INTEGRATION OF JAVA AND GIS FOR VISUALIZATION AND ANALYSIS OF MARINE DATA

T. C. Vance [a]*, N. Merati [b], C. Moore [b]

[a] NOAA/NMFS/AFSC, 7600 Sand Point Way NE, Seattle, Wa. 98115, USA and
Department of Geosciences, Oregon State University, Corvallis, Oregon, 97331, USA tiffany.c.vance@noaa.gov
[b] JISAO, University of Washington, Seattle, Washington, 98195, USA

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ABSTRACT:

Ideally, scientists should be able to format, explore, analyze and visualize data in a simple, powerful and fast application that would seamlessly integrate georeferenced data from a variety of data sources into a powerful intuitive visualization. Geographic information systems (GIS) provide a high level of functionality for spatial analyses, but are not yet able to provide the extended functionality needed to create a truly "scientific GIS". Java can be used to program scientific calculations and analyses, but it isn't inherently spatial. VRML provides the ability to visualize scientific data and to allow the user to interact with the data by rotating, zooming and panning, but you cannot easily query VRML objects. Recent developments in GIS and in Java can be exploited to produce a prototype of this kind of integrated scientific system.
In this project we used a combination of Java/Java3D and a commercial GIS package (ArcGIS) to create a prototype for a scientific GIS. We combine the spatial tools exposed through the ArcEngine API with the analytical capabilities of algorithms written in Java with the complex visualization capabilities of Java3D. Modules from each of these technologies are combined to create innovative tools to allow users to import data, perform spatial and scientific analyses and output the results as visualizations for further examination.

1. INTRODUCTION

1.1 Background

One of the basic tenets of cartography is that reducing the dimensionality of a phenomenon can be the key to its display, and ultimately to understanding. The spherical world with three dimensions is reduced to two dimensions of a paper map; the four dimensions of oceanographic and atmospheric phenomena are reduced to three dimensions in a scientific visualization. Many geographic topics – for example human settlement patterns or the diffusion of ideas or the locations of the transcontinental railroads – are inherently four-dimensional. In most cases, though, their display and representation are two- dimensional. The UCGIS white paper on visualization (Buckley et al., 2001) calls for unifying graphics over a variety of dimensions - e.g. 2D points with 3D volumes - but the research described is more concerned with cognition and usability than the implementation of higher dimensionality.
By contrast, in oceanography and meteorology, the use of three-dimensional plots and various types of scientific visualizations seems to be much more widely accepted. Scientific publications use a variety of standard multi-dimensional plots, virtual reality is starting to be a commonly used tool, and the nightly weather report shows animations and multi-dimensional plots. While some of these differences may simply be due to the types of data collected in the three disciplines, the amount of computer processing time available to researchers, and the funding available to create advanced visualizations, this contrast also suggests there are important historical and cultural differences.
Given that phenomena in the ocean are inherently three-dimensional, it would seem intuitive that GIS applications for marine use should also be three-dimensional. Many of the experiments reported in the literature are conducted in three and four dimensions and analyses are made in multiple dimensions. The distribution of tuna in the Pacific is presented as a function of biotic and abiotic environments (Bertrand et al., 2002). The distribution of hydrothermal venting on mid-ocean ridge systems is explored by Urabe et al. (1995). Patterns of circulation and the variability of frontal locations and dynamics are considered in Hermann et al. (2002) and Kachel et al. (2002), respectively. The marine GIS literature contains descriptions of the need for truly three-dimensional GIS [Lockwood and Li, 1995; Valavanis, 2002; Fox and Bobbitt, 2000; Meaden, 2000] and theoretical descriptions of what this might entail [Mason et al., 1994; Miller and Kemp, 1997; Pequet and Wentz, 1994; Kraak and MacEachren, 1994; Yuan, 2001].
The applied marine GIS literature does not describe many truly three-dimensional analytical applications. The applications that do use GIS to portray three- and four-dimensional phenomena tend to use a GIS for data storage and two-dimensional calculations. Scientific tools such as Matlab or custom code for 3D and time series calculations, and a separate visualization tool such as Vis5D (Su and Sheng, 1999), Fledermans (Goldfinger et al., 1997), VRML (SAIC, 2003) or EVS and VRML (Vance et al., 2003) are used for the actual visualizations. Part of this is probably because GIS is still

* Corresponding author.

inherently terrestrial and most terrestrial phenomena are 2.5 or 3.5 dimensional. Various authors have eommented on the basic differences between the static terrestrial environment and the dynamic marine environment (Lockwood and Li, 1995; Wright and Goodchild, 1997).

1.2 Motivation and aims

Geographic information systems (GIS) provide a high level of functionality for spatial analyses, but are not yet able to provide extended funetionality needed to create a truly "scientifie GIS". Examples of the functionality that is lacking include time series analyses, calculation of the volume of the overlap between two volumes – for example between a school of fish and a prey field – or calculation of the intersection of a veetor path with a volume - for example the route of a marine mammal through a pool of cold water. Other functions might include the ability to speeify a slice through a three-dimensional lattice of model output data and to make various analyses along that sliee. As an example of a 'scientific GIS' [1], a test application using the project framework was put together to view high-resolution global topography/bathymetry, ocean model outpnt, and standard ocean hydrographie data (Figure 1).

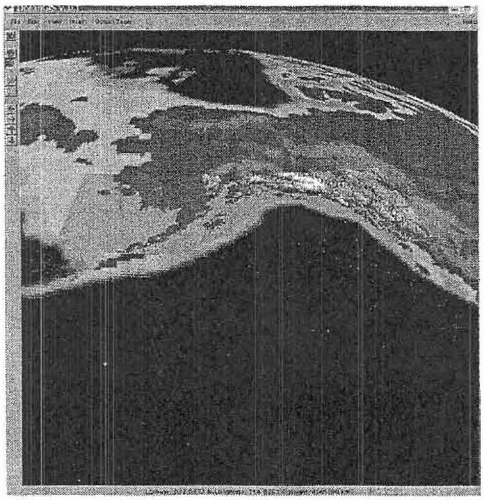

Figure 1. Bathymetric data displayed as a perspective plot

Java can be used to program scientific calculations and analyses, but it is not inherently spatial. Datasets can have a spatial component, but Java treats this as it would any type of coordinate system. Topology, or the spatial relationship between objects, is not stored with data. Funetions such as map projections, slope calculations and spatial interseetions are not native to the language. However, Java is easily extensible and functions written in other languages can be integrated.

VRML provides the ability to visualize scientific data and to allow the user to interact with the data by rotating, zooming and panning, but you cannot easily query VRML objects. Ideally one would be able to point at a three dimensional location in a VRML view and return a reference to the object that lists the analytical methods that act on the data, and allows the user to execute these methods. VRML scene navigation generally requires that a separate VRML plug-in application be installed on the client system. From the user's perspective, plug-ins are poorly integrated into the browser environment, and the browser itself may be superfluous. Additionally, user plug-ins may only be available for the more popular client platforms. Recent developments in Java3D extend the functionality of VRML and answer a number of the limitations mentioned.

The Java tools described herein were designed using a framework approach that enables them to be integrated into an application (OceanGIS), or interfaced with major off-the-shelf software products (e.g. ESRI AreEngine). We aimed to develop these tools for a broad range of potential users. This project focuses on tools that convert non-spatial data into GIS compatible data, expedite the transfer of spatial data to eoastal professionals and emergency managers, and enhanee analyses used for disaster preparedness and response activities. As the tools we develop can be deployed without a full ArcGIS license, we hope to make them widely available to better integrate field activities during disaster responses.

2. METHODS AND RESULTS

2.1 Methods

In this project, we use the flexibility of Java to integrate GIS functionality with Java3D (and Java-wrapped OpenGL) visualization capabilities. Specifically we are using a combination of Java/Java3D and the reeently introduced ArcEngine product to create a prototype of a scientific GIS. We combine the spatial tools exposed through the ArcEngine Java API with the analytical capabilities of algorithms written in Java with the complex visualization capabilities of Java3D. Modules from these technologies are combined to create innovative tools to allow users to import georeferenced data, make spatial selections, perform spatial and scientific analyses and output the results as visualizations for further examination. (Figure 2) Use of the ArcIMS Java Connector will allow these modules to be implemented in ArcIMS sites for web-based analysis.

Java allows us to make a variety of scientific calculations on the data and to provide the results both to the GIS component and to a Java3D based visualization component. We are able to take advantage of a number of Java utilities sueh as Unidata Integrated Data Viewer (IDV)[2], OceanShare, neBrowse, the Scientific Graphics Toolkit (SGT)[3], and TimeSeries applet.

[1] By the term "scientific GIS," we mean more than simply adding scientific visualization capabilities to an existing GIS package. Indeed, we envisage a tool that, fully within a GIS, combines three distinct capabilities: the traditional spatial tools of a GIS, analytical and computational tools for scientific analyses in multiple dimensions, and the ability to display the results using advanced visualization techniques.

[2] See a description of IDV at http://my.unidata.uear.edu/eontent/software/IDV/index.html

[3] For informationon SGT and the TimeSeries applet see http://www.epic.noaa.gov/java/sgt/ and

The ArcIMS Java Connector could be used to produce a map coordinates-base that would allow data retrieval from a Distributed Oceanographic Data Systems (DODS) server[4], and subsequent plotting with tools designed for interaction with gridded fields.

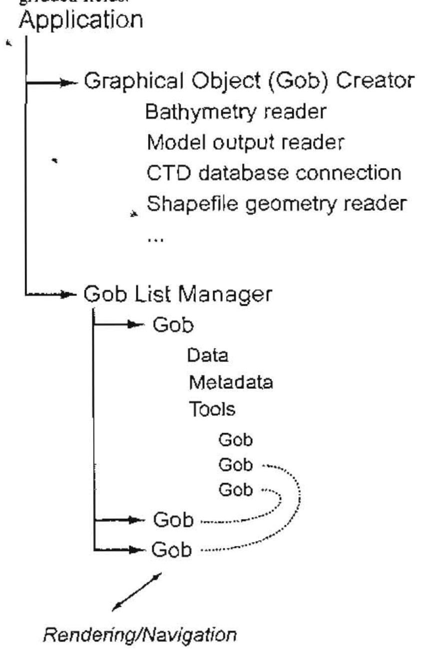

Figure 2. Diagram of the components of the OceanGIS system

2.2 Software Components

ArcGIS Engine is an ESRI developer product for creating and deploying ArcGIS solutions. It is a simple API-neutral cross-platform development environment for ArcObjects - the C++ component technology framework used to build ArcGIS. ArcObjects are the core of the ArcGIS functionality and include tools such as overlay - union, interseet; proximity - buffer, point distance; surface analysis - aspect, hillshade, slope; data conversion - shapefile, coverage and DEM to geodatabase. ArcEngines' object library makes full GIS functionality available through fine- and coarse-grained components that can be used in Java and other environments. Using ArcEngine, one can build solutions and deploy them to users without requiring the ArcGIS Desktop applications (ArcMap, ArcCatalog) to be present on the same machine. It supports all the standard development environments, including Java, C++, and .NET, and all the major operating systems. In addition, one can embed some of the functionality available in the ArcGIS extensions. This product is a developer kit as well as deployment package for ArcObjects technology. Using ArcEngine we will integrate GIS functionality into an application with the data being available for calculations in non-GIS components.

The Java3D API is an application programming interface used for writing stand-alone three-dimensional graphics applications or Web-based 3D applets. It gives developers high level constructs for creating and manipulating 3D geometry and tools for constructing the structures used in rendering that geometry. With Java3D API constructs, application developers can describe very large virtual worlds, which, in turn, are efficiently rendered by the Java3D API. The Java3D API extension is designed as a high-level platform independent 3D graphics programming API, and is amenable to very high performance implementations across a range of platforms. To optimize rendering, Java3D implementations are layered to take advantage of the native, low-level graphics API available on a given system. In particular, Java3D API implementations are available that utilize OpenGL, Direct3D, and QuickDraw3D. This means that Java3D rendering will be accelerated across the same wide range of systems that are supported by these low-level APIs. The Java3D API is aimed at a wide range of 3D-capable hardware and software platforms, from low cost PC game cards and software renderers, through mid-range workstations, all the way up to very high performance, specialized, 3D image generators. Support for run-time loaders was included to allow Java3D to handle a wide variety of file formats such as interchange formats, VRML 1.0, and VRML 2.0.

We also explored the use of a second 3D API called the Visualization Toolkit (www.kitware.com). Like Java3D, VTK is a cross-platform 3D application programming interface built upon, and independent of, the native rendering library (OpenGL, etc). It exposes Java bindings (as well as Tcl and Python). It is written in C++, uses the object oriented modeling approach of Rumbaugh et al. (1991), and includes similar scene-graph, lighting models, and graphic primitives as Java3D. What VTK does that Java3D doesn't (yet) do is boolean operations on 3D volumes (intersection, union), volume rendering, filtering, including convolution, FFT, Gausian, Sobel filters, permutation, high- and low-pass Butterworth filters, and divergence and gradient calculation. The VTK data model allows for fast topology traversal, making these filters very fast, and allows for rapid mesh decimation. VTK also offers powerful 3D probe "widgets" that allow easy interaction with the data, and has methods to utilize parallel architeeture through the Message Passing Interface (MPI).

2.3 Results

For this application (dubbed OceanGIS) we created a number of Java objects that wrap data and methods for acting on the data. For bathymetry data, this was just the ability to exaggerate the vertical coordinate and to decimate and smooth the resulting mesh. But for more complicated data like hydrographic surveys, the objects allow for the dynamic creation of such typical oceanographic parameters as dynamic height, mixed-layer depth, and geostrophic flow. For model output, variables such as salinity can be shown as an isosurface or vector fields such as water velocity can be shown as a plane of 3D vectors that the user can move to "probe" the data. The user can seed the flow field with lagrangian floats that are time-stepped to show particle paths. In Figure 3, bathymetry from the Smith and Sandwell dataset (1997) are selected in the Aleutian Island chain, and the vertical dimension is exaggerated to show the Aleutian trench. The image also

http://sopac.ucsd.edu/processing/refinedJavaTimeSeriesDoc.html

[4] See http://dods.ndbc.noaa.gov/ for a description of DODS.

shows how a direct link to a DODS data source can be included.

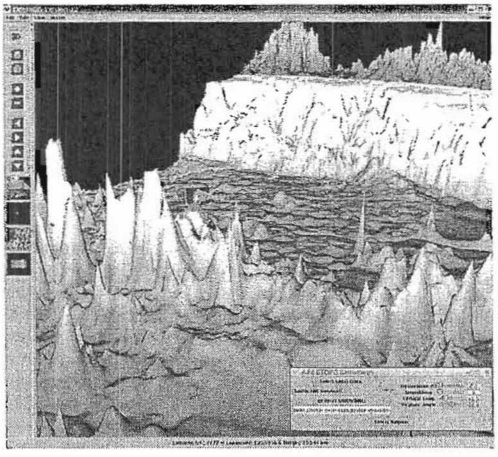

Figure 3. Bathymetric data and link to DODS data server

In Figure 4, a CTD survey just north of the archipelago is imported in shapefile format, and mixed-layer depth is calculated using a kriging method. Note the data-object icon on the left panel, exposing tool methods to the user - in this case a hydrographic data object was clicked.

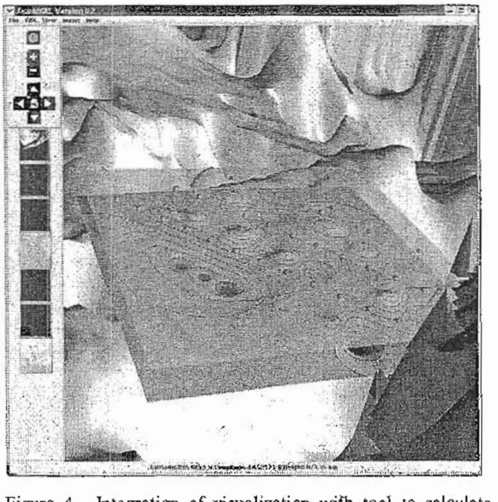

Figure 4. Integration of visualization with tool to calculate mixed layer depth and kriged surface

Figure 5 shows an even higher-resolution bathymetric data set (multi-beam), as well as model output of a hydrothermal vent, plume. Dissolved aluminum concentration is shown as a volume, and a plane probe widget slices through the data. The user can re-size the widget or push it through the volume to show concentration at that location, or to calculate volume of the plume.

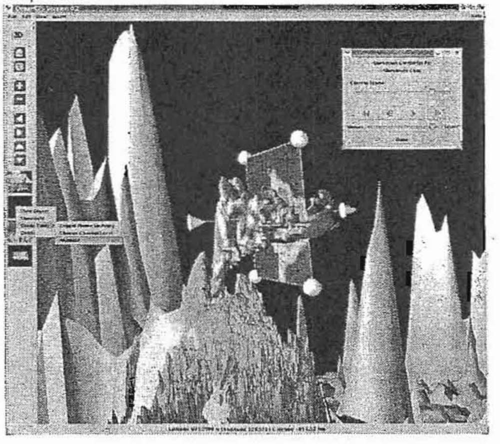

Figure 5. Image of a hydrothermal plume with slicing plane for analysis

One of the challenges in creating a GIS for marine research is linking existing databases with a GIS. Oceanographers are familiar and comfortable with extracting data from various large archives for immediate analysis. A process that involves reformatting these data for inclusion in a GIS is likely to be seen as cumbersome. Figure 6 shows a direct link between an OPeNDAP server and OceanGIS.

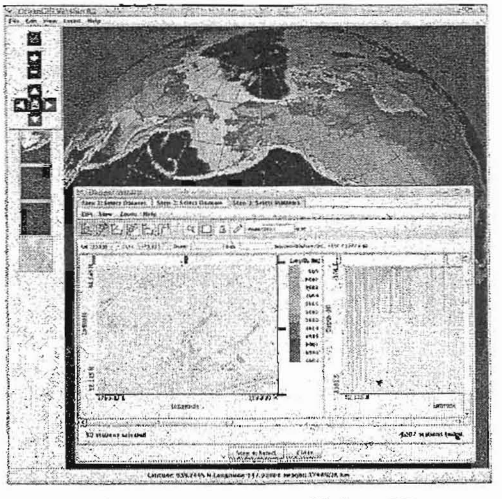

Figure 6. Using an OPeNDAP server with OceanGIS

DODS/OPeNDAP servers serve geo-referenced data by allowing the user to select data based on available meta-data. In the marine application shown, hydrographic data are selected first by a simple "rubberbanding" of geographic location, and then fine-tuning the spatial extent using several selection tools, and time and depth extent through the adjacent panels. This allows the user very fine selection of large data sets. The data transferred back, while not in a standard GIS format (they are actually in netCDF format), are georeferenced and can easily be converted. The OceanGIS application allows a user to select a dataset using a familiar interface and have the data automatically added to the OceanGIS.

3. CONCLUSIONS

Future plans for OceanGIS include the development of marine-science related tools, including towed-instrument (fence-line) rendering, three-dimensional statistical tools such as optimal interpolation, and the porting of standard hydrographic algorithms to the GIS application [UNESCO 1981].

The OceanGIS application demonstrates the integration of advanced visualization techniques with standard GIS techniques, and moves the user from thinking in a two-dimensional plane to a more interactive three and four-dimensional world. Additionally, the ability to connect to distributed data servers and project and visualize data on the fly opens this application to a new group of users, including emergency managers and scientific modellers who must respond to disaster management scenarios rapidly.

While none of the various technologies we used is complete in and of itself, the linking of GIS, Java, Java3D and VTK provides a powerful mechanism to create the beginnings of a "scientific GIS". Once the technologies have been linked, the form of the final tools deployed will be dependent upon the users needs and the relative costs of the GIS portions of the technologies. Because we are creating scientific tools rather than a commercial product, license costs may have to play a large role in our choice of which GIS tools to use.

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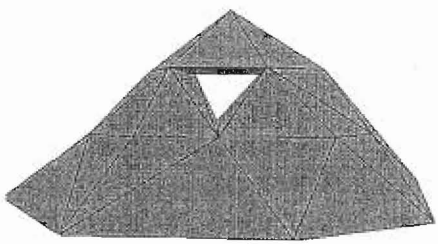

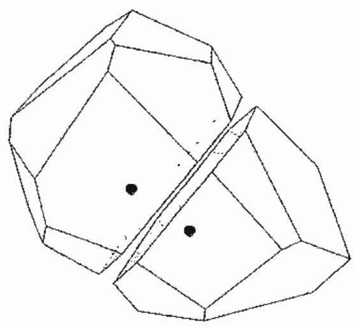

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