Outside the Box - Creating Real-time Inspection Modules to Monitor Earthquake Hazards - A Case Study on Integrating Dynamic Geographic Information Systems

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Abstract— Recently, many geospatial sources have had the arduous task of redesigning their GIS infrastructure to release scientific results over large-scale external mapping networks. Given their large volumes and low retention rates, these libraries have usually been restricted to a small group of resourceful entities (e.g. agencies carrying high-bandwidth networking capabilities.) Thus, most geospatial users do not have the resources to disseminate a GIS of such a large scale. Moreover, their main attempts to conduct geospatial registry updates are constantly being affected by their lack of structure, reference (i.e. metadata) and geospatial characterization (e.g. implementing old georeferenciation methods and optimization algorithms to integrate unscaled coverages or to modify the existing ones.) These issues inevitably produce datasets that could potentially misrepresent the actual spatial components under study. This report presents an optional methodology to better manage large-scale GIS frameworks. Particularly, it details various GIS design methods and GIS tools to create faster, more consistent geospatial components— i.e. Dynamic Geographic Information Systems (D-GIS.) Results from a recent case study on Earthquake Hazards are presented as well.

Index Terms— GIS, Coverage, Geographic feature, Metadata, OGC, XML

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I. Introduction

Since 1998, the NASA Partnership for Spatial and Computational Research (UPRM-PaSCoR: NASA grant number NCC5-340) has been developing an extensive framework in the areas of Remote Sensing Analysis (RS), Satellite Image Processing, and Geographic Information Systems (GIS.) Today, these tools have experienced remarkable advances from a technology applications standpoint. Emerging GIS frameworks that manage large libraries of geospatial content are adapting novel geocoding strategies to integrate scientific data into a single framework that can serve for the display and analysis of real-time geospatial content. From universities to local emergency and investigation agencies, real-time GIS applications (i.e. D-GIS) can provide crucial results for users that frequently rely on geospatial analysis to address the difficulties around such transitory events as natural hazards, (e.g. earthquakes, tornadoes, or hurricanes) as well as other urban-related events and issues (e.g. fires, crime prevention, or ambulance logistics support.) Mainly, D-GIS frameworks are being implemented at NASA-PaSCoR through various undergraduate research activities, where remote users in the United States and Puerto Rico can update GIS coverages and retrieve earthquake seismicity records from the US Geological Survey's National Earthquake Information Center (Román-Colón, et al. 2003.) These methods used various spatial limits and standardized guidelines (i.e. OGC compliant guidelines), which resulted in the creation of a dynamic mapping module for ground based geospatial observations (Fig. 1.)

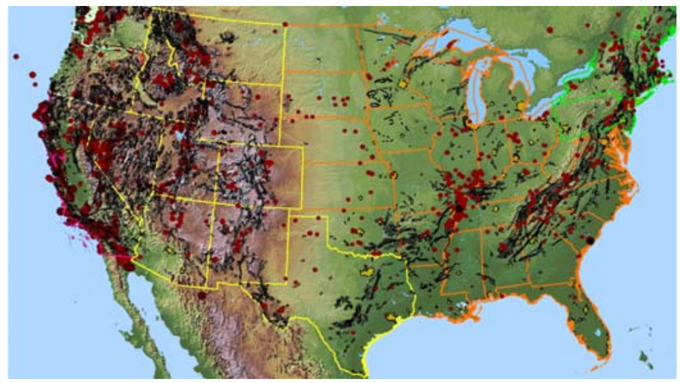

Fig. 1. The Continental US Domain: Geographic coverages include: (1) Shaded Relief, (2) Urban Areas, (3) Geological Faults, (4) Real-Time Seismicity Observed for 2002.

II. D-GIS Requirements and Design Objectives

The main objective of this study was to characterize, understand, and enable computationally efficient GIS techniques that could potentially downscale the analysis and retention of large geospatial sources. In order to meet this objective, we focused our efforts to answer following question: How will D-GIS benefit the current domain of geocoding services without sacrificing the usual advantages of discrete geospatial extraction schemes?

Primarily, D-GIS projects follow a more controlled methodology based on taxonomic rules and information architecture schemes. This technique was created in an effort to meet the user's retrieval needs for real-time seismic parameters that descended from sources that have distinct records of regional seismic activities. Accordingly, we concluded that a D-GIS can become a very resourceful component of dynamic content delivery when it complies with the following conventions:

1) To abide with the latest standards of the Open GIS Consortium (OGC); hence, enabling information architecture schemes that facilitate the interaction between different geospatial environments (Buehler, Kurt 2000.)
2) To provide dynamic response frames in real-time periods, by using reliable monitoring sources (both human and artificial.)
3) To implement "picture-perfect" coverage visualizations, by using Internet Mapping Servers (IMS) that are understandable to the general public.

4) To engage into continuous feedback with emergency and investigation agencies that may require GIS data in moments of crucial decision making analysis, so that their technical requirements and individual guidelines are fully met.

Most importantly, the primary source for geospatial content retrieval should descend from regional libraries that could quickly transform the existing geographic extraction modules for real-time GIS reception into a user-enhanced interface. This selection process must aim at even more precise acquisitions, based on local user familiarity to the geospatial components under study.

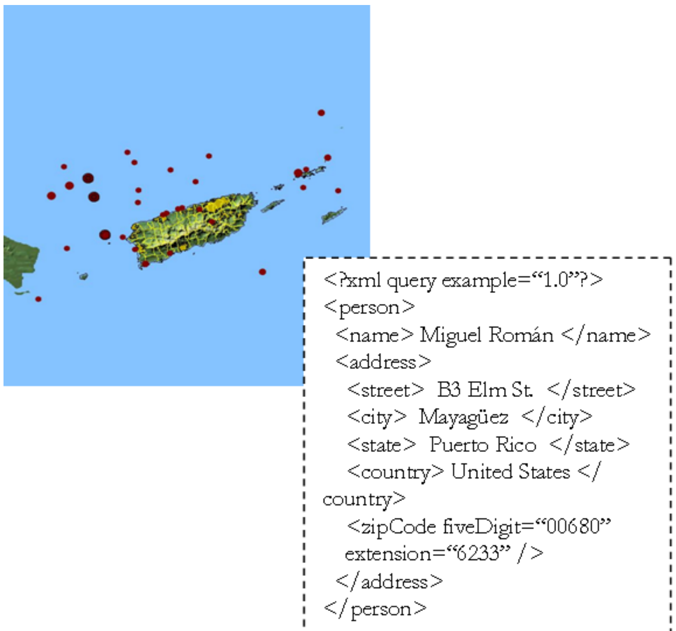

Fig. 2. Seismic activity observed for the Puerto Rican Archipelago and its descending XML Query.

Analogously, our results demonstrated that the geographic inspection modules available for the Puerto Rican Archipelago domain (i.e. local and regional projects) clearly surpassed large scale GIS projects in providing concurrent datasets that fulfilled our particular needs and requirements— hence, yielding precise geospatial environments. Real-time seismicity could therefore be represented in point-to-point data, by expanding the unit magnitude to express larger seismic activity (Fig. 2.) We also included geographic coverages to identify urban sectors by municipality, cities, and highly populated areas (Figs. 3 and 4.)

III. The Earthquake Hazards Theme

One of the main requirements of the mapping environment was to expand its applications domain to support different themes and scenarios (e.g. invasive species reconnaissance and management of water quality.) Initially, all information sources were set to be identified as specific and detailed as possible, which made the preceding coverages of US County boundaries fairly general for the proposed module.

We developed various coverages that were comprised of up-to-date information on US population density and postal (Zip-Code) designations from every US State and Territory. Once all the input tables of earthquake seismicity were setup to support concurrent modules from updated remote sources, an application server was designed using various XML-based taxonomic query-rules. Since the XML query reflected the structure of the information— rather than limiting the application-specific geographic configuration— the environment was very specific to regional application domains, even when the content seemed arbitrary.

In order to meet our demands to create a faster geospatial environment, we created an ArcXML based script that could handle an easy to use search engine. By interconnecting the XML searching structure of the D-GIS with a JAVA-based ArcIMS server, we could easily disseminate and extract every single geospatial feature from the mapping environment.

Fig. 3. The United States Southwest Region: National County Boundaries were integrated into the D-GIS.

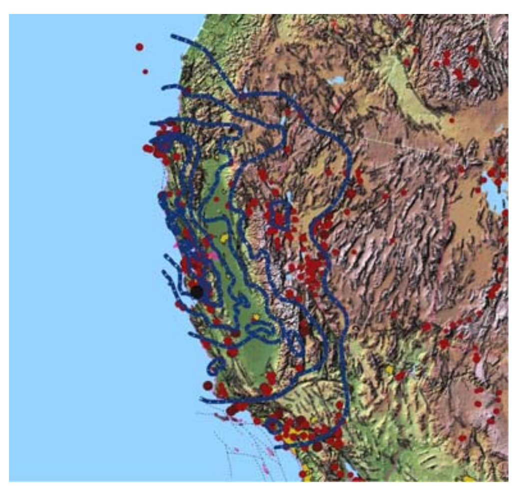

Fig. 4. In addition to launching regional coverages on seismic activity, an iterative array of potential seismic occurrences has been characterized, based on prior reports.

IV. Implementing the Extensive Markup Language

Emerging technologies in object oriented computing were one of the main tools used in this project to fulfill all D-GIS conventions. These tools provided a highly structured medium from which we could easily parse and interpret geographic attributes. Most recently, the Extensive Markup Language (XML) has become one of these premier technologies. There are various advantages when a design module for a D-GIS is created in parallel with XML-based procedures. Primarily, XML supports various open-source environments without limiting the use of external access gateways that could potentially alternate the information structure of an environment into a smaller more manageable memory interface. Other advantages that XML compounds are: (1) XML clearly reflects the Structure of the Information, (2) XML is specific to a particular application domain, (3) XML documents can handle arbitrary taxonomy rules. Moreover, XML handles information sources through Metadata by integrating a content delivery engine that fully obeys Open GIS Consortium requirements.

Various software technologies implementing XML such as Microsoft's .Net Smart Client and IBM's Tivoli Automated Management tools have been the usual pick for industries working to disseminate their complex geospatial sources. Yet, many experts agree that XML can be utilized as a standalone environment without the need for implementing large resources beyond the desired geospatial characterization domains. In fact, according to Geospatial Solutions Magazine, XML was catalogued as "the only language available today that supports Web-based discovery of geographic sensors and its stored data"; hence, providing an object-oriented approach, which recreates a convenient way to automatically generate standard-scheme metadata for information produced by sensors, facilitating the discovery and interpretation of geospatial information.

For this study, we launched an XML query-set in a successful effort to devise a highly efficient distribution environment for earthquake seismicity information retrieval. Furthermore, we extracted various arrangements of earthquake information records into a graphical user interface (GUI) through ESRI's ArcGIS. Afterwards, we transferred the results into a mapping server using an JAVA-based internet mapping environment via ArcIMS. Using a comprehensive mapping environment of the North American Continent, we included additional layers such as geological characteristics (e.g. rock formations and tectonic faults) and demographic properties (e.g. roads, counties, and cities.)

The majority of the proposed geographic coverages contained very sensitive and raw data packets, which had exclusive formatting restrains. This matter presented challenges when designing the D-GIS, since various coverages presented projection misalignments, as well as other georeferenciation issues. Consequently, we developed a risk-benefit analysis to evaluate and converge all the information sources into a single spatial framework (i.e. ArcGIS/ArcXML — Fig. 5.)

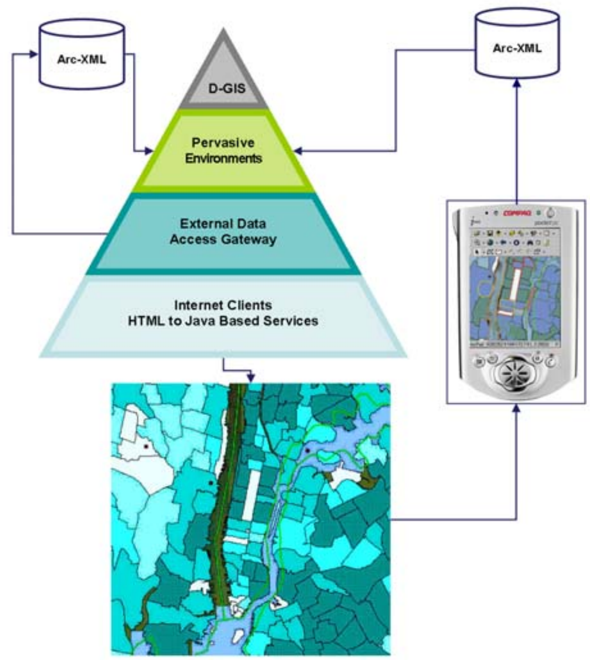

Fig. 5. Final Dispatch of the Internet Mapping Service: A remote source from the New York Tri-State area can make reports on pre-established locations by accessing the D-GIS through a JAVA based Internet Mapping Server (IMS), by using ESRI's ArcPad toolbox.

V. Conclusions

Most of the updated coverages were fully active every ten minutes. Thus, the availability of real-time information on earthquake seismicity was outstanding. We also achieved stronger feedback from external entities with access to pervasive resources, since we considered including additional themes and geospatial scenarios. Moreover, we modified the existing Internet Mapping Service architecture with a JAVA based environment. Consequently, we had the liberty to continue expanding the external data access gateway via hundreds of independent modules that could constantly remodel the environment through various mobile systems (e.g. Tablet PCs and PDAs such as Compaq's Pocket PC.) Finally, the D-GIS successfully provided a comprehensive evaluation of the seismological status of several surveillance stations in the event of an earthquake hazard by allowing external sources to view, interact, and even merge concurrent datasets into a single dynamic interface.

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References

[1] Román-Colón M., and Vásquez-Espinoza, R., XML Integrations to Geographic Information Content Delivery Systems, The American Association for the Advancement of Science (AAAS) International Meeting, Student Poster Competition. Physical Sciences, Denver, CO., 2003.

[2] Govoni, David L., Gateway to the Earth 101: USGS Libraries: Connecting Resources for Integrated Science, USGS Library Consortium, August 7-9, U.S. Geological Survey, Reston, VA, 2001.

[3] Ryan, B.J.,USGS Gateway to the Earth - Transforming our Understanding of the Environment, Second International Digital Earth Symposium, June 24-28, Fredericton, New Brunswick, Canada, 2001.

[4] Apache Web-Server Environments, www.apache.org. Networking Software.

[5] Lowe, Jonathan. The Real-Time Continuum. Geospatial Solutions, November, 40-43, 2001.

[6] Buehler, Kurt,"OpenGIS® Reference Model" (1st ed.) Reston, VA, 2000.

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