Creating 3D Oceanographic Data Visualizations for the Web

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ABSTRACT

In 1999 the Monterey Bay Aquarium Research Institute (MBARI) began a project to create 3D visualizations for each of its Remotely Operated Vehicle (ROV) dives in the deep waters of the ocean. The goal was to synthesize various ROV-generated data sets for visualization in a common, compelling, efficient, and easy-to-use system. Integrating these visualizations into the Institute's database of dive information is a key component that helps make the data more understandable and useful. The architecture of the system was designed to allow for incremental improvements in the presentation and in the underlying data quality. An object oriented approach for the data access and use of the VRML97 EXTERNPROTO feature provided the framework for this architecture. The visualization system has been in place for over a year, internal users now have adequate platforms to visualize their data, and we are beginning our evaluation for a next cycle of improvements that will employ features of the next generation of VRML, including GeoVRML.

Categories and Subject Descriptors
J.2 [**Computer Applications**]: Physical Sciences and Engineering – *Earth and atmospheric sciences.*

General Terms
Performance, Design, Human Factors, Standardization.

Keywords

VRML, GeoVRML. Web3D, oceanography, ROV, underwater, scientific visualization, exploration, marine geology, databases.

1. INTRODUCTION

The Monterey Bay Aquarium Research Institute operates two Remotely Operated Vehicles (ROVs) in the deep waters of Monterey Bay and the greater eastern Pacific Ocean. MBARI's mission is to develop state-of-the-art systems for conducting scientific research in the deep waters of the ocean. The ROV's act primarily as the eyes and hands of the science teams who operate the vehicle from the support ships; they are also observing and sensor platforms that often enter into areas that have never before been explored. Over its thirteen-year history MBARI has routinely logged the variety of data that come from these underwater activities. These data include Ship and ROV navigation information, bathymetric maps of the dive areas, collections of geologic and biologic specimens, video frame grabs, and annotations of the recorded video. It is a rich collection of data that presents interesting challenges for visualization.

In order to be more responsive to user needs the Information Applications Group at MBARI has designed databases specific to each form of data. For example, the specimen collection database is separate from the video annotation database. Navigation data are stored as simple text files that are easily imported into Geographic Information System (GIS) tools. Video frame grabs are available on MBARI's Intranet through thumbnail indices organized by time and ROV dive number. A catalog of all these data sets is maintained in a relational database called the Expedition Database. The database is managed and queried through a Web interface. Because all of this information is web accessible, the system works fairly well for the user who needs to assemble data for most research needs. This "federated" approach to data management is superior to a more monolithic approach, which provides uniform access, but is difficult to scale to new types of data while being responsive to user needs.

The downside of this federated approach is that the information in these data sets can be difficult to assemble into a coherent picture. The result is that the data often go un-visualized and un-interpreted, and so do not effectively contribute to our scientific or operational understanding. Conducting operations at benthic sites (locations at the bottom of the ocean) is hampered by an inability to view features on a scale larger than the limit of what can be seen through the ROV's video cameras. For instance, for work at cold seep sites there is a need to visualize an area bigger than a room; the visualization needs to contain objects representing experiments in progress, as well as geographic and geologic features. For mid-water work there is a requirement to better understand the 3D aspects of the observations.

Creating useful and interesting visualizations of the variety of data collected by MBARI presents a challenge whose solution may benefit the greater oceanographic community. The assembly

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of our various data sets into a common, compelling, efficient, and easy-to-use visualization system is the goal of this project.

This paper describes a system that has been developed to meet the need of visualizing disparate data in a common way. "Common" here means two things: accessible to most people (i.e. available via an ordinary web browser), and accessible through a single tool that can handle a wide variety of data in a comprehensive fashion. This work has been presented before at a Web3D Roundup [1] (winning best education demo) and at an Oceanography conference [2]. Sections 2, 3, and 4 describe the architecture and implementation of the system. Section 5 discusses an evaluation of the system and outlines directions for improvement.

2. EXPEDITION OBJECT AND POST DIVE VRML CREATOR

Given that much of the data we wish to visualize is distributed among various databases and files we needed a way to efficiently assemble data from these sources into a form which can be translated into the 3D markup language that the browser understands. To do this, an object-oriented Perl module was written to provide a programmatic interface to the various kinds of data that need to be translated into VRML. The EXPD.pm module was developed to allow access to data, whether it came from a relational database or a flat file. This abstraction, which implements data hiding and encapsulation, was a great improvement over a previous proof-of-concept program which did not take this O-O approach.

Below is a diagram showing where the EXPD.pm module fits into the data stream.

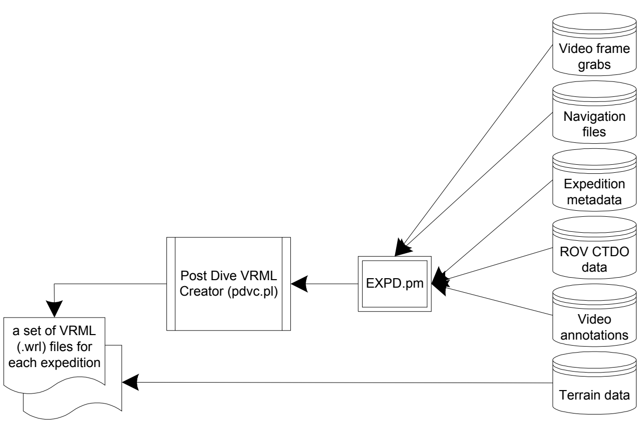


Figure 1: Data flow from various databases and files into Expedition object for use by the Post Dive VRML Creator. Pdvc.pl. produces a set of 3D world (.wrl) files.

The Post Dive VRML Creator (pdvc.pl) retrieves Expedition information and converts it to the specific VRML nodes that are used to visually represent the expedition. For each expedition a set of static VRML (.wrl) files is created to represent the timeline of positions & orientations of the ship & ROV, a set of selected video frame grabs, environmental data, and other data that relate to the dive. These files can be independently evaluated and tested.

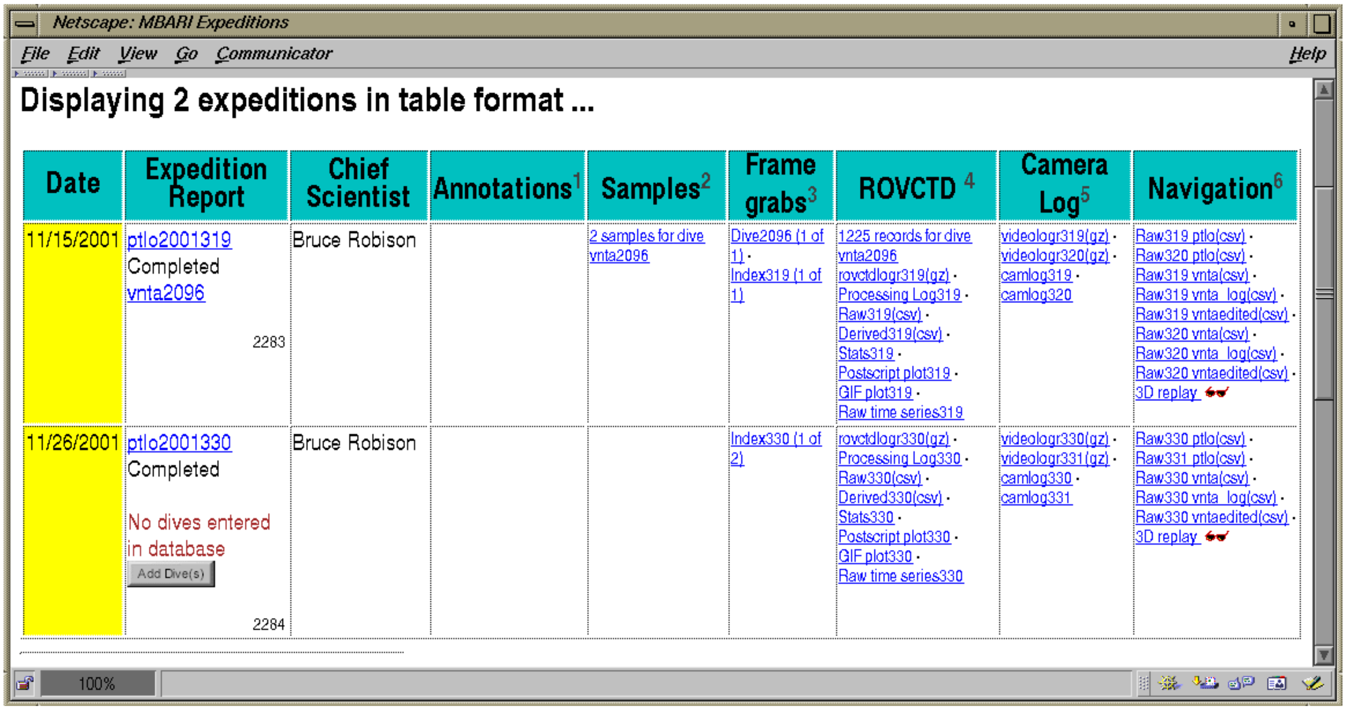
Table 1. Set of VRML files created by pdvc.pl. A selection of these files for an expedition constitutes a 3D Replay of the expedition and the ROV Dive data. The string *pre* is replaced by the shipname, year, and year-day of the expedition.

VRML file	Contents	Typical size
*pre***tracks**.wrl	PowerDivePlayback node defining timeline slider and vehicle positions. All events for the 3D user interface are encapsulated in the PowerDivePlayback node.	200-400 KB
*pre***fg**.wrl	Set of FrameGrab nodes	5 KB + about 40 KB for each image
*pre***O2**.wrl	Color-coded IndexedLineSet representing dissolved oxygen concentrations	200-300 KB
*pre***Temp**.wrl	Color-coded IndexedLineSet representing water temperature	200-300 KB
*pre***Sal**.wrl	Color-coded IndexedLineSet representing salinity	200-300 KB
*pre***Light**.wrl	Color-coded IndexedLineSet representing transmissivity of light	200-300 KB
*pre***lookup**.wrl	A key to the mapping of colors to values of environmental data	10 KB
*pre***rpt**.wrl	Text of expedition report	2 KB

As with most other MBARI data, files are organized simply by platform name and year/year-day. For instance the tracks file for Research Vessel *Point Lobos* on January 3, 2001 would be ptlo2001003tracks.wrl. A collection of these component files constitutes a *3D Replay* of the ROV dive.

If pdvc.pl is successful in creating at least the tracks file then a record is added to the Expedition Database. A user can then query this database through the web interface and can with a few more clicks begin viewing the expedition and dive information in 3D.

If new data becomes available, or if data changes (e.g. edited navigation data becomes available) then the pdvc.pl program is run again to reproduce this set of files. If a change in the presentation technique needs to be made (e.g. adding an orientation reference such as a north arrow) then the External Prototype is updated. In this case the static .wrl files (of which there are thousands) do not need to be updated. The next section describes the External Prototypes developed for this project.



Netscape: MBARI Expeditions

File Edit View Go Communicator Help

Displaying 2 expeditions in table format ...

Date	Expedition Report	Chief Scientist	Annotations[1]	Samples[2]	Frame grabs[3]	ROVCTD[4]	Camera Log[5]	Navigation[6]
11/15/2001	ptlo2001319 Completed vnta2096 2283	Bruce Robison		2 samples for dive vnta2096	Dive2096 (1 of 1) · Index319 (1 of 1)	1225 records for dive vnta2096 rovctdlogr319(gz) · Processing Log319 · Raw319(csv) · Derived319(csv) · Stats319 · Postscript plot319 · GIF plot319 · Raw time series319	videologr319(gz) · videologr320(gz) · camlog319 · camlog320	Raw319 ptlo(csv) · Raw320 ptlo(csv) · Raw319 vnta(csv) · Raw319 vnta_log(csv) · Raw319 vntaedited(csv) · Raw320 vnta(csv) · Raw320 vnta_log(csv) · Raw320 vntaedited(csv) · 3D replay
11/26/2001	ptlo2001330 Completed No dives entered in database Add Dive(s) 2284	Bruce Robison			Index330 (1 of 2)	rovctdlogr330(gz) · Processing Log330 · Raw330(csv) · Derived330(csv) · Stats330 · Postscript plot330 · GIF plot330 · Raw time series330	videologr330(gz) · videologr331(gz) · camlog330 · camlog331	Raw330 ptlo(csv) · Raw331 ptlo(csv) · Raw330 vnta(csv) · Raw330 vnta_log(csv) · Raw330 vntaedited(csv) · 3D replay

100%

Figure 2. Results of an Expedition database search for Bruce Robison dives done in the last 60 days. The columns are the major categories of data that can be delivered to the browser by clicking on the links. The automatically generated 3D replays are accessible under the Navigation column (near the eyeglasses). The goal of the tool is to provide a tool for visualizing all of these categories of data for a dive.

3. EXTERNAL PROTOTYPES

The VRML97 language can be extended by defining new nodes through the EXTERNPROTO mechanism. This proved quite useful for this project in that we could separate data from the presentation technique, allowing us to update one without affecting the other.

Here is a brief description of each of the External Prototypes developed for this project

3.1 PowerDivePlaybackProto

All of the navigation information (ship and ROV positions and orientations over the duration of a dive) are fields of a `PowerDivePlayback` node. Below are all the field definitions:

```
EXTERNPROTO PowerDivePlayback [
        field SFString shipName
        field SFVec3f shipStartLocation
        field SFRotation shipStartOrientation
        field MFVec3f shipLocation
        field MFRotation shipOrientation
        field MFInt32 shipIndex
        field MFFloat shipKeys
        field SFInt32 shipStartEpoch
        field SFInt32 shipEndEpoch
        field SFString rovName
        field SFVec3f rovStartLocation
        field SFRotation rovStartOrientation
        field SFVec3f diveMidpoint
        field MFVec3f rovRawLocation
        field MFVec3f rovLocation
        field MFRotation rovOrientation
        field MFInt32 rovIndex
        field MFFloat rovKeys
        field MFVec3f frameGrabTimelines
        field MFInt32 frameGrabTLIndices
        field MFColor frameGrabTLColors
        field MFVec3f rov_iwTimelines
        field MFInt32 rov_iwTLIndices
        field MFColor rov_iwTLColors
        field SFTime cycleTime
] [ "PowerDiveplaybackProto.wrl" ]
```

The `PowerDivePlayback` node also implements a `TrackingViewPoint` node [3] and a `Slider` node (modified slightly from [4]). Behavior is encapsulated in the proto as events which are routed from the slider position to the ship and ROV position and orientation interpolators.

3.2 FrameGrabProto

The purpose of the FrameGrab proto is to generalize the display of video frame grabbed images inside the 3D Replay world. Currently, a billboard node is used so that the image is always facing the viewer. In the future, when vehicle navigation and camera field width data are improved the images can be accurately sized and oriented based on the information logged at the time of frame capture.

Here are the field definitions for the FrameGrab node:

```
EXTERNPROTO FrameGrab [
        field SFString imageDescription
        field MFString imageURLs
        field SFVec3f imageLocation
        field SFVec3f imageScale
        field SFVec3f viewPosition
        field MFString imageFieldWidthString
        field MFString imageAncillaryData
        field SFFloat fontSize
] ["framegrabproto.wrl"]
```

3.3 MBTerrainProto

The External Prototype for Monterey Bay terrain provides for transparency and image size selection for the terrain rendering. It uses an 82x77 ElevationGrid node that represents a rendering of about 13,000 triangles. These dimensions were chosen because our target hardware platform is able to render these scenes at greater than 15 frames per second.

```
EXTERNPROTO MBTerrain [
        field SFFloat terrainTransparency
        field MFString terrainImageURL
] ["MBTerrainProto.wrl"]
```

Transparency is user selectable because the approximately 800 meter spacing in the elevation grid presents faces through which dive tracks penetrate. Being able to choose transparency allows for visualization of the entire dive track, even as it goes beneath our rough approximation of the ocean's bottom. The terrainImageURL is user selectable so that users with limited texture memory in their hardware can choose a smaller image size and achieve better performance.

4. PULLING THE COMPONENTS TOGETHER

The final piece of development required for deployment is the tool that allows the user to bring all of the desired component pieces of an expedition visualization into the final VRML content that is loaded into the browser. For this, a standard HTML form is provided where the user can select the components to visualize. These components currently include:

- ROV & ship tracks and orientations
- Which environmental data to map to the ROV track: dissolved oxygen (O2), water temperature (Temp), salinity (Sal), light transmissivity (Light)
- Video frame grabs
- Expedition report
- Terrain

Each of these components corresponds to one of the .wrl files in Table 1. The action of the web form is to dynamically create a VRML file that "inlines" the components that the user has selected from the form. This was implemented as an active server page written in Perl. Hartmut Palm's Perl VRML.pm module simplified the coding of the dynamic VRML file generation.

One of the difficulties with VRML97 is the level of high performance interactivity that can be provided. The External Authoring Interface is available, but it is cumbersome and has different behaviors (and bugs) depending on the combinations of web browsers and VRML plugins. There is also the general problem of interactive human interfaces in any 3D immersive environment. The approach taken for the 3D Replays is to strike a balance between interactivity and simplicity in the 3D interface. Interactivity is needed to make the world compelling, yet simplicity is needed for ease of development and also to provide for an uncluttered interface.

The web form lets the user select which features to visualize and then generate the 3D world. For example, if the user wants to visualize the quality of the ROV navigation in relation to the ship navigation then only the tracks would be selected. If the desire were to create a visual representation of the dive track in relation to bathymetry then terrain and tracks would be selected. This approach is linearly scalable in that to visualize other information (e.g. video annotations) then only another world file needs to be generated to represent that information. (There would be a limit in the ability of the browser to render the scene at acceptable frame rates depending on the number of component objects selected.)

The implementation of our 3D Dive Replays has one major interactive component. This is the timeline slider in which the user can control the playback of the dive. This is analogous to a jog/shuttle control on a video tape deck. Its utility is that the playback can be positioned to a particular time, acting as a reference for viewing other data represented in the world.

Navigating a 3D world with a mouse that moves in 2D is always a challenge. For viewing 3D Dive Replays, the CosmoPlayer VRML browser is preferred because of the utility of its Examine functions. The user can position the ROV to an area of interest along the dive track and “Seek” on it. This action resets the center of rotation to the seek point and moves the viewpoint closer. He or she can then rotate about this point to visualize nearby features. To facilitate this mode of operation, the default behavior of the Shift key should be changed. In CosmoPlayer’s preferences, Keyboard tab, select the “Turbo Mode and Continuous Seek” option. With this setting the Shift key now modifies the action of the mouse. The user holds the Shift key down and clicks once to Seek to a point. To rotate about this point the user holds the Shift key down, clicks and holds the mouse button down while moving the mouse. With the Shift key held down, the Alt and Ctrl keys can be used to switch to the Pan and Zoom controls. The Shift key also disables TouchSensors within the world. A little experimenting and practice will give the user confidence in navigating the 3D world to provide whatever view of the data is desired. If the user gets lost in the world then one of the set viewpoints can be selected to reset the view.

5. EVALUATION

In the fall of 2000 a review of the 3D Replay work was conducted by MBARI scientists and engineers. The comments from this review reflect many of the issues that most Web 3D developers face. In general, the scientific applicability of the 3D Replay is not yet realized. There is agreement that being able to interactively navigate in 3D around a geospatial data set is "cool", yet addressing the scientist's need to access, assemble and visualize a variety of data in a variety of methods is not met by this current

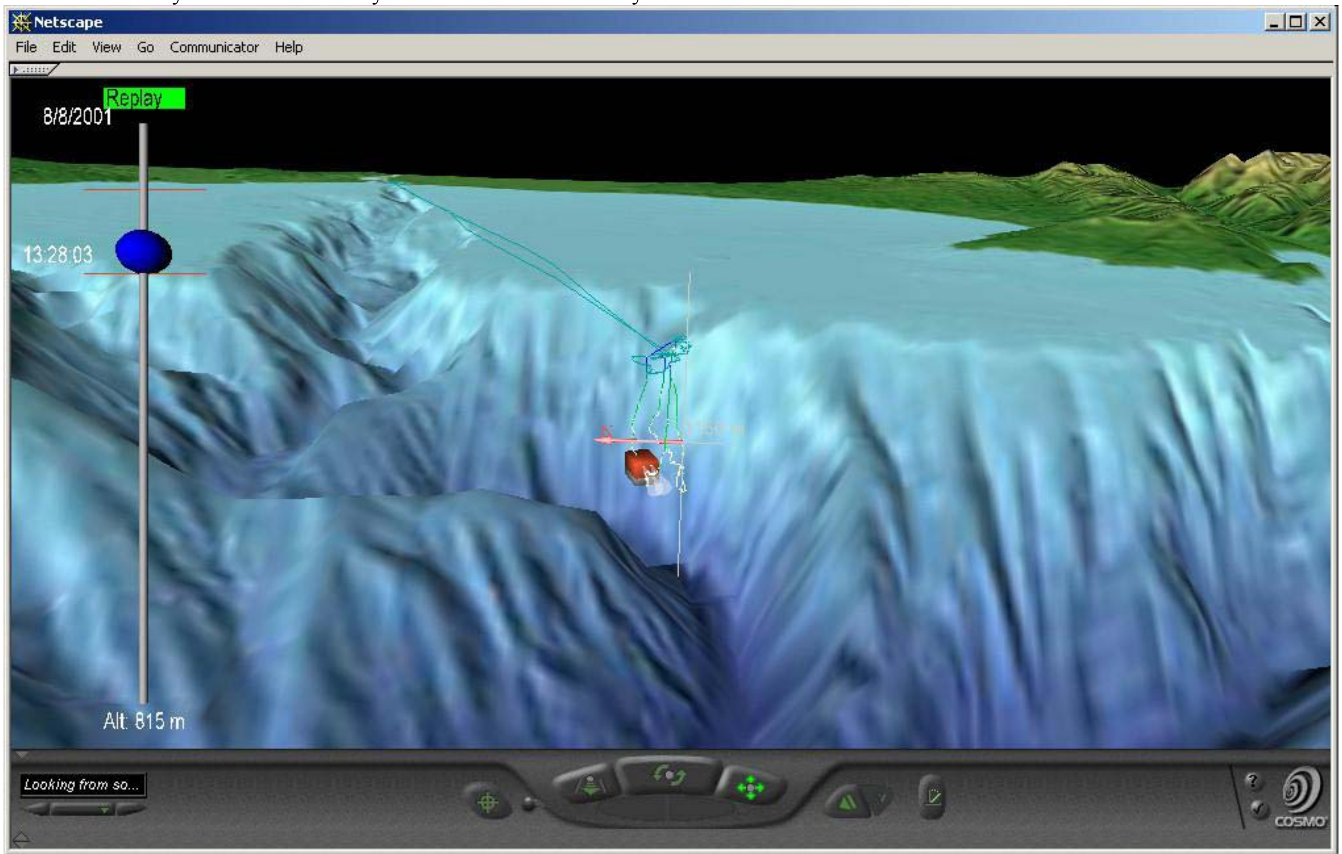


Figure 3. Visualization of a mid-water dive conducted on 8 August 2001. The view is looking east towards shore from 815 meters above the ocean over Monterey Bay. The user can navigate around the dive profile, zoom in and out using the browser's navigation controls. The user can adjust the positions of the ship (not visible, as it is actual size) and ROV (scaled to be visible from far away) by dragging the blue ball along the timeline slider. The horizontal red lines on the timeline represent the duration of the dive. The size of the ROV scales with distance so that its orientation and position are always visible from the user's viewpoint within 20 km of the dive area. Outside of this perimeter a ProximitySensor unloads timeline slider widget and ship & ROV objects. Within 6 km of the dive area a ProximitySensor turns on a Fog node which linearly blends objects more than a 1 km away to black. This helps with depth perception and performance. These behaviors are embedded in the PowerDivePlayback external prototype.

implementation. What follows are specific comments by the reviewers in response to the question "How useful is this tool for supporting your science program?"

"At its present stage of development, the project is not particularly useful in advancing the science goals of my projects. It is very nice to have the ability to do 3D flythroughs of ROV dives over terrain, but it doesn't yet provide the spatial context of experiments, data, etc."

"I have played some with the program and feel that it is a neat piece of software. These experiences leave me with the impression that I should be able to use the program as a research tool, but do not yet quite know how. Thus, I think that this is a classic case of the software potential developing faster then the scientists can figure out how to utilize it. For me, the reasons for not being more experienced with the program is partly a function of timing. I fully intend to spend time using this software (at least as an independent way of confirming impressions) when we get into the final stages of our efforts to examine seepage distributions in Monterey Bay. However, we will not be doing that until later this fall or early next winter. I also think that the program is still hard to access, which makes me less likely to experiment with it. "

"At the review I was pleased to see the progress that Mike has made and my optimism was renewed that this system will be of real value to our midwater research program. At present, we have not yet used the ROV data visualization system except as a demo, but we believe that once it is available to us it will be of considerable importance to our science and will open up new ways to use the data we have collected over several years."

"To date, though there was vague enthusiasm from the scientists, it was difficult to see any concrete or clear evidence of the scientific utility of the program for analyzing data to understand ocean physics, geology, chemistry, or biology."

"For my present research program, it does not appear extremely useful at present. 3D replay, the major display element of the system, is not a real requirement for our analysis needs. Rather, ready access to databases of synoptic data, and mathematical tools for searching and displaying temporal, spatial, and other correlations and trends, as well efficient means for displaying them, are more critical needs."

On balance, there was general recognition from the scientists of the potential utility of the system.

As far as improving the system, these are the words from one scientist's perspective:

"The utility of the project in advancing the science goals I have would be improved greatly if several capabilities were added. First, allowing users to display icons where events of selected types (e.g. sediment cores, instrument deployments) occur. Second, the capability to integrate information from several dives - fly up to a location on the seafloor and have a display of several icons (e.g. core locations) indicating the history of activities at the site. Each of the icons could be able to display frame grabs of video from the actual event. Third, some 2D and 3D displays of interpreted data. For example, a color coding of the sea floor if desired, according to data collected from sediment cores (during many dives). Or the overlay of a 2D section (either horizontal or vertical) within the 3D space illustrating selected parameters (temperature, oxygen, methane, or whatever is of interest)."

These added capabilities speak to a higher level of interactivity for the interface, almost approaching that of a commercial Geographic Information System tool. In fact, in the time since this project was started commercial GIS vendors, such as ESRI, have developed and now sell tools like ArcScene which provide some of this capability in 3D. These tools are somewhat limited with respect to true 3D data such as information collected well above the bottom in the mid-water. Most GIS tools are 2D map-based, but that may be sufficient for many of our potential users. Another thing that has been introduced since this project began is GeoVRML [6]. This is an extension to the VRML97 standard that allows for accurate geo-referenced data inside true 3D environments. GeoVRML helps bridge the gap between VRML and GIS.

Based on feedback from customers and on availability of new tools there are some logical next steps to improve this system:

- Convert the 3D Replays to use GeoVRML nodes where appropriate. This will allow easier creation of 3D dive worlds for areas other than Monterey Bay.
- Provide simplified routine methods to convert GIS coverages and shape files to VRML nodes.
- Create more component 3D world files of objects that users wish to visualize, e.g. video annotation data, samples information, and sediment core data.
- Provide the ability to visualize multiple dives and multiple sets of data. This can be integrated as a display feature option in the results of an Expedition database query.

6. CONCLUSION

We have shown that 3D visualizations of oceanographic data can be routinely provided to the desktops of scientists. The scientific usefulness of this current implementation is not yet fully realized, but with the planned upgrades this system will meet stated science needs. In particular, GeoVRML provides a general way to specify many of the features that scientists need to visualize, including seafloor terrain at the highest resolution. Development of this system continues, and early results from the conversion to GeoVRML suggest that this will be a valuable scientific tool.

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