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Agent-as-a-service-based geospatial service aggregation in the cloud: A case study of flood response

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ABSTRACT

An Agent-as-a-Service (AaaS)-based geospatial service aggregation is proposed to build a more efficient, robust and intelligent geospatial service system in the Cloud for flood emergency response. It involves an AaaS infrastructure, encompassing the mechanisms and algorithms for geospatial Web Processing Service (WPS) generation, geoprocessing and aggregation. The method has the following advantages: 1) it allows separately hosted services and data to work together, avoiding transfers of large volumes of spatial data over the network; 2) it enriches geospatial service resources in the distributed environment by utilizing the agent cloning, migration and service regeneration capabilities of the AaaS, solving issues associated with lack of geospatial services to a certain extent; 3) it enables the migration of services to target nodes to finish a task, strengthening decentralization and enhancing the robustness of geospatial service aggregation; and 4) it helps domain experts and authorities solve interdisciplinary emergency issues using various Agent-generated geospatial services.

1. Introduction

Natural and environmental disasters (flood, earthquake, pollution, and etc.) frequently occur and endanger lives and cause tremendous losses across the globe each year. In China, flood is one of the most frequent and serious disasters because 50% of the population and over 2/3 of the agricultural and industrial products of China come from flood-prone regions (Luo et al., 2007). To save lives and reduce economic losses during flood events, the Flood Control and Drought Relief Office (FCDRO) of the central and provincial governments of China must make rapid, effective and appropriate decisions when responding to these emergencies, such as population evacuation, temporary settlement, dike repair and enhancement, and utilization of flood diversion areas. This decision-making process involves experts and decision makers from various authorities and organizations who are responsible for flood control, agriculture, forestry, water resources and hydrology, land resources, transportation, medical treatment, and disaster relief. Generally, authorities and organizations involved in this decision-making process have domain-specific geospatial data, services, algorithms and models. Traditionally, during flood emergencies, FCDRO must collect and combine all the required data from those sources. Based on the data, the FCDRO organizes all relevant personnel to discuss and evaluate each situation and establish the "best" flood response scheme. The FCDRO will then communicate the appropriate actions that responsible agencies should conduct in a top-down manner. Finally, all responsible parties will conduct the flood control and mitigation actions according to the scheme. Unfortunately, this process is usually time consuming and labor intensive and is not suitable for real-time decision making. Real-time decisions are required when a situation is urgent or when a new situation occurs during the action, requiring an immediate response. In these scenarios, the traditional decision-making process will not allow the FCDRO enough time to develop an effective

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strategy.

An effective disaster prevention and reduction decision support system can assist decision makers in developing rapid and sound decisions during disasters. In the 1990s and early 2000s, many centralized disaster prevention and reduction systems were established to assist decision makers. These systems manually collected required data in advance and stored them in a database. Therefore, it was difficult to acquire the latest distributed geospatial data using these systems. As mentioned above, the most accurate data often belong to professional authorities and organizations, and a lengthy process is required to incorporate data into these systems to support decision making by the FCDRO. Furthermore, these systems are unable to rapidly upgrade to better algorithms or models. Consequently, disaster prevention and reduction systems based on the centralized approach cannot satisfy requirements associated with supporting decision making, notably, during emergencies.

Compared to centralized approach-based systems, disaster prevention and reduction systems based on distributed approaches (e.g., Service Oriented Architecture (SOA)) generally exhibit better capabilities. In SOA-based systems, geospatial resources are retained in distributed nodes, and such systems can use these distributed geospatial resources through standard geospatial services (i.e., Open Geospatial Consortium (OGC) Web Services, including the Web Map Service (WMS), Web Feature Service (WFS), Web Coverage Service (WCS) and Web Processing Service (WPS)). To solve complex tasks, the individual services are typically aggregated into a composite service. In this manner, the distributed geospatial resources can easily be integrated into a disaster prevention and reduction system to support decision making. As a result, the SOA-based method has played a considerable role in supporting decision making over the past decade.

However, in traditional SOA-based systems, all services are built and published in a fixed manner in the webserver, making it difficult to move such services from one server to another. Additionally, it can be challenging or even impossible to automatically migrate services while processes are taking place. As a result, the traditional SOA-based method faces challenges such as the low transfer efficiency of large-volume spatial data and service node failure, which reduce the efficiency and robustness of service aggregation. Moreover, experts from different domains are involved in different phases of emergency and disaster response activities. Traditional SOA-based geospatial service aggregation requires experts from different domains to build individual services. This requirement implies that domain experts must also become familiar with geospatial services (e.g., OGC Web Services specifications), which is typically difficult for experts, especially when issues span multiple disciplines. Thus, it is necessary to take advantage of SOA engineering (Bræk and Melby, 2005; Sawyer, 2005; Usländer et al., 2010) to optimize the SOA-based method, allowing experts to focus on their own domains without having to become geospatial service experts, thereby optimizing the participation of domain experts (Leskens et al., 2014).

Drawbacks of the traditional SOA-based method can be overcome by agents, which are capable of flexible, autonomous actions and migration across different environments to meet designed objectives (Jennings, 2000). Cloud computing highlights the merits of agents, as the Cloud facilitates the configuration of agent environments across a distributed network. This allows agents to migrate and compute autonomously throughout the distributed environment. Cloud- and Agent-based methods can solve several challenges associated with applying the traditional SOA-based method (Tan et al., 2015). However, the agent designed by Tan et al. (2015) communicated in a non-standard manner (e.g., invoking *ResultWFS* and *ResultWCS* services to return results), limiting its capability and applicability. To overcome limitations in existing methods, a new Agent-as-a-Service (AaaS)-based service aggregation method is presented in this paper. This method aims to capitalize on the geoprocessing service capabilities of agents, optimize the efficiency and robustness of composite geospatial services, enrich feasible geospatial service resources in distributed environments, and resolve issues of non-standard communication between agents while promoting the participation of domain experts and authorities. The feasibility of the AaaS-based method is demonstrated and evaluated through a flood response prototype system, which effectively and efficiently helps the decision makers, authorities and domain experts to collaborate together during disaster responding. Moreover, this research also offers new idea and perspective to the existing disaster response mechanisms (Alongi, 2008; Tralli et al., 2005; Quinn and Jacobs, 2007; Dokas et al., 2009; Van et al., 2010; Xu et al., 2014; Kauker et al., 2016) and environmental decision making approaches (Bianconi et al., 2004; Voinov and Bousquet, 2010; Samarasinghe and Strickert, 2013; Rajib et al., 2015).

2. Related work

2.1. Disaster response research

Numerous studies of disaster response (such as for floods, earthquakes, hurricanes, tsunamis, etc.) have been conducted in the past two decades, and many of them are based on centralized GIS systems (Brivio et al., 2002; Thumerer et al., 2000; Lan et al., 2004). Because of the shortcomings of centralized disaster decision support GIS systems, researchers in the geosciences have established Distributed Geographic Information Processing (DGIP)-based methods, such as SOA, Federal Enterprise Architecture (FEA)-based DGIP architecture and spatial service chains (Di, 2004; Di et al., 2006; Zhao et al., 2007, 2009; Yang and Raskin, 2009; Deng and Di, 2009, 2010). New methodologies in information and communications technologies (ICTs) have been used to build early warning systems for tsunami detection (Wächter et al., 2012). A grid-based SOA-supported disaster management mechanism was proposed to solve heterogeneity, distribution, and efficiency issues and further the ability of the government to manage disasters (Chen et al., 2009a,b; Fang et al., 2009). To estimate potential storm damage, an ontology-based distributed geospatial service finding method was proposed to search for services in the distributed environment and apply the services to disaster management (Klien et al., 2006). A flexible SOA-based framework was proposed for environmental crisis management decision support to assist in decision making during emergencies (Vescoukis et al., 2012). Cloud computing and SOA methods were explored to address communication problems among authorities during the emergency rescue process (Lehto et al., 2012). The use of utility Cloud services and SOA in public protection and disaster relief (PPDR) operations has been investigated, and the benefits of the standardized PPDR SOA were evaluated (Rajamäki and Rathod, 2014).

2.2. Geospatial service aggregation

Researchers in computer science have developed service aggregation theories and methodologies (Sivashanmugam et al., 2004; Arpinar et al., 2005; Oh et al., 2007; Hwang et al., 2008; Huang et al., 2009; Hadad et al., 2010). Based on OGC Web Services specifications, studies of spatial service aggregation have been conducted (Di, 2005; Sayar et al., 2005; Di et al., 2006; Yue et al., 2007; Deng and Di, 2010; Yu et al., 2012). Based on OGC Web Services specifications regarding data services (e.g., WMS, WCS, and WFS) (Swain et al., 2015; Sadler et al., 2016) and geoprocessing services (e.g., WPS) (Castronova et al., 2013), service aggregation