An enterprise geospatial application to support expeditionary naval warfare

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The planning and support of military naval expeditionary operations relies on precise environmental data, which must be available on time, at the right place and in the requested format. These data sets, usually obtained from a wide number of sensors (satellites, sonars) and models (meteorological and oceanographic), have a common feature: the geospatial component.

This paper presents a client-server Geographic Information System, developed at the NATO Undersea Research Centre, based on an enterprise Java application and a geospatial database, to store, convert, fuse and deliver the above-mentioned data sets. The system is also able to run applications deployed on the server to produce new products (for tactical decision support) from the data stored in the database. Users may use many types of client applications to connect to the server, ranging from thin clients, like a web browser, to thick clients, like ESRI ArcMap/ArcView (provided with ad-hoc extensions).

1 Introduction

1.1 Expeditionary naval warfare and GIS

The goal of the EOS (Expeditionary Operations Support) is to develop new technology to support NATO naval expeditionary operations that are expected to be conducted out of area, primarily in littoral environments. In these environments, Task Force Commanders and operating units cannot expect to have pre-existing adequate knowledge of the local conditions affecting their missions. Sudden changes in meteorological and oceanographic conditions have resulted in loss of life, platforms and weapons effectiveness and become more critical as an operation approaches. By providing timely characterization in near real time, a picture of the littoral battle-space (which is an extremely dynamic and variable region complicated by the interaction of the ocean, atmosphere and overland environments) will be available for expeditionary operations. Within this framework a combination of GIS and communication technologies provides all the tools required for the acquisition, processing, assimilation, fusion, distribution and presentation of data and the products required at tactical and operational level.

1.2 The environmental data asset

A large amount of NURC work is at sea and generates, as a by-product of the research activity, high quality environmental data, which are a valuable asset for NURC and other cooperating laboratories. Classification, storage and distribution to the scientific community of such data is made by means of GIS and geographic data servers.

1.3 Lesson learned

Since 1997, NATO Undersea Research Centre has supported EOS (also known as Rapid Environment Assessment, REA [3] [4]) sea trials with diverse GIS technologies. Starting with single user systems [1] [2], during the recent years a fast evolution to a client-server system was made [6]. In addition some work on Tactical Decision Aids based on geospatial data has been carried out [5].

This article describes a new system, started in mid-2003, which benefits from the knowledge gathered at NURC in the client-server GIS field. This system, which is still under development, will be used in the NATO Exercise CWID in June 2005. In the following paragraphs the system requirements are reported and, after a short overview of the OGC web service architecture, the system is described using a bottom-up approach: firstly the low level concepts, followed by the high level services.

2 System description

2.1 System requirements

The following are the system requirements:

r.1 **Client server system with different client types:** Expeditionary Operations Support (EOS) implies sparse agents on the battlefield (also away from it), therefore the client-server is the correct paradigm. Each agent has different exigencies: map consultation only, map editing, data provider, etc., therefore several client types are necessary, ranging from desktop GIS (like ESRI ArcView) to web client.

r.2 **Store raster and vectorial data:** having the whole data set in the same place supported by coherent metadata, provides an effective platform for data fusion. Moreover conversion between data type should be possible (e.g. convert a raster to a vector). Note that rasters may be organized into 2, 3 or 4 dimensions (x, y, z, t).

r.3 **Handling coordinate reference systems:** conversion between datasets with different reference systems should be possible for both data types (rasters and vectors).

r.4 **Automatic data ingestion system:** data ingestion (especially for raster) should be performed via an automatic ingestion engine: datasets are delivered to the server and then read and stored by the server without human supervision.

r.5 **Efficient data management and intelligent data retrieving:** storage and retrieval should be based on the geospatial attributes, on the alphanumeric attributes associated with the geospatial objects and on the metadata.

r.6 **Extract vector data in read/write mode:** vectors once extracted by the client can be modified or deleted by the user, for instance using advanced clients such as a desktop GIS. Afterwards, these changes should be updated back into the server. To support the vector write mode a transaction system should be present on the server.

r.7 **Interoperability (adhere to standards):** for a multinational military organization such as NATO, a client-server GIS is an essential tools for sharing tactical information. Despite its importance, at the moment a widely accepted standard Geographic Information System is far from being reality. Therefore, to reduce the potential communication clashes between systems belonging to different nations or NATO agencies, the basic idea is to follow the standards provided by the Open Geospatial Consortium (OGC)[1] and by ISO T.C. 211[2] to implement systems that provide a standard interface. This idea has also been endorsed by NATO, which promotes the use of OGC interfaces during its exercises.

r.8 **Multi platform and replicable:** the system should be easily replicable across different computer networks based on different systems and with different security level. The cost of a new system installation should be kept low.

r.9 **Sensitive data management:** the system should be able to work with classified data, and also for unclassified data, encrypted transmission should be possible (namely HTTPS).

r.10 **Extensible and flexible:** the system should be easy to extend and able to receive new functionality with little effort.

r.11 **Application deployment:** other server applications should be able to access the system's services (both in read and write mode) to generate new geospatial products using the datasets available on the system.

2.2 Open Geospatial Consortium interoperable services

The Open Geospatial Consortium (OGC) and the ISO T.C. 211 provide several specifications for many aspects of a GIS application, ranging from web services to data structure specification. The followings are the web services specification:

- **Web Map Service (WMS)** [8]: Exposes an XML interface to provide the clients with a map (a georeferenced raster image[3]) containing the image of heterogeneous datasets (both raster and vectorial).

- **Web Feature Service (WFS) [7]**: Exposes an XML interface to let the clients extract vectorial data. After a data extraction, an update can be performed. GML[4] [10] should be used to express vector datasets within the interface (but other formats are allowed). A transaction system might also be provided in order to support the data update and delete.

- **Web Coverage Service (WCS)** [9]: Exposes an XML interface that supports the exchange of geospatial grid as "coverages"[5]. It provides access to intact (which is somehow a synonym for

[1] http://www.opengis.org
[2] http://www.isotc211.org
[3] Typically the map is returned as a georeferenced image in a common format: GeoTIFF, TIFF, GIF, PNG or JPG image.
[4] GML stands for Geographic Markup language and it is an XML based language for the representation of geographic entities.
[5] Coverages are digital geospatial information representing a space-varying phenomenon (usually earth-phenomenon) in 2,3, or sometimes 4, dimensions. They are based on a tessellation of the covered extent into small units. This view is usually associated with a mathematical function (in the simplest 2-dimensional case, given 2 coordinates i, j, the value is provided by a matrix M[i, j]) able to produce one or more values for each grid square.

unrendered) geospatial information for client-side rendering, or input for numeric processing (e.g. meteorological forecast models). Note the difference with the WMS, which produces simple images of the data while the WCS provides row gridded data directly to the clients, enabling the client itself to perform its own rendering and/or processing operations.

- **Web Catalogue Service (WCaS)** [13]**:** Catalogue services are the key technology for locating, managing and maintaining distributed geo-resources (i.e. geospatial data, applications and services). With catalogue services, client applications are capable of searching for geo-resources in a standardised way (i.e. through standardised interfaces and operations) and, ideally, they are based on a well-known information model, which includes spatial references and further descriptive (thematic) information that enables client applications to search for geo-resources in very efficient ways.

In figure 1 the above-mentioned services are represented.

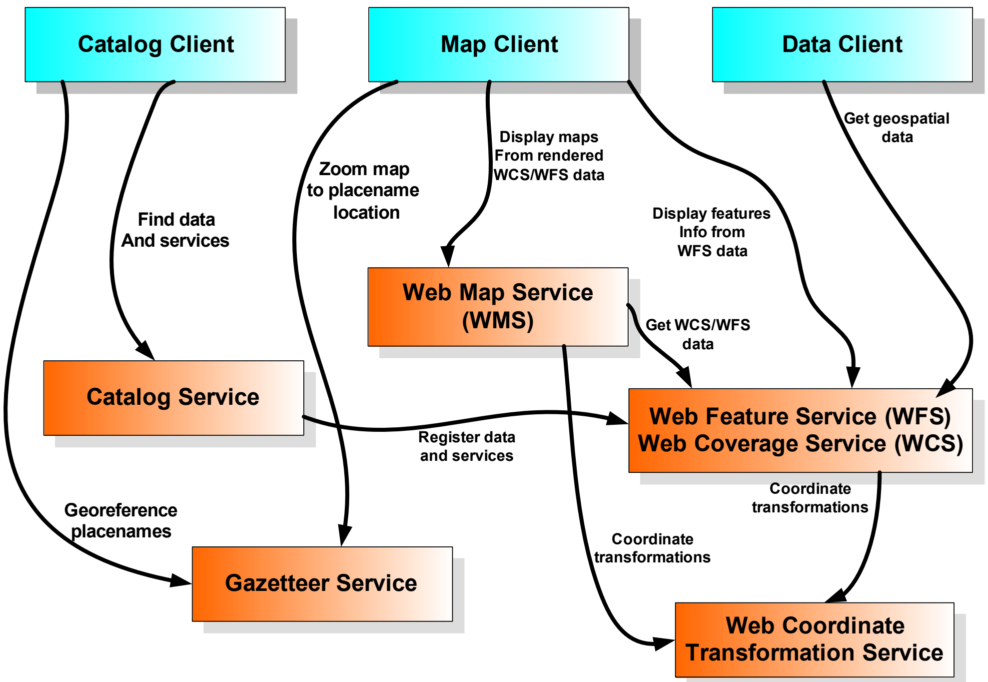

Figure 1: OGC web services architecture

2.3 System foundation

For the client-side ArcView has always been considered the reference client. A web client should also be available for simple data consultation (tabular data reporting and map consultation). Nevertheless, due to requirements r.1 and r.7, all the clients which adhere to the OGC standards can connect to the servers.
For the server-side, the picture was a bit more complex. A COTS system would not have covered all the requirements, especially r.2, r.6, r.7, r.8, r.9, r.10 (at least when this project started in mid-2003). On the other hand, an in-house built system would have implied a huge effort in terms of money and manpower.

The decision was to base the system on top of two open-source packages which have reached a reasonably high quality level[6]: GeoTools and Geoserver. Let's describe them briefly:

- GeoTools[7] is an open source Java-based project that provides several functionalities for creating a geospatial-aware Java application ranging from clients to server side applications. GeoTools is based on many other libraries which are mainly open source as well. GeoTools implements the followings OGC specifications: Geography Markup Language [10], Styled Layer Descriptor Implementation Specification [11], Grid Coverage [12], Coordinate Transformation Services [14], Simple Features For SQL [15], Spatial Referencing by Coordinates [17] and Features Collection [18].

- Geoserver[8] is a Java 2 Enterprise Edition (J2EE) application which implements the WFS (with transaction support), WCS and WMS OGC specifications. It is based on GeoTools and it is considered the OGC reference implementation for the WFS specification.

The open source systems did not cover all the system requirements, so they have been extended with in-house developed code. Part of the code, once developed, was donated to the open source projects. The final system is composed of open-source, COTS, and in-house developed software, therefore a "mixture" of extremely different systems can work together, thanks to respecting the OGC specifications. Figure 2 describes the overall system structure.

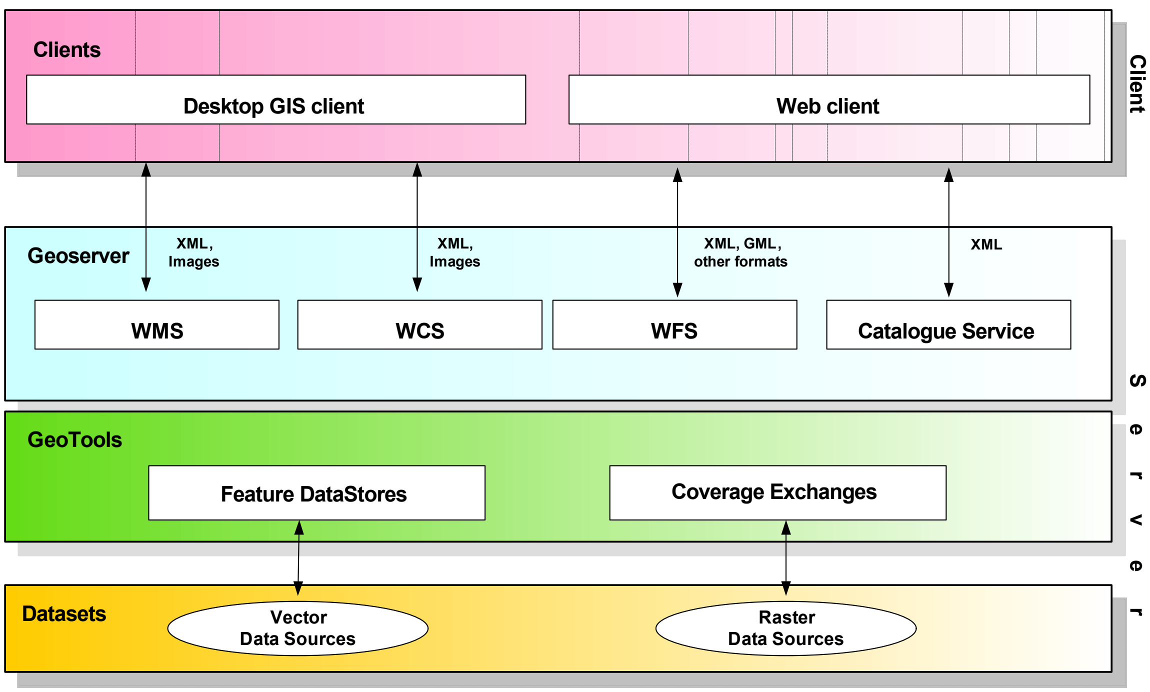

Figure 2: system overall architecture

[6] Even if the documentation is very poor. A lot of effort by the programmer is needed in order to get confident with these packages.
[7] http://www.geotools.org
[8] http://www.geoserver.org

2.4 *Data layer management core concepts*

In the following sub-paragraphs, some of the innovative and interesting characteristics, mainly provided by GeoTools, are described.

2.4.1 The common format

The data types can be divided into two main classes, as stated in requirements r.2:

- Vector, also known in the OGC view as Feature with Geometry (or, for sake of simplicity, just Feature).
- Raster, also known in the OGC view as Coverage.

Following this view, and implementing the related OGC specification, the GeoTools library is capable of seamlessly handling several different data types which fall into one of these two categories. GeoTools uses the Feature Collection [18] concept as an internal common format for vector data and the Grid Coverage [12] as an internal common format for raster data.
It is worth pointing out that this process is performed regardless of the format of the original data source[9]. The connection between the data source and the common format is made by two abstract objects: Reader and Writer. Concrete implementations of these objects allow saving/creating an in-memory object to/from a concrete dataset. For instance given vectorial data stored in an ESRI Shape File [21] on disk, a Feature Collection object can be created allocating a proper data reader. Later, the same object can be saved on disk in a GML [10] file using the appropriate writer.
The common format concept allows the system to treat each geographic object separately from the format used for the storage, and makes it possible to have all the geographic objects stored in the same way in a central repository (see r.2). Moreover, if a requirement for a new format arises, the system can easily be extended by adding a new Reader and/or a new Writer for the new requested format (this feature covers the requirement r.10).
During the development of the system, many new readers and writers have been developed in-house to cope with specific requirements of NURC (namely ESRI ArcGrid, GTopo30 from USGS, GRIB Edition 1, GeoTIFF, Georeferenced Images). These new readers and writers have been donated to the GeoTools project.

2.4.2 Implementation of widely accepted Application Programming Interfaces (APIs)

The GeoTools library draws part of its power from the fact that all its classes are implemented using interfaces which strictly follow the class model that the OGC provides in its specifications. This fact allows it to not only interoperate with anyone that implements the same interfaces, but also gives the opportunity for checking where the specifications are poor and to propose new solutions and improvements.
Following this paradigm of work, anyone can provide his own plug-in to read and write his proprietary format (see par. 2.4.1) for both rasters and vectors, without the need to reveal the format itself.

2.4.3 Database support

When the amount of data increases, database support is necessary. The geospatial object (both raster and vector) can be stored in a database (see r.2) record together with the alphanumeric data and metadata (see r.5) using the appropriate writer (see par. 2.4.1). Moreover, the alphanumeric

[9] Data source can be anything: file, data stream, URL, database table

data related to geographic objects can be accessed, even without a geographic interface, as simple tabular data (for instance using dynamic HTML pages for data reporting).
GeoTools is provided with database readers/writers for PostgreSQL/PostGIS, Oracle Spatial, ESRI ArcSDE and MySQL.
The database used at NURC is PostgreSQL[10] with the extension PostGIS[11] (both free software) which allows many geospatial operations to be performed natively in the database (e.g. geographic projections, topological predicates, etc) using an extended SQL.

2.4.4 Reference system handling

Most users are not aware of the issues that map projection involves (sometimes error are not obvious to the user), therefore is worth delegating this task to the server in order to ensure the consistency of different layers containing data from different data sources. GeoTools has a projection engine (see r.3) that can work on demand: data stored in a given reference system can be delivered in the reference system requested by the users (applying a projection algorithm if necessary). This is true for vectorial and raster layers (even if projecting a raster implies a more complex task: regular grids might become irregular). A huge effort has also been dedicated to support the EPSG[12] Geodesy Parameter Database in order to cover all the possible reference systems in standard fashion.

2.4.5 Rendering based on the OGC specification

The rendering of vectors and rasters can be customized using user-defined symbology. The OGC has standardized the concept related to this issue with the Style Layer Descriptor (SLD) specification [11]. SLD is a map-styling language, XML based, which allows the user to decide the legend of a layer using typical GIS rendering options (e.g. if a line has to be rendered the user can decide the thickness, the colour, whether it is to be a dashed line or not, etc.). GeoTools fully supports styled rendering for vectors, while for rasters, at the moment of writing, there is a huge amount of on-going work. GeoServer, as it relies on GeoTools, also supports SLD.

2.5 The server side

Geoserver was used as a core component for the server side. It provides three services: WMS, WFS (with transaction) and WCS (see paragraph 2.2, and requirements r.7). The WCS was implemented at NURC and later donated to the Geoserver project. A Catalogue Service [13] is also present but not yet exposed as an external interface. The system overall architecture is described in figure 2.
Geoserver, which is based on Java 2 Enterprise Edition (J2EE), is composed of two main parts:

- The Remote Administration Area
- The Server Core Services

The Remote Administration Area lets the system administrator control and configure each Geoserver's service, manage the data storage (for both rasters and vectors dataset) and manage the meta-data. From the system architecture point-of-view, the Remote Administration Area is based on the Model-View-Controller (MVC, see [19] [19]) pattern in order to separate the core business model functionality from the way this functionality is presented to the user. This allows

[10] http://www.postgresql.org
[11] http://www.postgis.org
[12] EPSG stands for European Petroleum Survey Group: http://www.epsg.org

the support of different client types. At the moment, the client is HTML based. The MVC pattern is supported by the Apache Struts Web Application Framework[13].
The Server Core Services, which is based on the Java Servlet, provide the three services WMS, WFS and WCS. Communication towards the clients is based on XML over HTTP in accordance with the OGC specifications. The three services provided are completely independent, letting the administrator run all or only a subset of them. Geoserver uses GeoTools through an indirection layer, which allows the decoupling of Geoserver from the geospatial library.

2.6 The client side

As mentioned before, ESRI ArcView is considered the reference client (see par. 2.3). Unfortunately ArcView, both 3.x and 8.x/9.x, is unable to connect to OGC compliant web services. Actually ESRI provided "OCG ArcMap interoperability Add-on" (for WFS in read-only mode, WMS and GML) and the Service Pack 3 for ArcGIS 9.0 (for WMS), which are still far from being usable in an operational context. An extension for WMS exists also for ArcView 3.2, which has not been tested. NURC plans to develop an ArcView extension (probably for both ArcView 3.2 and 8.x/9.x) which will allow ArcView to connect to the three OCG services: WFS, WMS and WCS (it would be interesting to see an integration between WCS and the ESRI Spatial Analyst).
Other OGC compliant clients (see r.1) are also used (even if less powerful compared to ArcView): User-friendly Desktop Internet GIS[14] (UDIG) developed on top of GeoTools and Gaia[15].
The Web Browser (thin client, see r.1) is used to connect to the WMS for quick map consultation (Web GIS), but also to access the alphanumeric data associated with the geographic features. This is a valuable tool for data reporting, especially for system administrators.
An automatic ingestion engine (see r.4) is also provided (hidden behind an FTP server) used especially for raster dataset ingestion This is extremely handy, especially during the EOS/REA exercises, when a large numbers of grids are delivered to the central server containing mainly oceanographical and meteorological forecast gridded datasets and satellite data.

2.7 Tactical Decision Aids

The OGC services can also be accessed by other server applications (see r.11) thanks to the well-known XML interface. These applications are mainly Tactical Decision Aid systems that provide an effective tool to help decision makers. These systems are based on the impact of METOC[16] values on military operations (for previous work on this topic see [5]). Therefore each military operation will have a set of associated METOC data with thresholds that specify the condition when the operation success will be likely, unlikely or unknown. The inputs to the system are comprised of the chosen operation, the geographic bounding box, a time and the set of gridded data extracted through the WCS. A fuzzy logic engine containing rules based on the thresholds of the METOC values is run to obtain the output grid which will be converted into a polygon layer, grouping together the points which belongs to same class (operation favorable, marginal and unfavorable). These polygons can be stored in the central geospatial repository (using the WFS), making them available for all the users. Figure 3 shows ESRI ArcMap visualizing the resulting polygons with a traffic-light legend for the operation "Naval re-fuel" at a given time stamp.

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[13] http://struts.apache.org
[14] http://udig.refraction.net
[15] Gaia, The Carbon Project: http://www.thecarbonproject.com
[16] METeorological and OCeanographical

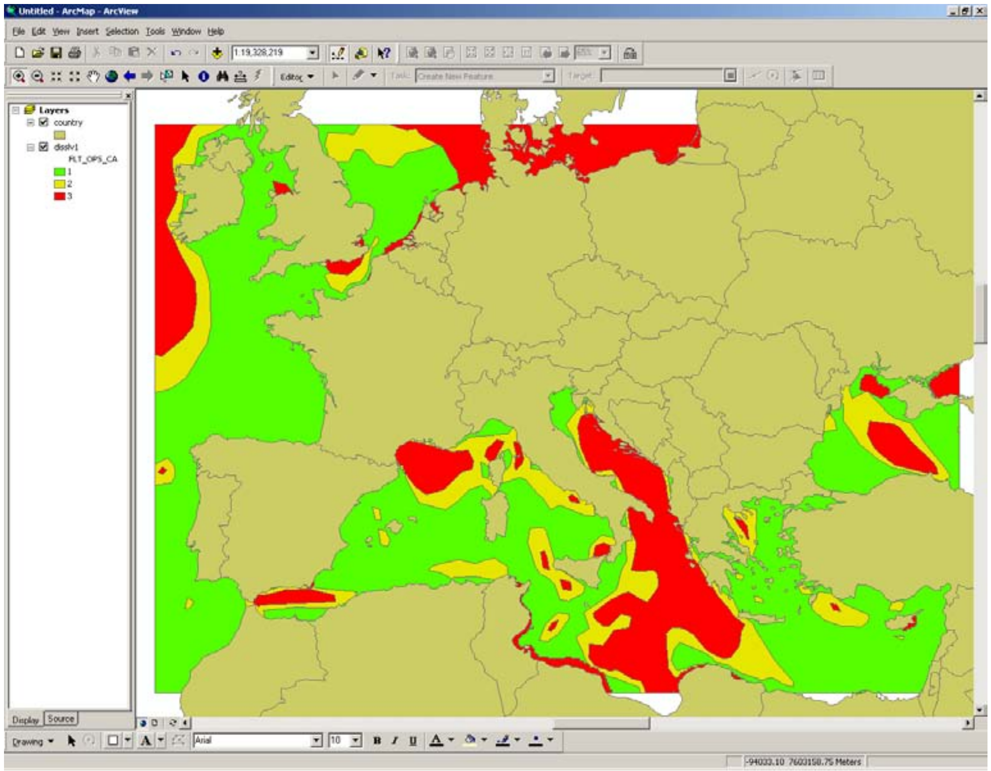

Figure 3: tactical decision aids for operation "Naval re-fuel"

3 Conclusions

A client server GIS has been presented developed with the integration of open source, COTS and in-house software. This system adheres completely to the Open Geospatial Consortium specification, making clients and servers truly interoperable, moreover, the use of high-quality open source packages keeps the development cost low. The power of a state-of-the-art Desktop GIS is provided by the use, as a reference client, of ArcView 3.x, 8.x or 9.x.

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