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Performance improvement techniques for geospatial web services in a cyberinfrastructure environment – A case study with a disaster management portal

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ABSTRACT

High population growth, urbanization, and global climate change drive up the frequency of disasters, affecting the safety of people's lives and property worldwide. Because of the inherent big-data nature of this disaster-related information, the processes of data exchange and transfer among physically distributed locations are increasingly challenging. This paper presents our proposed efficient network transmission model for interoperating heterogeneous geospatial data in a cyberinfrastructure environment. This transmission model supports multiple data encoding methods, such as GML (Geography Markup Language) and GeoJSON, as well as data compression/decompression techniques, including LZMA and DEFLATE. Our goal is to tackle fundamental performance issues that impact efficient retrieval of remote data. Systematic experiments were conducted to demonstrate the superiority of the proposed transmission model over the traditional OGC Web Feature Service (WFS) transmission model. The experiments also identified the optimized configuration for data encoding and compression techniques in different network environments. To represent a real-world user request scenario, the Amazon EC2 cloud platform was utilized to deploy multiple client nodes for the experiments. A web portal was developed to integrate the real-time geospatial web services reporting with real-time earthquake related information for spatial policy analysis and collaborative decision-making.

1. Introduction

High population growth, urbanization, and global climate change drive up the frequency of disasters, affecting the safety of people's lives and property worldwide. For example, in China 74% of state capitals and over 62% of counties are located in earthquake risk zones with potential for earthquakes larger than magnitude 7. Additionally, regions with high risk of natural disasters contain half of China's population, who live within 70% of the urban centers where 75% of the national gross domestic product are distributed. Disaster management aims at alleviating the effects of disasters by supporting timely collection of disaster-related data, estimation of damage, evacuation routes planning and effective resource scheduling (Auf der Heide, 2006; McEntire, 2002; Goodchild, 2006; Alinia and Delavar, 2011). More specifically, a management system should be able to coordinate disaster-related data, most of which may be heterogeneous across geographically dispersed government agencies. Also, the system should provide an efficient transmission model for rapid response of end users' spatial information requests. Lastly, the disaster management system should provide a user-friendly, and responsive web portal to facilitate human–computer interaction for successful decision-making purpose.

The emerging geospatial cyberinfrastructure (GCI; Yang et al., 2011) is a promising instrument for building a disaster management system by harnessing tremendous advances in computer hardware, GIS middleware, network and sharable geospatial web services. GCI is a descendent of Spatial Data Infrastructure (SDI). It focuses on providing better organization, integration, computation and visualization of institutionally scattered geospatial resources through the development of computationally efficient middleware. Within the context of GCI or SDI, service-orientation is a well-accepted strategy to improve the integration and exchange of heterogeneous geospatial data (Li et al., 2011). Using an Earthquake study as an example: to study the correlation between the location and magnitude of earthquake events and

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the mortality rate caused by earthquake-induced disasters, location data may come from a vector data model, such as an ESRI shapefile, whereas, the mortality data may cover a continuous surface, in a raster format. A service-oriented approach enables the conversion of various raw data types into a commonly understandable format to improve geospatial interoperability. Some web service solutions, such as Open Geospatial Consortium (OGC) Web Map Service (WMS), enhance remote interoperation by converting raw data into static images. The conversion comes at the cost of losing substantial attribute information from the original data. The OGC Web Feature Service (WFS), in comparison, is capable of preserving actual data, but it generates very large file while serializing the geospatial and attribute data. This leads to a long delay in data transfer in a client–server model. In this paper, we introduce a network transmission model that improves the performance in remote data transfer in a cyberinfrastructure environment by combining multiple data encoding and compression techniques. This model is successfully integrated into a GCI portal for efficient disaster data management.

The rest of the paper is organized as follows: Section 2 reviews recent literature in Cyberinfrastructure and geospatial interoperability. Section 3 describes the architecture of a disaster response system. Section 4 discusses the solution techniques to accelerate geospatial processing in terms of vector data encoding and transmission in a service-oriented cyberinfrastructure environment. Section 5 demonstrates the performance of proposed methods through a series of experiments. Section 6 demonstrates a Graphic User Interface (GUI) for real-time disaster analysis. Finally, Section 7 concludes the work and proposes future research directions.

2. Related work

2.1. Service-oriented geospatial cyberinfrastructure

In a disaster management scenario, the required data (e.g. satellite imagery showing the change before and after a disaster) are often geographically separated from (1) the web server portal on which the data is processed, and (2) where the decision-making takes place. This scenario requires the adoption of a decentralized and interconnected architectural design: distributed geoprocessing capabilities need to be supported and distributed resources should be reused and integrated easily. A service-oriented GCI fits right into this vision (Foster, 2005). However, existing researchers mostly focus on a single aspect of technological advancements in a GCI portal, such as service access, integration or high performance geospatial computing. For example, Li, Yang, and Yang (2010) and Lopez-Pellicer, Florczyk, Béjar, Muro-Medrano, and Zarazaga-Soria (2011) adopted large-scale web crawling to discover scattered geospatial web services to enhance accessibility and to foster better geospatial data usage. Mansourian, Rajabifard, Valadan Zoej, and Williamson (2006), Wei, Santhana-Vannan, and Cook (2009) and Li et al. (2011) proposed implementations of service-based spatial web portal to integrate distributed web services and visualize composite maps from data hosted through these services. Wang, Armstrong, Ni, and Liu (2005), Wei et al. (2006), Yang, Li, Xie, and Zhou (2008), Zhang and Tsou (2009) proposed grid-enabled cyberinfrastructure with a geoportal to speed up computational-intensive tasks. Though local processing performance is greatly improved, these processes are implemented in a standalone application, rather than in widely adopted OGC web services. Therefore their reusability is limited. To address this issue, Wang (2010) proposed a CyberGIS framework to synergize advancement in both cyberinfrastructure and geospatial sciences. Accordingly, this project seeks to provide parallel data processing through standardized geospatial web services.

2.2. Geospatial web services and their performance issues

Geospatial web services, which foster the interoperability among heterogeneous data and computing resources, are a key component of service-oriented GCI (Li, Li, Goodchild, & Anselin, 2013; Li, Goodchild, Anselin, & Weber, 2015). Since the 1990s, a number of government agencies, research institutes, and non-profit organizations have been collaborating to foster interoperability for geospatial data. For example, the standards organization OGC has released a number of specifications allowing uniform requests and exchange of geographic features over the Internet. These service standards have been intensively used to search, analyze, and update crucial disaster related information for disaster management (Weiser & Zipf, 2007). Among over 60 standards, the most widely adopted services are OGC Web Map Service (WMS; de La Beaujardière, 2002) and Web Feature Service (WFS; Vretanos, 2005a). A WMS allows the request of geo-referenced, raster, imagery over the Internet. When a GetMap request arrives at the server side through HTTP (Hypertext Transfer Protocol), a dynamic rendering process is triggered to generate a static image from vector feature data. This process is easier when hosting raw raster data since raster data can be tiled and cached in advance. Once completed, the map image is returned to a client for visualization with other resources, e.g. base maps or images layers. A WFS service, in comparison, allows the retrieval of actual feature data. When a GetFeature request is received by a WFS server, the vector feature geometries are selected (Vretanos, 2005b), encoded usually by the OGC Geographical Markup Language (GML; Cox et al., 2002) and returned to the client. Hence, WFS delivers actual data to the client and allows users to perform spatial analyses in addition to the visual display.

Despite their popularity, WMS and WFS suffer from performance bottlenecks. Performance improvement techniques for OGC WMS have been widely discussed, such as that in Yang, Wong, Yang, Kafatos, and Li (2005), Mikula, Trotts, Stone, and Jones (2007), Baumann (2001), Hu et al. (2010), primary due to its easy implementation and visualization. However, in a WFS environment, the transmission of actual data poses big challenges in making data exchange among WFS servers efficient. Server-side encoding, data transmissions, client-side decoding and client side rendering remain the primary WFS performance bottlenecks. This may be the reason why WFSs have not yet been adopted as widely as WMSs. Zhang, Zhao, and Li (2013) describes a technique to improve the query performance of WFS using a Voronoi diagram indexing and parallel task scheduling. Yang et al. (2011) conducted some preliminary study on encoding data by a binary XML with some compression techniques, which form the basis of this work.

To overcome the WFS performance bottleneck, three research questions arise concerning the implementation of a high performance disaster management system: (1) how can spatial data be efficiently encoded and transmitted to support near real-time, remote data retrieval, (2) is a single pre-defined encoding and transmission strategy suitable for diverse hardware and network environments encountered by users? and (3) what form does an extendable architecture take such that distributed and heterogeneous geospatial services can be seamlessly integrated? In this paper, we will discuss our solution to the above questions toward building a service-oriented high-performance cyberinfrastructure for rapid disaster response and decision-making.

3. Architecture

Fig. 1 demonstrates the service-oriented architecture for disaster management. From bottom to top, a disaster processing system