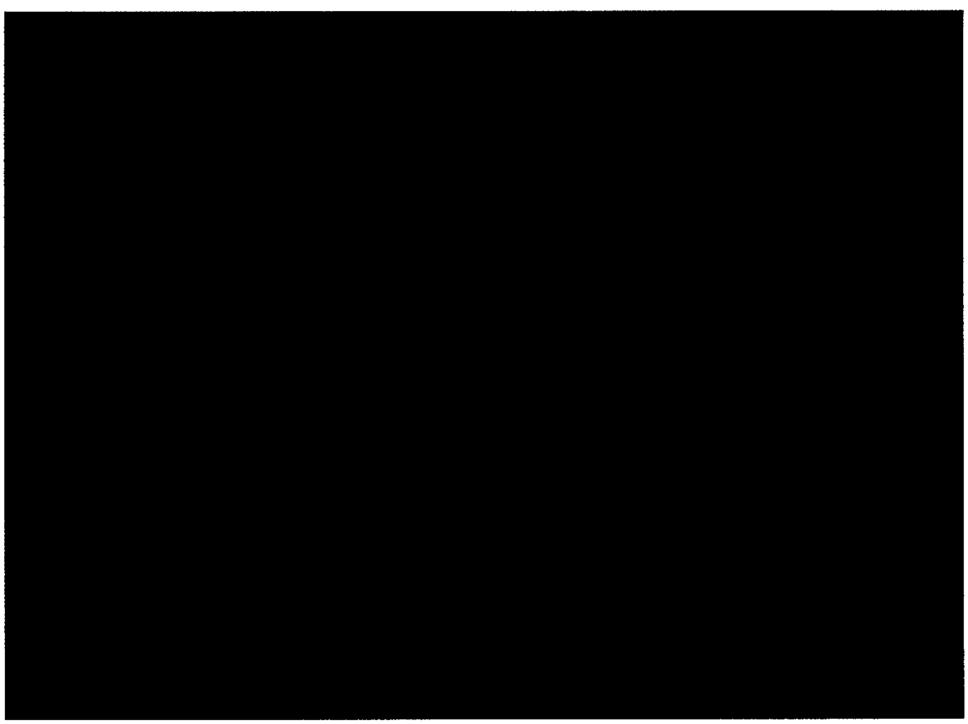
Color Plate 4: Multilevel Glyphs



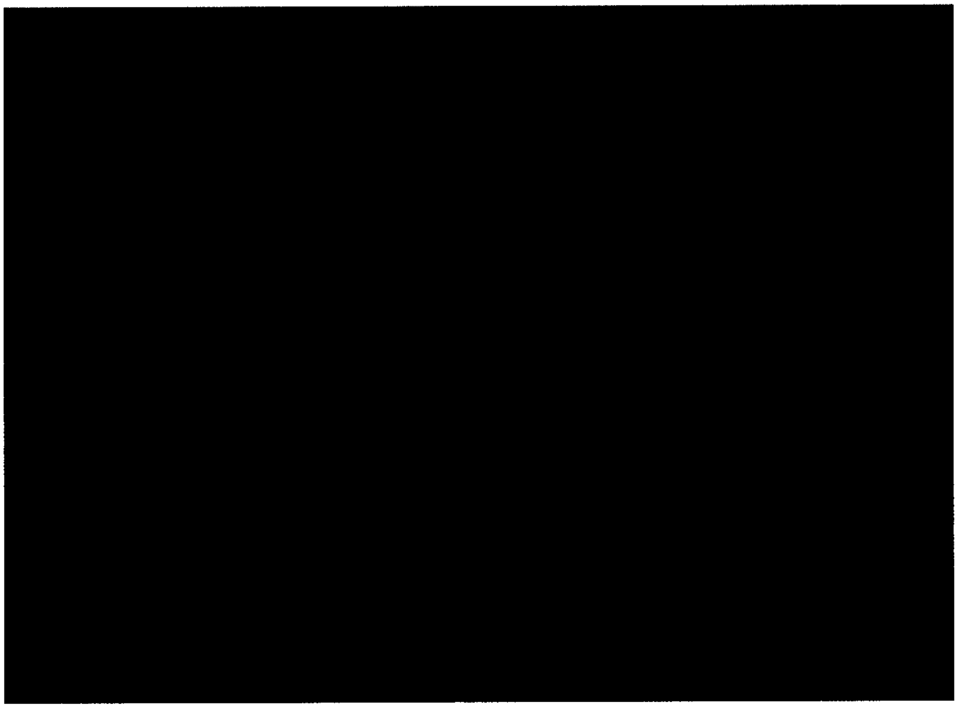
Color Plate 5: Cylinder Shaped Level One Glyphs



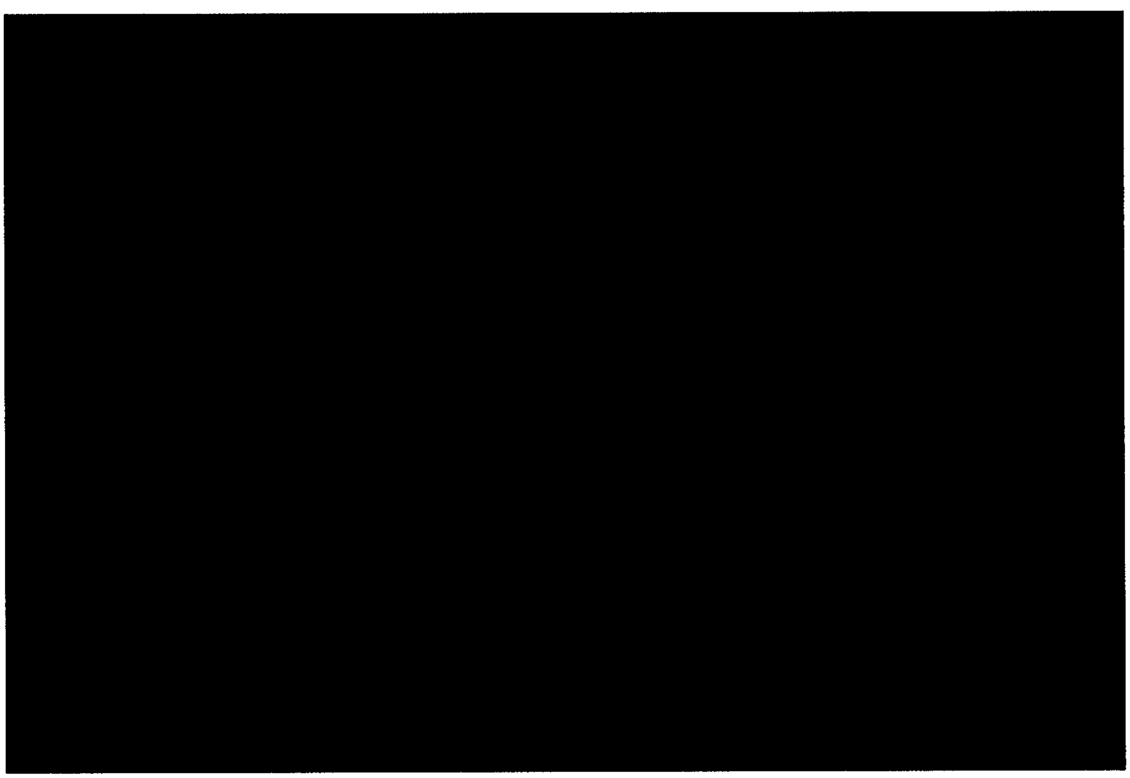
Color Plate 6: Cube Shaped Level One Glyphs



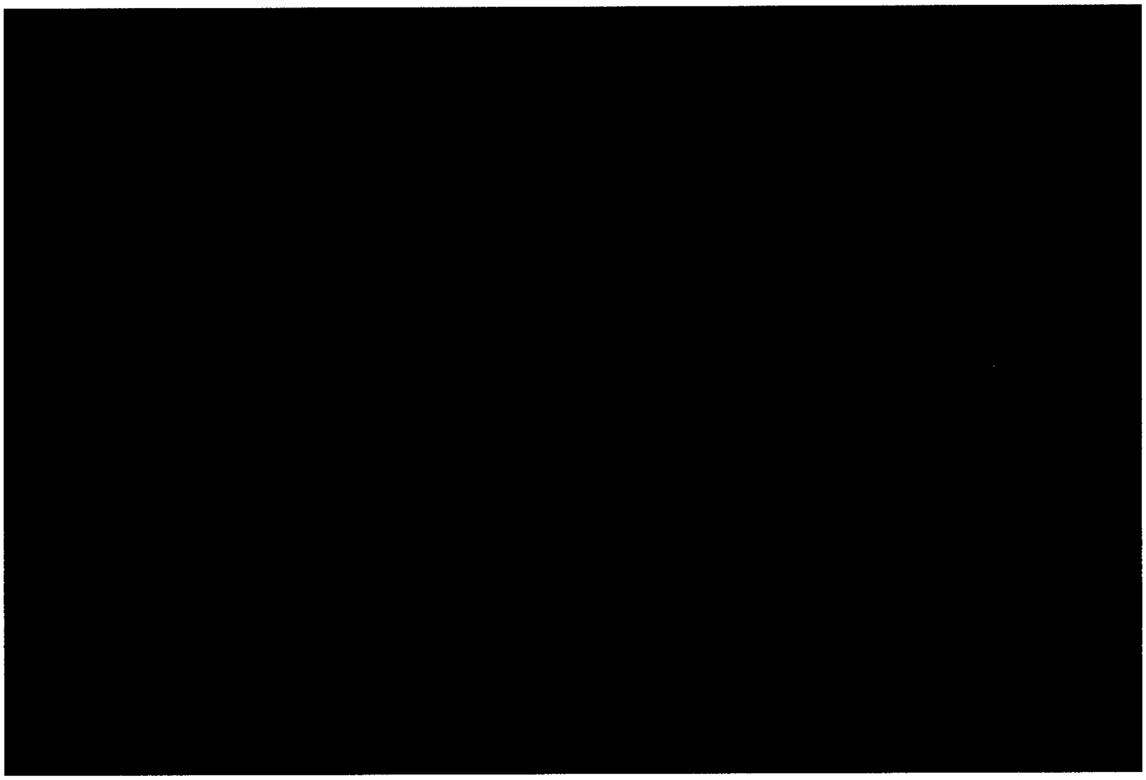
Color Plate 7: Transparency as Designed



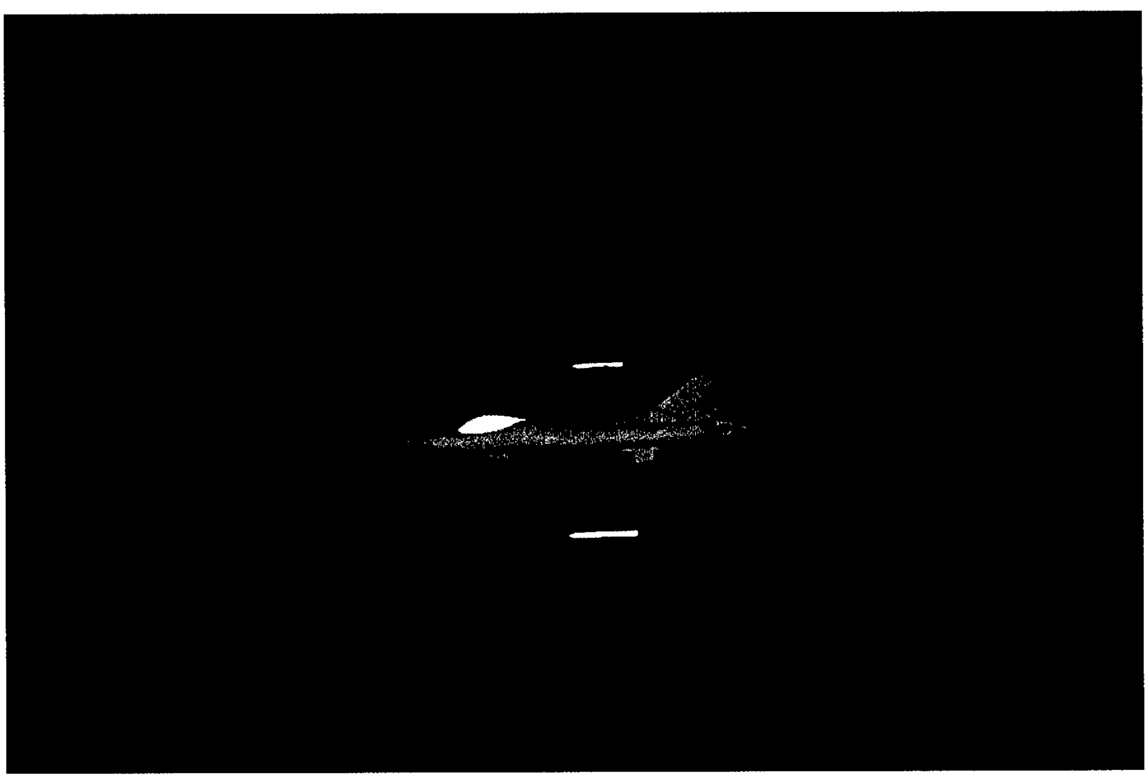
Color Plate 8: Transparency in Operational Environment



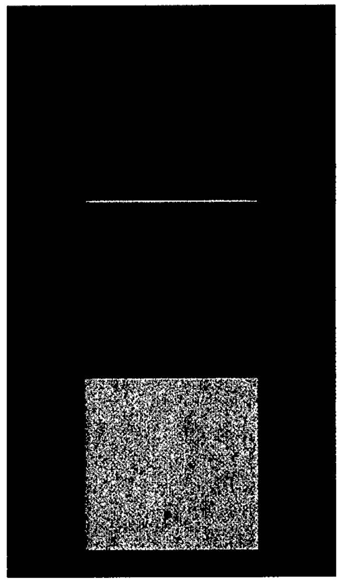
Color Plate 9: Redesigned Level One Glyph



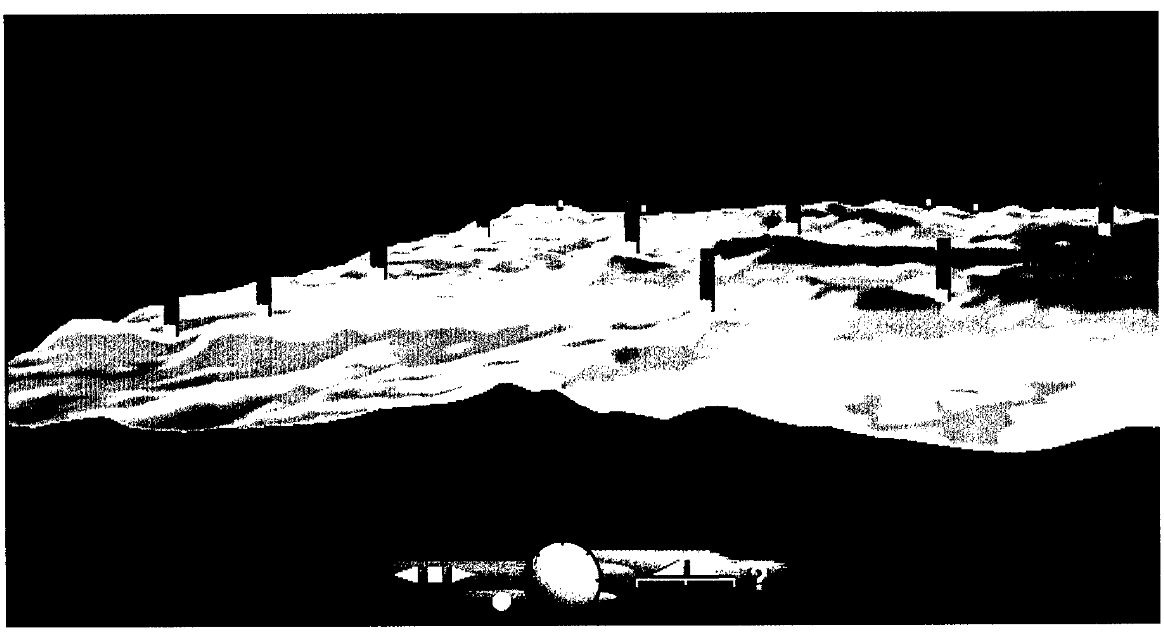
Color Plate 10: Abstract Level Two Glyph



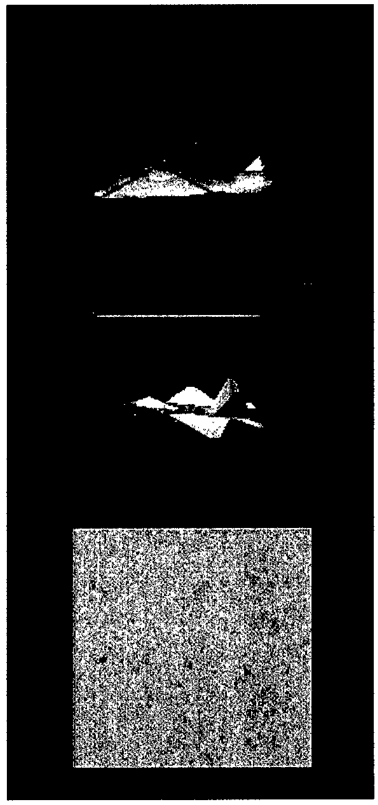
Color Plate 11: Model Based Level Two Glyph



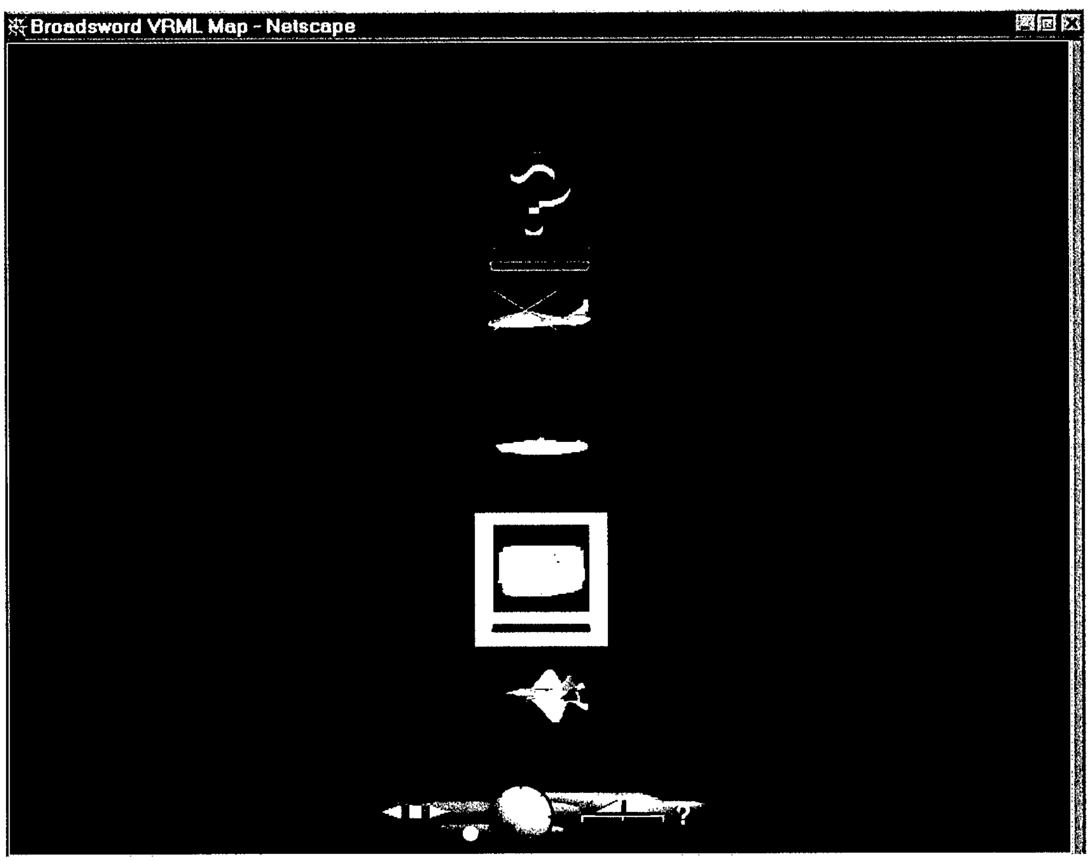
Color Plate 12: Low Level Of Detail Glyphs



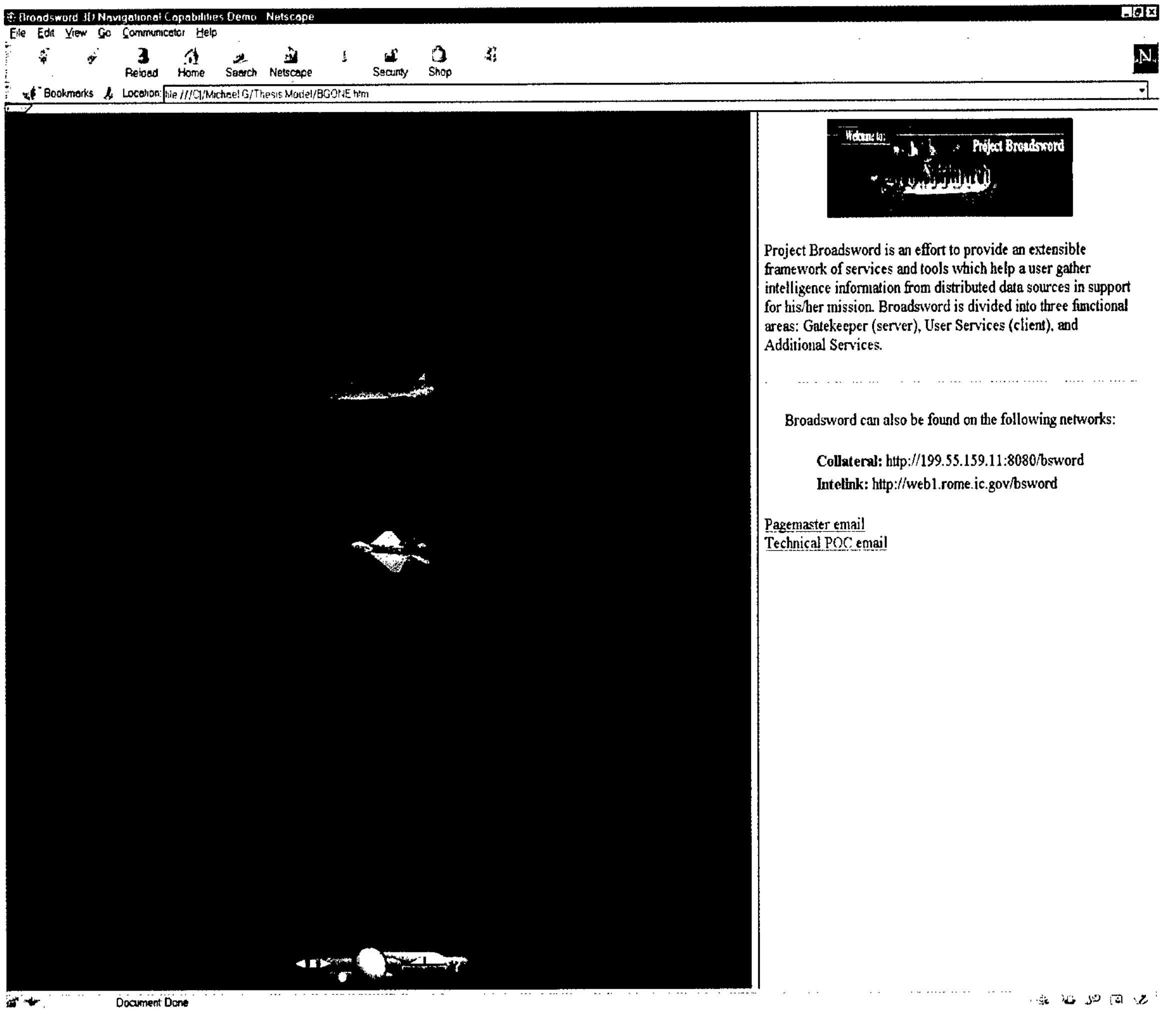
Color Plate 13: Low Level Of Detail Glyphs on a VRML Landscape Map



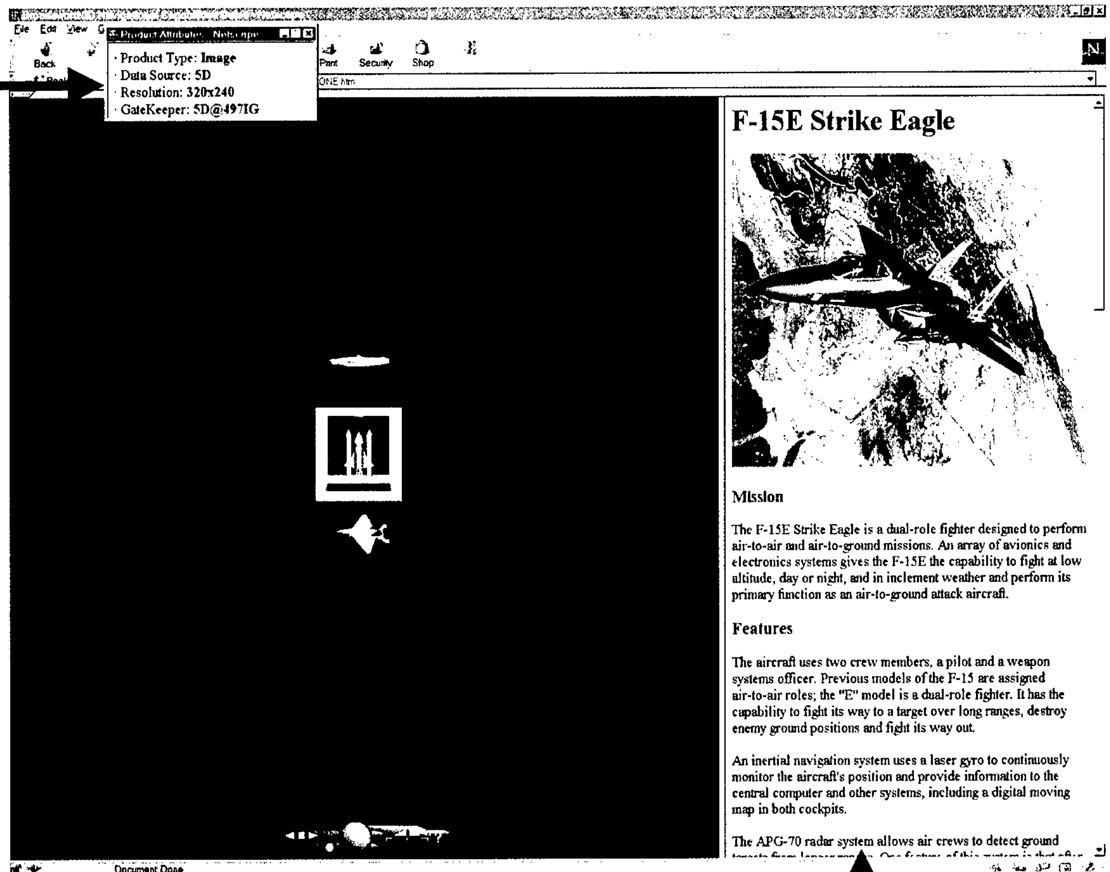
Color Plate 14: Proximity Sensor Activation Rendering



Color Plate 15: Products Represented by Gray Glyph



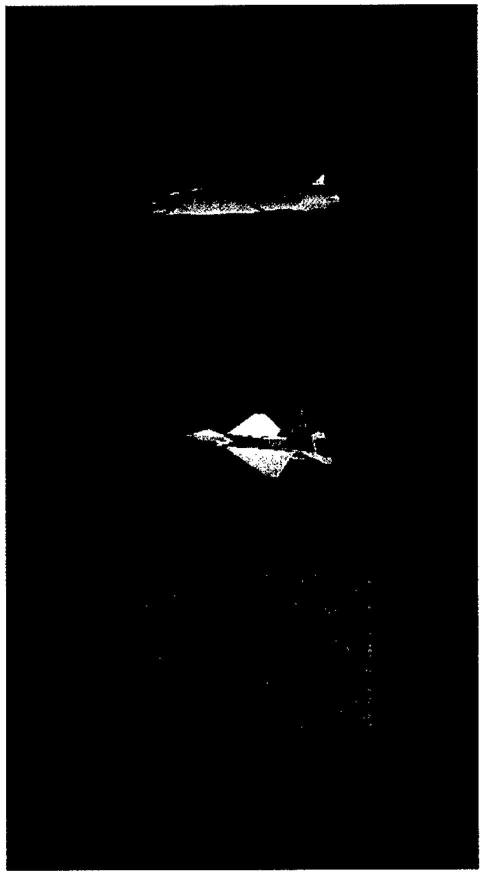
Color Plate 16: VRML Environment with Frames



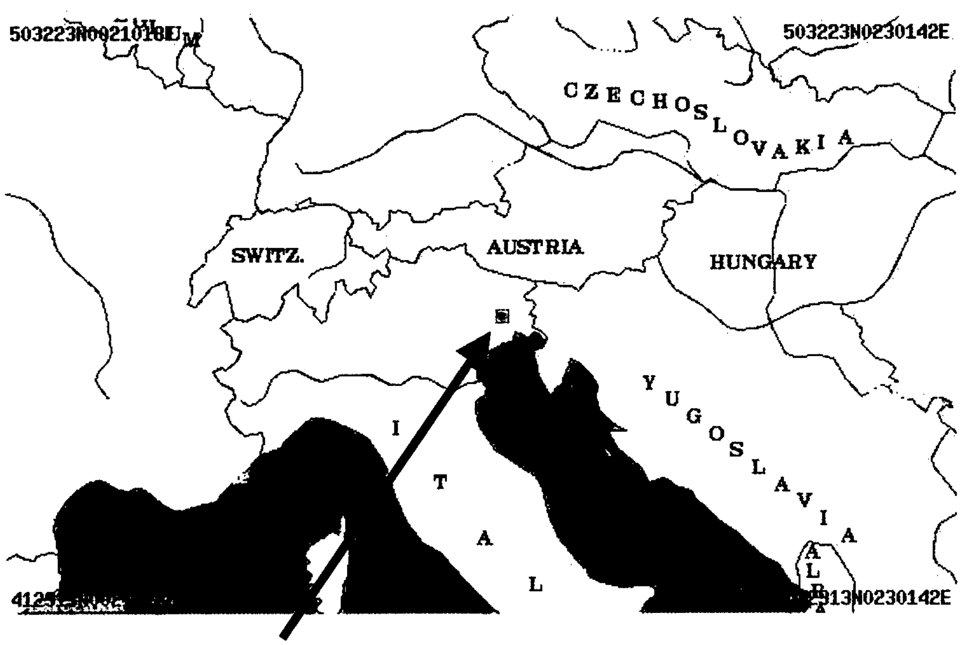
Dialog box generated by the *isOver* method

Data placed in frame via the *isPressed* method.

Color Plate 17: Text Handling

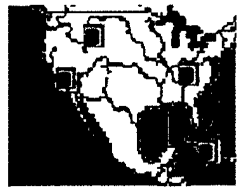


Color Plate 18: Glyph Representation

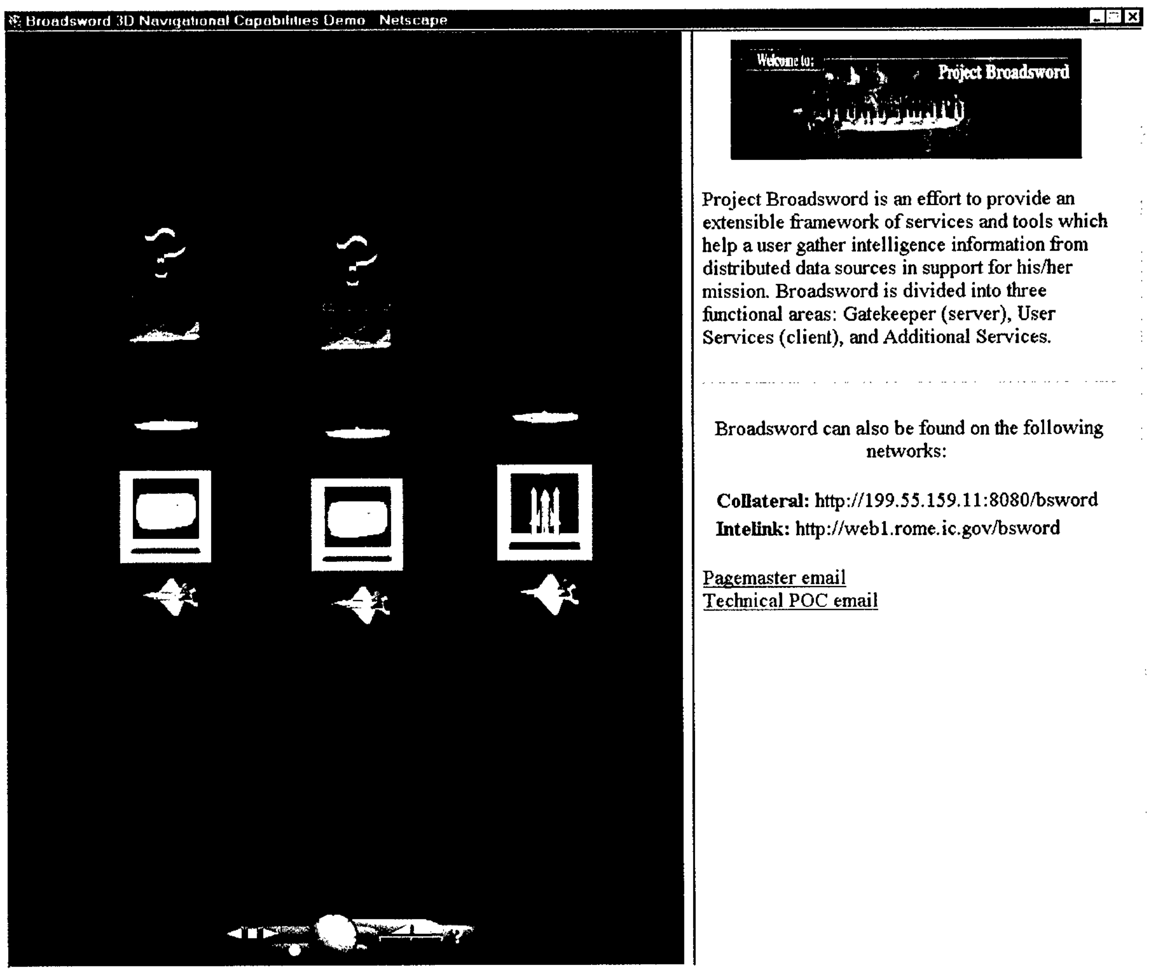


Single Green Square

Color Plate 19: Two-dimensional Geospatial Map



Color Plate 20: Current Results Display



Color Plate 21: BGONE Enhanced Results

Bibliography

1. Lee Paschall, "C3I and the National Military Command System", Command and Control Seminar, Harvard University, 1980

2. Memorandum to Dr. McCall from General Fogleman, CSAF and Dr. Widnall, SecAF, entitled "New World Vistas Challenge for Scientific Advisory Board (SAB)", 29 November 1994

3. USAF Scientific Advisory Board, "New World Vistas Air and Space Power for the 21st Century," Summary Volume, December 1995

4. William E. Colby, "The Developing Perspective of Intelligence", Command and Control Seminar, Harvard University, 1980

5. Christopher G. Healy, "Choosing Effective Colours for Data Visualization", Proceedings of IEEE Visualization '96, 1996

6. L. D. Bergman, B. E. Rogowitz, L. A. Treinish, "A Rule-Based Tool for Assisting Colormap Selection", Proceedings of Visualization '95, 1995

7. B.E. Rogowitz, L .A. Treinish, "An Architecture for rule-based visualization. In Proceedings Visualization '93, 1993

8. John W. Senders, Marc Green "Expert Witness and Human Factors Design", http://www.ergogero.com, 1999

9. W. Cleveland, "The Elements of Graphing Data", Wadsworth, Command and Control Seminar, Harvard University, 1984

10. R. Abarbanel, "Problem Solving with and without Visualization", Proceedings of Visualization '93, 1993

11. D. Woods, "The Cognitive Engineering of Problem Representations", In G. Weir and J. Alty, "Human-Computer Interaction and Complex Systems", Academic Press, 1991

12. Alan M. Davis, "Software Requirements", University of Colorado at Colorado Springs, Prentice Hall PTR, 1993

13. "ISO/IEC 14772-1:1997 Virtual Reality Modeling Language (VRML97)", htttp://www.web3d.org/Specifications/VRML97, 1997

REPORT DOCUMENTATION PAGE	*Form Approved* *OMB No. 0704-0188*

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED *(From - To)*
xx-03-2000	Master's Thesis	Feb 1999 - Mar 2000

4. TITLE AND SUBTITLE

THREE-DIMENSIONAL DATA VISUALIZATION OF ELECTRONIC MILITARY INTELLIGENCE USING THE PROJECT BROADSWORD SYSTEM

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

Goeringer, Michael L, Lieutenant, USAF

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Air Force Institute of Technology
Graduate School of Engineering and Management (AFIT/EN)
2950 P Street, Building 640
WPAFB, OH 45433-7765

8. PERFORMING ORGANIZATION REPORT NUMBER

AFIT/GCS/ENG/00M-08

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

Dr. John Salerno
32 Brooks Road
Rome, New York 13441
Phone: (315) 330-4429 DSN:587-4429
Fax: (315) 330-3913

10. SPONSOR/MONITOR'S ACRONYM(S)

AFRL/RRS IFED

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED.

13. SUPPLEMENTARY NOTES

14. ABSTRACT

This thesis explores procedures for enhancing the capabilities of Project Broadsword, an intelligence data retrieval system, using three-dimensional data visualization. Employing a stand-alone representative environment, this research develops methods and techniques for overcoming problems encountered when visualizing large quantities of data. Textual handling through graphical triggers is also addressed.

The results of this research demonstrate the effects of utilizing three-dimensional visual cues to organize, perceive, and navigate vast amounts of intelligence products and their associated metadata. Conclusions drawn from this research directly affect the next major release of the Project Broadsword system, currently under development.

15. SUBJECT TERMS

Three-dimensional Data Visualization, Intelligence Products, Project Broadsword, Computer Graphics

16. SECURITY CLASSIFICATION OF: a. REPORT	b. ABSTRACT	c. THIS PAGE	17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
U	U	U	UL	91	Lt. Col. Timothy Jacobs, ENG
					19b. TELEPHONE NUMBER *(Include area code)* (937) 255-6565 x4279 / DSN 785-6565 x4279