INTEROPERABILITY ON THE WEB: THE CASE OF 3D GEO-DATA

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ABSTRACT

Geographic information (also called geo-information, spatial information or geospatial information) plays an increasingly important role in our society. Location Based Services, applications for urban planning, disaster management systems rely on geo-data and in many cases up-to-date geo-information is crucial, e.g. in disaster response systems.
In this paper we focus on a special kind of geo-information: 3D spatial data to be used in 3D GIS (Geographic Information System), CAD (Computer Aided Design), Virtual Reality or Augmented Reality applications.
Because the production of up-to-date and accurate geo-information is very costly, exchanging and sharing data between organizations is often the only way to get all relevant information to decision makers and other end users. In principle Internet has created new possibilities for the shared use of geo-data. Data sets do not have to be copied anymore on CD's or tape, but could be accessed online, via Web services. Progress towards shared use of geo-data via the Web is slow however. One of the bottlenecks is the heterogeneous nature of geographic data, both in a technical sense (data format) and in a semantic sense (data model and meaning). Interoperability (of data and software) is therefore a key issue that needs to be resolved.
In this paper we will look at the interoperability initiatives of the OpenGIS Consortium (OGC). One of the main principles of OGC is, that in order to improve data and software interoperability, it is necessary to create standardized interfaces between the different components (possibly of different vendors) of geo-information systems.
We will investigate possibilities to publish 3D geo-data on the Web using OpenGIS compliant Web services. We will report on a 3D Web Mapping prototype environment built at our research institute. One purpose of the prototype is to see whether the present OGC specifications are adequate for access to 3D geo-data (query, visualization, navigation and analysis).
Apart from the OpenGIS Web service specifications also another emerging Web standard is used in the prototype: X3D (eXtensible 3D) of the Web3D Consortium.

KEYWORDS

3D geo-information, OpenGIS specifications, interoperability, X3D

1. INTRODUCTION

Geographic information (also called geo-information, spatial information or geospatial information) plays an increasingly important role in our society. Geo-data is not only used as the basis for (digital) maps, but also as input for 'spatial' analysis. Spatial analysis tries to solve questions such as:

- what area needs to be evacuated when there is a threat of flooding or of forest fire (disaster management);
- how many houses (and households) will be affected by the (re)construction of this highway (accessibility vs. noise, air pollution);
- what parcels have to be bought by the city council when a tramway has to be constructed (local administration).

To solve these and other questions geo-information systems have operators like 'intersects', 'is Neighbour Of', 'within Buffer' (see e.g. Longley et al, 1999).

Geo-information has already proven its importance for many applications and daily use. A large number of human activities utilise 2D geo-data in some form (paper or digital maps) to complete different tasks. However, the world we are living in is three-dimensional and in many cases the two dimensions are not sufficient. The 3D objects presented as 2D projections may lose some of their properties and relations to other objects and this may create difficulties to understand, analyze and evaluate the real-world objects and real-world situations represented by this geo-data.

Many applications are already aiming at 3D solutions. Examples are: urban planning (Nebiker, 2003), landscape planning (Lammeren et al, 2002; Blaschke and Tiede, 2003), city government (Zlatanova, 2000), disaster management (Razo and Sol, 2001; Zipf, 2004), road construction (Bresters, 2003), railway and building construction and documentation (Pomaska, 2003), 3D cadastre (Stoter, 2002), utility management (Roberts et al, 2002), shopping and tourism (Coors, 2002; Höllerer et al, 1999). Figures 1-3 show examples of prototype systems developed to respond to these needs.

Figure 1: Left: Augmented Reality system for utility management (Roberts et al, 2002) and right: 3D navigation for Location Based Services (Coors, 2002)

Figure 2: Left: Road design (Bresters, 2003) and right: Urban planning (Nebiker, 2003)

What the end user sees while using these applications, is the 'outside' of very data intensive information systems. The (carto)graphic visualization in 2D maps or 3D 'worlds' is only one part (one component or one set of components) in a more complex architecture. What these applications have in common is that they depend on large amounts of geo-data, either in the form of vector data (point, lines, polygons or shapes with coordinates) or raster data (pixels or voxels) (Longley et al, 1999; Stoter and Zlatanova, 2003).

Because the production of up-to-date and accurate (2D or 3D) geo-information is very costly, exchanging and sharing data between organizations is often the only way to get all relevant information to decision makers and other end users. In principle Internet has created new possibilities for the shared use of geo-data. Data sets do not have to be copied anymore on CD's or tape, but could be accessed online, via Web services.

The first examples of publishing geo-data on the Web were: a map of a city with hotels and restaurants (tourist information site), a site to find the location of an address and the shortest route between two addresses, real estate sites that show houses for sale etc. This is the oldest type of so-called 'Web Mapping'. It is meant as information service for the general public, is dedicated to one purpose and will primarily be used for ad-hoc information queries. From an information engineering perspective a second type of Web access to geo-data is more challenging: the multi-source or data sharing type (De Vries, 2002). The goal of this second type of data exchange is the online combination of geo-data from more than one data provider, hosted on different remote servers, in real-time. This could be:

- in an Intranet setting: different departments of the same company or organization;
- in a 'closed' Internet or mobile network setting (only authenticated users have access to the information on different servers);
- in a 'open' Internet setting: everybody has access (a digital library for geographic information).

Clearly, both data providers and end users will benefit from Web access to 3D geo-information. However, progress towards shared use of geo-data via the Web is slow. One of the bottlenecks is the heterogeneous nature of geographic data, both in a technical sense (data format) and in a semantic sense (data model and meaning). There is a notorious abundance of vendor-specific data formats in GIS and CAD, without an obvious de-facto exchange standard.

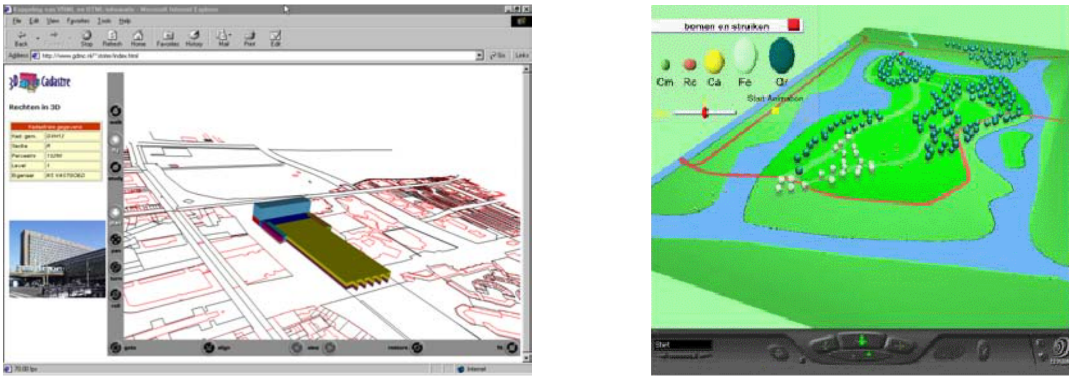

Figure 3: Left: 3D cadastre (De Vries and Stoter, 2003) and right: Landscape design (Lammeren et al, 2002)

In this paper we investigate possibilities to publish 3D geo-data on the Web using open standards, meant for the improvement of interoperability between application environments. In Section 2 we will look at the interoperability initiatives of the OpenGIS Consortium. We concentrate on the OpenGIS specifications that are most relevant with respect to accessing 3D geo-information over the Web: Web Feature Service (WFS), Geography Markup Language (GML) and Web Terrain Service (WTS). In Section 3 we briefly discuss different options for the (functional) architecture of geo-Web applications. In Section 4 we address another new Web standard: X3D, of the Web3D Consortium. In Section 5 we will report on a prototype environment built at our research institute, based on these OpenGIS and Web3D standards. Main purpose of the prototype is to test the suitability of these standards for retrieval and use of 3D geo-data over the Web (query, visualization, navigation and analysis). We conclude with a first analysis of the performed tests together with some directions for future research.

2. INTEROPERABILITY: OPEN GIS

The OpenGIS Consortium (OGC) was founded in 1994 by a number of companies (both producers and users of GIS software), database vendors and research institutions. The OpenGIS Consortium can be considered an industry-wide discussion and standardization forum for the geo-application domain (OGC, 2004). One of the main principles of OGC is, that in order to improve data and software interoperability, it is necessary to create standardized interfaces between the different components (possibly of different vendors) of geo-information systems (OGC, 1998). The Web service specifications discussed in this Section must be seen in this light.

The Web Map Service (WMS) specification was the first developed in the line of OpenGIS interface specifications (WMS, 2001). The WMS specification defines three operations: GetCapabilities, GetMap and GetFeatureInfo. In the GetMap request the map layers, styles, bounding box of the area, etc. are passed to the Web service as arguments in the request string (name-value pairs). The result of the GetMap request is a (2D) image (GIF, PNG, JPEG). The GetFeatureInfo operation is meant for 'identify' purposes: the xy position in the map window ('onclick' event) is passed to the WMS service, the service performs a spatial query on the geo-data, retrieves attribute information of the object(s) at that location, and sends this attribute information back to the client as XML or HTML.

The Web Feature Service (WFS) specification was the second interface specification proposed by OGC (WFS, 2002). A WFS service supports the following operations: GetCapabilities, DescribeFeatureType and GetFeature. Besides this so called Basic WFS there is also a Transaction WFS. There are two additional requests in this case: Transaction and LockFeature.

The GetFeature request can contain selection conditions (a filter). Both spatial and non-spatial properties of the features can be used as conditions in the filter. Its output is not a bitmap (as in the case of a WMS service) but an XML stream of vector data. The data structure of this XML output is not free, but is subject to another OpenGIS specification: GML, or Geography Markup Language. GML is one of the other important interoperability initiatives of OGC (e.g. Reichardt, 2001). Its current version is 3.0 (GML, 2003). GML can be considered a domain specific XML vocabulary meant for the exchange of geo-data. Until version 3, the GML specification concentrated on the basic geometry types (point, polygon, line string). Version 3.0 introduced more complex geometry types and also topology (see below).

The WMS and the WFS specification were designed (and tested in Web Mapping Test Beds) by OGC for the purpose of publishing 2D geo-information. Because of the increased demand for 3D information the OpenGIS Consortium is now working on a new Web service specification: the Web Terrain Service (WTS, 2003).

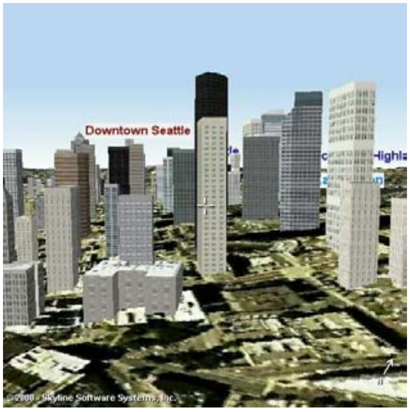

Figure 4a: 3D perspective image (WTS)

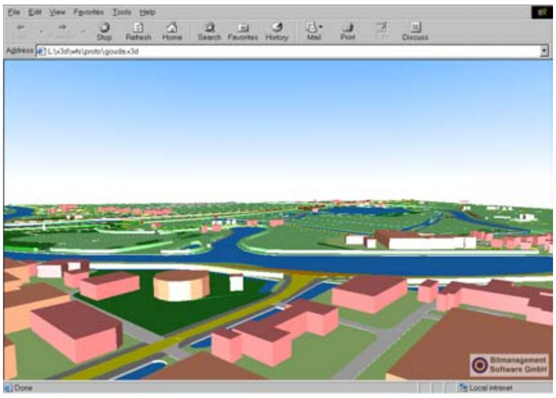

Figure 4b: Topographic data (1:10,000) (WFS/GML)

The Web Terrain Service (WTS) specification defines a standard interface for requesting 3D terrain scenes from a server capable of their generation. A WTS service has to support two operations: GetCapabilities and GetView. The view or 3D 'scene' is defined as a 2D projection of three-dimensional features into a viewing plane. To be able to create this view, a number of parameters have to be provided to the server: Point of Interest (x,y,z of user focus); the distance between the user and the POI; the vertical angle between the user and the POI; the horizontal angle between the north direction and the horizontal projection of the 'user-POI' line; and the Angle of View. The server returns a raster image of the 3D data. For example, the WTS request in the fragment below will return a 3D scene of downtown Seattle (see Figure 4a):

```
http://alpha.skylinesoft.com/services/ogc/WMS/WMS3D.asp?server=WTS&request=GetVie
w&version=0.3&srs=EPSG:4326&poi=-
122.3341683,47.61022834,0&distance=1400&pitch=5&yaw=30&aov=15&width=512&height=51
2&format=jpeg&quality=medium
```

The WTS specification is issued by OGC as 'companion specification' to the WMS specification. In both cases the output is a raster image (a bitmap). A WTS service is a good solution when the purpose is to publish 3D perspective views of e.g. a city or a landscape. For other purposes however a WTS service is not sufficient: for navigation through the 3D scene, for 'identify' operations (getting more information about an object) and for spatial analysis. For navigation through the scene (a car or a person that moves around) a series of images will have to be generated (at the server), which means continuous round-trips to the server.

Local interaction with cached (vector) data would be a better solution (better performance, more scalable, more diverse navigation possibilities). The same is true when the 3D data is used as input for spatial analysis (e.g. answering questions like: which pipelines or which metro corridors pass under this building?).

When WTS is not sufficient for our purpose (setting up a Web service and a Web client to access and use (navigate, query) 3D geo-data over the Web), the question is: what about WFS? The Web Feature Service specification itself does not discuss the dimension of the geometries (2D or 3D). Because the output format of a WFS service is GML, it is rather the GML specification that is important here. GML geometry types allow for x, y and z-coordinates, so modeling 2.5D information is possible in GML. In addition, GML version 3.0 introduced the 'Solid' geometry type, which can be used for 'full' 3D objects. GML 3.0 also offers the possibility to use a topological data structure (a 3D object as a TopoSolid with references to Faces, Edges and Nodes). So theoretically GML does not have any limitations in maintaining 3D objects (geometry and/or topology).
(Note: The fourth OpenGIS Web service specification that could be mentioned here is the Web Coverage Service (WCS) specification. More information can be found in (WCS, 2003).)

3. FROM DATA TO VISUALIZATION

In the case of a WMS or a WTS service a user request for a 2D map or 3D view results in a raster image (GIF, PNG, JPEG etc.) that can be viewed in the browser (see previous Section). With every 'zoom in', 'zoom out' or 'pan' action of the user ('pan' = shifting the part of the map that is displayed), a round-trip to the server is necessary: a new user request has to be constructed at the client and sent to the server, the server has to perform a spatial query and produce another image which is then returned as output to the client.

In contrast, in the case of a WFS service (GML data instead of raster images as output of service requests) the transformation into a graphic format is handled by the client and not by the server. Many user actions can therefore be processed at the client side, on the (cached) vector data. In the typology of Web Mapping solutions these two (technical) architectures have been called 'picture case' or 'thin client' versus 'data case' or 'thick client'. There is also a third type: the 'medium client', or 'graphic elements case', where the data sent to the client is in a graphic vector format (like SVG or X3D) which leaves only the rendering of the image and the display to be handled at the client (OGC, 2000). See Figure 5.

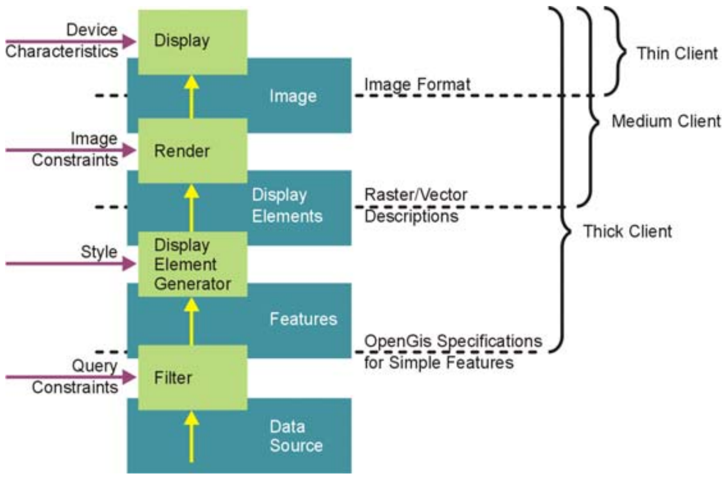

Figure 5: From geo-data to digital map or 3D 'world' (based on OGC, 2000)

There is always a fixed set of steps to get from the stored geo-data (in object-relational databases or in file-based formats) to the cartographic presentation as 2D map or 3D 'world'. One of these steps is the transformation from the stored geo-data into a graphic format (either raster of vector) that can be displayed in the browser. What is not fixed is the place and time of this transformation: by the Web service itself (thin client), by middleware (this can be another (intermediary) Web service) (medium client) or at the client (thick client).

4. WEB3D CONSORTIUM: X3D

The GML output of a WFS service is not a 3D scene yet. It has to be transformed into a graphic format for which visualization software is available. A good candidate is: X3D, the new (draft) standard of the Web3D Consortium (Web3D, 2003).

X3D (eXtensible 3D) can be considered the XML version of VRML (Virtual Reality Modeling Language). VRML was launched in the nineties, and became an ISO standard in 1997. The VRML format was designed for the basic requirements of 3D applications: hierarchical transformations, illumination models, viewpoints, geometry, fog, animation, material characteristics and texture, sensors and interpolators. The development of VRML has stopped since the Web3D Consortium started to work on X3D. In May 2003 version 1.0 of the X3D specification was published. The data structure of X3D is very much comparable to the data structure of VRML. The difference lies in the technical format: while VRML is text (with accolades for structuring), X3D is coded in XML (with markup tags for structuring).

X3D offers a lot of possibilities to developers of 3D applications. The first interesting aspect of X3D's data structure is that the IndexedFaceSet and IndexedLineSet constructs of X3D not only contain the xyz-coordinates for an object, but also an index list of pointers to these coordinates. In other words, 3D objects are stored with 'internal' topology. This means that nodes (vertices) that are part of two or more faces (sides) of the object only have to be stored once (per object). The way 3D data is stored in X3D is therefore very efficient. The second X3D construct that is interesting for 3D geo-data retrieval is the <Anchor/> element. This can hold a URL to be accessed when an event occurs (e.g. a mouse click). This can be used for 'identify' operations, or - in OpenGIS terminology- a GetFeature or GetFeatureInfo request.

5. PROTOTYPE

As a proof of concept for the use of open standards for Web access to 3D geo-data, we set up a prototype environment based on the OpenGIS specifications discussed in Section 2 (WTS and WFS/GML). Aim of our research is to investigate and estimate the following issues: connect to different servers and combine output of these servers in the client in one integrated 3D view; experiment with different options (e.g. transformation from GML to X3D at the server or in the client); combination of different data formats and storage types (file based, object-relational spatial databases, raster images); generation of a 3D vector 'scene' with navigation and interaction functionality; possibilities for spatial analysis; and the potential of X3D as graphic format for 3D geo-data.

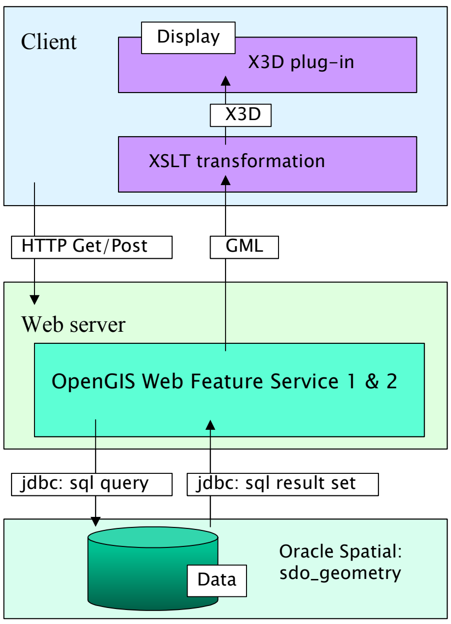

Figure 6: Prototype architecture

We installed and configured two different OGC compliant Web Feature Service implementations: RedSpider Web (IONIC, 2004) and GeoServer (an open source product) (GeoServer, 2004). We implemented the services on two hardware platforms: a Linux host and a Windows 2000 host.

Several 3D data sets from certain areas in the Netherlands and Austria have been used to test the approach and the performance. At this moment all the data is stored in Oracle Spatial (Oracle, 2004). The two WFS server products (RedSpider Web and GeoServer) can also be used to connect to other 'spatially enabled' databases and to file-based formats (e.g. ESRI shapefiles).

Besides the Web service software itself (for handling the client requests, retrieving the 3D geo-data and producing the output responses) there are two other important components: the transformation software (from GML to X3D) and an appropriate plug-in at the client side for visualization and interaction (navigation and other forms of interaction, e.g. 'identify' operations).

The transformation software has to read the geometries from the GML output stream and re-write them according to the model of X3D. When the media-type is set to ‘model/x3d+xml’, the transformed output is recognized by the browser as X3D, and the right viewer plug-in is activated. In our present prototype we use XSLT for the transformation from GML to X3D. With XSLT (eXtensible Stylesheet Language for Transformations) it is possible to transform XML documents or XML data streams into other XML documents or data streams (e.g. Gardner and Rendon, 2002). We chose XSLT for the transformation part in the architecture because GML and X3D are both coded in XML. Disadvantage of XSLT is that it can be slow, depending on the size in bytes of the GML output that is parsed and processed. In the next version of the prototype we will look at other transformation possibilities.

As has been pointed out in Section 3, there are a number of options for the Web server/client architecture: from 'thin client' to 'medium client' to 'thick client'. Only in the case of a WTS service (raster images as output) a 'thin client' architecture is possible. For the tests with Web Feature services (GML as output) we decided on a 'thick client' architecture, i.e. not only the display on screen is handled by client software, but also the transformation from the GML output of the WFS service into the graphic format (X3D in our case).

The client is based on a combination of HTML and JavaScript for the user interface, an XML parser and XSLT processor for handling the incoming GML and transforming it into X3D, and a non-commercial version of BS Contact, one of the first X3D plug-ins that were available (see links in (NIST, 2003)). Figure 4b shows an example of 3D topographic data visualized with the BS Contact plug-in (after transformation from GML to X3D).

6. CONCLUSION

In this paper we discussed the use of OpenGIS compliant Web services for access to 3D geo-data over the Web, in combination with another open standard: X3D. We also reported on a prototype Web environment (services and client) based on these standards.

While WTS is a good solution for orientation purposes (3D perspective views of a point-of-interest, seen from a certain standpoint in a certain direction), a WFS service seems a better choice when navigation is important. For interaction, selection queries and spatial analysis, and also for editing of 3D geo-data, a Web Feature service is the only option: i.e. real selection queries (in stead of only a point-of-interest as in the case of a WTS service), 'identify' possibilities etc.

As far as the interoperability aspect is concerned the first test results are hopeful. Building and configuring the prototype environment proved relatively easy. The combination of two different WFS implementations (GeoServer and RedSpider Web) with our own Web client worked well. This shows the clear benefits of the standardization of interfaces (response/request) between Web clients and Web services. Another positive aspect is the OpenGIS GetCapabilities mechanism: a Web service provides (part of) its own metadata as response to a client request (advertisement). GML as data exchange format means that data from different providers can be shared independent of the native geo-data formats. Finally, X3D looks like a promising option for a 3D graphic format for geo-data.

Future research will concentrate on a number of issues: how to include textures in GML; editing of 3D features via a WFS service; comparison of different transformation strategies (in the client, by middleware or at the server), in relation to finding methods to guarantee good performance in case of large 3D data sets.

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