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Web-based Open Source GIS Decision Support Tools: Explaining the Software Stack

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Abstract: As the analytical processing capabilities of software systems grow, so do the expectations of end users of those software systems. An ever increasing trend has emerged in the software domain to provide more functionality over the World Wide Web through web services. Web-based decision support tools are emerging as a viable solution to fulfill environmental management decision support needs, while addressing the desire for platform independent web-based interfaces. Managers of environmental systems are often held hostage to the lack of information about the very system they manage. While modeling techniques and capabilities continue to grow, the need for real-time decision support based on those models is no longer a wish, but instead a necessity. All of this has led to the confluence of web-based GIS technology with real-time modeling techniques.

This paper focuses on the creation of web-based decision support tools which utilize real-time GIS modeling and analysis to provide an enhanced capability to environmental managers. Specifically, we will focus on the use of a pilot software platform developed completely with Open Source tools, including many state-of-the-art Open Source GIS tools currently available. From the Linux kernel driving hardware support to server side GIS providing real-time analysis, we look at the tools needed to create a seamless experience for the end user in an interactive web-based decision support tool.

Finally, we present a case study of a new set of marine management tools called the OCEANSystem developed by Ecotrust, an environmental non-profit located in Portland, Oregon. The OCEANSystem integrates Open Source data management systems, server side GIS, custom models and scripts, and a web-based GIS front end. Through the integration of these disparate tools we have taken the first step toward supplying a new level of capability to marine environmental managers at very low cost. We will uncover the architecture and software stack of this pilot system as well as talk about the tangible benefits seen by end users of the system. We will also show that while this pilot has shown promise, there are very specific areas of work that still need to be completed to create a truly integrated Open Source GIS development environment capable of supplying decision support tools.

Keywords: GIS; Open Source; Modelling; Decision Support

1. INTRODUCTION

For many years there has been a great divide between science and policy. While driving forces such as economic risks, ecosystem degradation and human safety have caused science and policy to interact, there has been a lack of recognition of the importance in educating policy makers on what science says. A key barrier to educating decision makers is the inability to present scientific data in a practical and easy-to-understand format.

As a subset of this problem, policy makers often have trouble viewing and interacting with scientific data in a scenario based decision process. The need to have a GIS analyst or scientific modeler produce unique output based on a fixed number of scenario alternatives is often a great limitation to policy makers trying to understand complex systems. The introduction of decision support tools (DST) has brought about a new and innovative approach to decision making. A shift in focus toward tools that allow users to run targeted scenarios based on user defined requirements is starting to bear fruit. The introduction of “toolkits” and “plug-ins” for many of the mainstream desktop GIS systems has paved the way toward a new class of DST.

The next logical step in this progression is driving researchers to investigate utilization of these tools and technologies in the web-based arena. [Doyle 2006] Through the integration of web-based GIS interfaces with server side GIS systems, we have started to see the birth of real-time decision support tools on the web, focusing on scenario based decision making. [Raghavan 2002]

While many of the traditional plug-in type desktop tools developed to assist in the environmental decision support process have been technically powerful, many needs remain in getting this technology into the hands of the managers who need it. There are two fundamental hurdles that that this new wave of web-based DST tries to address; namely being tied to a desktop application, and cost of developing and utilizing the technology. This paper sets out to show how web-based decision support tools built on Open Source technology can help bridge this gap between traditional applications and tool utilization while doing it in a cost effective and appropriate manner for environmental managers. We build on the hypothesis that real-time DST development using Open Source tools will enhance usability and reduce cost of many environmental management tasks.

In this paper we first describe the underlying technology of a web-based DST built completely on Open Source technology. Section 2 reveals the software stack and tools utilized. It is only after evaluating the toolset that one can really begin to understand the effectiveness and power of integration between web-based and server side GIS for environmental decision support. Section 3 focuses on a pilot system utilizing the software stack described in section 2 and looks at the migration of an existing desktop DST to a web-based architecture. Lastly, section 4 focuses on lessons learned and marching orders toward future developments that will hopefully more tightly integrate the software stack needed to develop these tools.

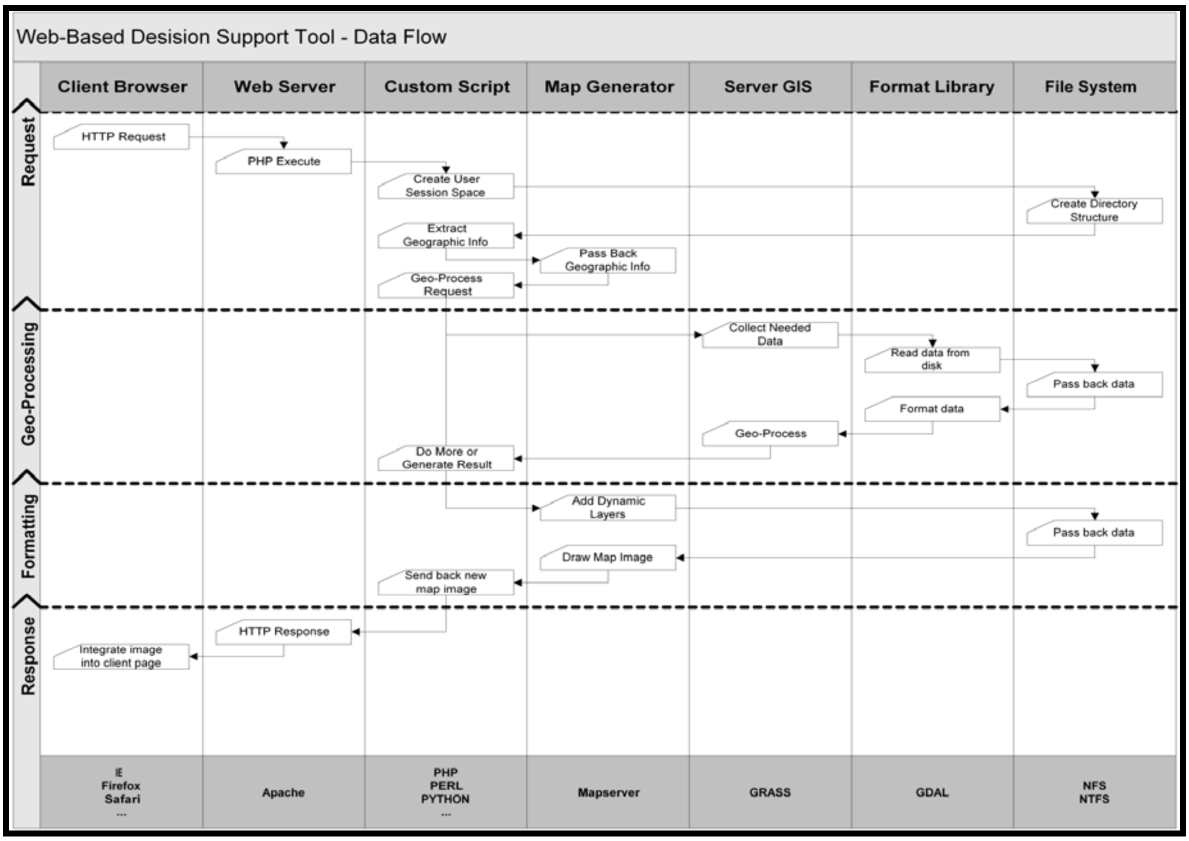

Figure 1. Data flow through DST.

2. SOFTWARE STACK

2. 1 Introduction

The software architecture for web-based DSTs is built around merging the architectures of traditional web-based GIS with traditional server side GIS. What makes this merger difficult is that these systems were never really designed to work together. It is gluing these disjoint systems together that provides the greatest challenge to implementing such a DST system.

2. 2 Open Source Software

Utilizing Open Source software for the DST stack provides many technical and social benefits that we will touch on throughout this paper. [Open Source Initiative 2006] The largest benefits can be summed up into the following recurring themes: 1) The dollar cost of the software used in this system is zero. 2) The development community around these software products are very active and robust. 3) The availability of source code provides opportunity to not only fix problems but to also enhance the capability of the software for others in the community. 4) Finally, Open Source solutions provide a very competitive solution for analytical capability in GIS that lends itself to this type of tool development.

We will describe the software used in this Open Source GIS stack, highlighting key functionality of individual tools. While many different software licenses surround the software being used, they are all considered Open Source, allowing for the basic rights and freedoms to modify, redistribute, and contribute to the individual products.

2.3 Data Flow

The basic data flow for the system is laid out in seven layer architecture (Figure 1). Starting at the client computer a data request is sent from the web client to the web server. This request is done through an HTTP request data transfer and contains pertinent user information, both geographic and flat data. The web server processes this HTTP request and parses the user specific POST or GET data into internal arrays to be used by the scripting layer. While many scripting languages can be used to process web requests, we focus on PHP in this paper due to its heavy use in the web mapping arena and its ease-of-use for web interface development. The web server then passes the user specific data to the server side script to take action.

The bulk of the server side work is orchestrated from the scripting interface, dealing with the entire lower half of the software stack. The scripting interface interacts with the map generator layer to handle user geographic information (such as current extents, user clicked coordinates, and layer visibility). The scripting interface also deals directly with the server side GIS to run analysis on data layers needed to provide DST analysis. Finally the scripting layer also deals directly with the format utility and file system layers for tasks such as session and directory management and image processing. While these seven layers contain many sub-layers of software, they provide a means to describe and categorize the vast Open Source software stack needed to create a DST.

Another way to evaluate a DST is to track data types as user requests filter through the system. In web-based DSTs there are three main formats that data reside in. First, user requests often come in POST/GET type variables. A typical user request from a web-based DST will include geographic elements (such as extent and layers visible) as well as form based elements (such as pull down selections and check boxes on the user submittal form). The second data type often encountered is that of geo-referenced data. Spatial data is at the root of being able to perform spatial analysis based on the user requests in real time. Lastly, imagery is used to convey results in the form of maps. It is the map generation software layer that has the ability to compile analysis results into a format readily useable by decision makers. This imagery is transferred from the web server to the client side interface as an output to the HTTP request.

2.4 Software

The software used in implementing a web-based DST is diverse but well suited to be linked together to make a system. We will start at the bottom of the stack (closest to the hardware) and work our way up the stack (toward the client interface) and describe key tools and reasons for inclusion in the software stack.

- Linux Operating System (Fedora Core 4):

The operating system resides at the core of the server side software. Linux is utilized to drive hardware and provide an operating environment for other server side programs. We have chosen Linux for its native support for many of the server side utilities used, but Windows and Macintosh versions of all of the server side software exist and can be utilized. Included in the operating system category are all of the base tools needed to build applications to run on that operating system. Important to note here are the existence of compilers, debuggers and hardware drivers needed to create software further up the stack. Our system utilizes the GNU set of development tools to build all other applications. [Fedora Core 4, 2006]

- Format Library (GDAL/OGR/PROJ.4):

This library set is essential for translation between diverse formats that many GIS data layers reside. GDAL (raster), OGR (vector), and PROJ.4 (projections) are just a sub-set of all of the format related tools that are needed to make a DST functional. [GDAL, 2006]

- Server GIS (GRASS 6.0/PostGIS/R) -

The server side GIS is used to do the "heavy lifting" geo-spatial operations needed in the DST analysis. Server side GIS is very efficient and full featured for doing analytical operations such as raster algebra or geospatial modelling. GRASS is a very powerful server side GIS system capable of many analytical features as well as providing both a graphical and command line interface. The command line interface is essential for integration into a web-based DST. PostGIS is a geo-spatial database enabler that provides spatial analysis capabilities to the SQL environment. [GRASS, 2006; PostGIS, 2006]

- Map Generator (Mapserver)

This is the core of the web-based GIS and provides the components needed to translate GIS data into a map image to be viewed by the client. It is critical that the server side GIS can talk to the web-based GIS system in order to transfer analysis results back to the client. [Mapserver, 2006]

- Scripting Languages (PHP)

Server side scripting provides the glue that holds the whole DST system together. Utilized to provide an interface to the operating system layer, format libraries, server GIS, web-based GIS, and database technology, this layer is essential to provide the linkage to create a system (Table 1).

We utilize PHP in this example due to the advanced support for Mapserver and database interaction. [PHP, 2006] Many other alternatives exist for providing scripting support for DSTs including Perl, Python, .NET, Java and many others.

```
$grass_sess = new Grass_GIS($session_grass_dir,
$session_grass_dir."/rc","/usr/local/grass-6.0.0",
"OceanMapset","OceanLocation");

$arr = $grass_sess->run_command("r.mapcalc
grass_minarea_b = if\(grass_minarea\ >0,1,0\)");
```

Table 1. Example PHP calls to execute GRASS commands based on a web request.

- Web Server (Apache)

Apache is known to be the standard for enterprise web serving around the world and is an obvious choice to be at the core of any Open Source web-based software stack. [Apache, 2006]

- Client Scripting (JavaScript/DHTML)

Chameleon, a JavaScript-based client interface, is at the core of the user interface design. Provided by DM Solutions Inc, Chameleon is a widget-based user interface closely linked to Mapserver to provide smooth and user friendly mapping front ends. [Chameleon, 2006]

3. PILOT - OCEANSystem

Evaluation of the hypothesis that real-time DST development using Open Source tools will enhance usability and reduce cost can be done through the development of a pilot system. Ecotrust has developed a DST framework that has been shown to be very useful to the management community dealing with Marine issues along the California coast called the Ocean Framework. [Scholz et al. 2005] Out of this initial framework has grown the need to migrate the analysis capabilities away from the traditional desktop GIS. This migration is partly due to technical experience needed to do the analysis using traditional tools as well as end user cost to acquire and operate the software. The OCEANSystem is a prototype marine DST built on the Ocean Framework that utilizes the Open Source software stack described in section 2 and attempts to enhance the usability of these tools for fisheries managers to help make more informed decisions. Exposing the methodologies of the original Ocean project through the web-based OCEANSystem shows great promise in increasing usability while reducing cost. (Figure 2)

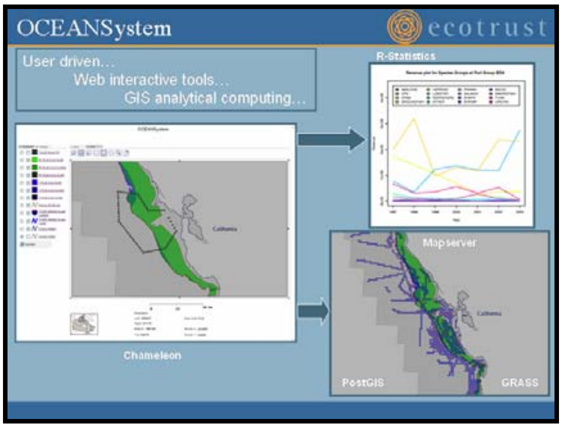

Figure 2. OCEANSystem web-based interface utilizing Chameleon and example outputs, both graphical and map-based.

The goal of the pilot system is to evaluate environmental and economic indicators for the fisheries of California in an attempt to make more informed decisions about fisheries management and protection. Distribution of commercial catch per fishery type based on spatially specific information collected through local knowledge interviews is used in conjunction with port based statistics to gain a better picture of fishing effort and distribution. This information is used to extrapolate economic distribution of landings data from landing receipts and attribute a portion of the total catch to any given location within the fishing grounds. Using this system we are able to get a better picture not only of where people are fishing (using aggregate statistics), but also which locations local fishermen consider to be "important". Due to the method of data collection, the base data set of interviews grows over time. Inherent in this system is an expectation that the picture this data paints on the spatial landscape will also change over time. As the data changes, new views into the data, via spatial analysis and map production, launch the traditional projects into a costly circular cycle of analysis. The goal of the OCEANSystem is to break that cycle and strive to put these analysis steps into an automated web-based tool which allows decision makers to run analysis on the most up-to-date data without the need for a costly spatial analyst or software.

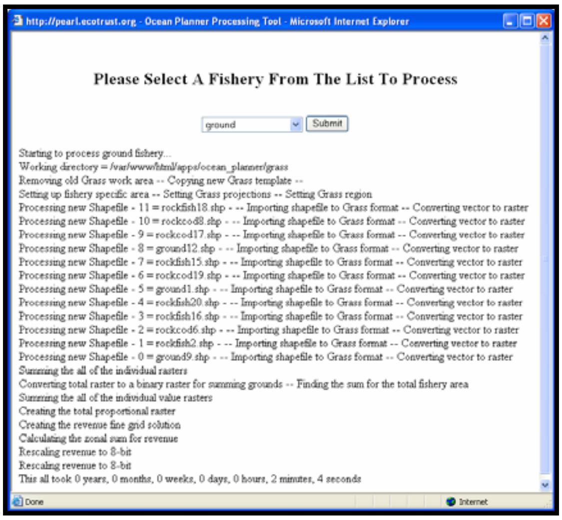

Figure 3. OCEANSystem web screen showing the output from processing fishery interview shapefiles via server side GRASS GIS.

Through the web-based interface field staff is able to upload new shapefiles generated from fishermen interviews to the Ecotrust server and load those shapefiles into a database for a particular fishery. The interface then allows managers to run the analysis needed to determine relative importance of fishing grounds to particular fisheries of interest (Figure 3). The user request is transferred to the server side where a scripting interface systematically loads all the associated shapefiles for a selected fishery into a dynamic GRASS GIS work area. All vector-based data gathered during the interview process (shapes located over fishing grounds) are converted to GRASS-based rasters for processing. Spatial analysis based on raster algebra is performed to produce a map of relative importance based on spatial and attribute data received during interviews.

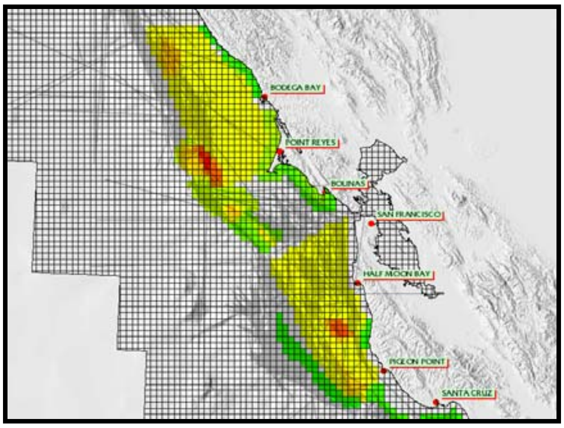

Figure 4. OCEANSystem output showing GRASS GIS based relative importance analysis of fisheries grounds along the California coast displayed via the web. Aggregate trawl fleet tow lines showing real fishing effort in the same location are overlayed for context.

Finally, map output is produced and converted into a form that can be added to Mapserver for web-based viewing. Users are able to take advantage of many of the built-in capabilities of Mapserver applications like zooming, panning, and querying the spatial display. (Figure 4).

The real-time nature of this workflow allows for managers to evaluate any number of scenarios and always be guaranteed to be utilizing the most up-to-date information available.

4. SYNTHISIS AND CONCLUSIONS

4.1 Synthesis

The time has come for DST development to make the leap from desktop to the web. With the cost and complexity of desktop GIS analysis going up, it is necessary to take a new approach to presenting analysis options to environmental managers. Specifically, it is no longer acceptable to pre-generate scenario based analysis for complex systems. Inevitably scenarios will be missed, analysis will not meet criteria, and re-analysis will be necessary. Distilling analysis techniques into discrete products and translating those into web-based applications alleviates the need for costly analyst time and brings a sense of real-time interaction to the manager. It is this synthesis of desktop GIS workflows encapsulated into web-based applications that creates a real opportunity for an increase in usability and decrease in cost. Building this application base on an Open Source software stack only reinforces those ideas.

4.2 Conclusions

As we are starting to see an increase in analytical capability in many Open Source GIS tools, we have yet to see the convergence of these tools into a cohesive "tool set". Our goal in developing the OCEANSystem was to start to break down the barriers that exist between many disparate Open Source GIS projects and bring the power of server side GIS to the web through the creation of a web-based DST. Through this project we have shown a path toward creating a useful DST for environmental managers that has clear financial, development, and time savings benefits.

While we have been able to demonstrate real-world benefits of web-based DSTs through economic and time savings achieved, integration of more user interactive analysis is still needed to provide the level of benefit that environmental managers are now envisioning. Features we see as being essential to future versions of these types of DSTs include interactive map manipulation (users drawing shapes on the map that affect the analysis being done) and adaptation of more server side modelling software than the GRASS GIS system alone. We also look forward to adding support for OGC standard formats such as WMS and WFS based on DST analysis results. [OGC, 2006]

4.3 Future

We look forward to the future; Ecotrust envisions our long term strategy to be around the creation of a network of DSTs supporting Ecotrust's core programs in fisheries, forestry, food and farms, and native programs. It is our goal to push the development of the linkage between many of the software packages described in this paper and make the distribution of web-based DSTs easier. The line between web-based application development and desktop environments is starting to blur and we envision a future where platform independence and ease of use will win out in the battle for tool development. Web-based DSTs are just beginning to show their true potential.

5. ACKNOWLEDGMENTS

Ecotrust has supported the development the prototype OCEANSystem detailed in this paper. We would also like to acknowledge the Open Source community around which this work was done. It is the great collaboration and support which the Open Source community lends to its users that makes it such a wonderful resource and shines the light on the future direction of many DSTs in the future. In particular we would like to recognize the tremendous effort undertaken by the communities supporting the core software used in this pilot system; namely Mapserver, PostGIS, PostgreSQL, GRASS, PHP and Chameleon.

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