Future Generation Computer Systems 28 (2012) 593–604

Contents lists available at SciVerse ScienceDirect

Future Generation Computer Systems

journal homepage: www.elsevier.com/locate/fgcs

A service oriented architecture for decision support systems in environmental crisis management

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ARTICLE INFO

Article history:
Received 14 May 2010
Received in revised form
2 March 2011
Accepted 11 March 2011
Available online 22 March 2011

Keywords:
Environmental modeling
Computer applications
Service oriented architectures
Decision support
Crisis management

ABSTRACT

Efficient management of natural disasters impose great research challenges to the current environmental crisis management systems in terms of both architecture and services. This is mainly due to the fact that a large amount of geospatial content is usually distributed, non-compliant to standards, and needs to be transmitted under a QoS guaranteed framework to support effective decision making either in case of an emergency or in advance planning. Incorporating real time capabilities in Web services, both in terms of dynamic configuration and service selection, is an open research agenda. The things get worst in geospatial context due to the huge amount of data transmitted from distributed sensors under heterogeneous platforms, making the need of synchronization an important issue. In this paper, we propose a flexible service oriented architecture for planning and decision support in environmental crisis management. The suggested architecture uses real time geospatial data sets and 3D presentation tools, integrated with added-value services, such as simulation models for assisting decision making in case of emergency. The proposed architectural framework goes beyond integration and presentation of static spatial data, to include real time middleware that is responsible for selecting the most appropriate method of the available geospatial content and service in order to satisfy the QoS requirements of users and/or application. A case study of a complete, real world implementation of the suggested framework dealing with forest fire crisis management system is also presented.

1. Introduction

The great increase of natural disasters (e.g., forest fires, flooding, landslides) has stimulated a great research interest in developing smart and intelligent Environmental Information Management (EIM) Systems able to collect, process, visualize and interpret geospatial data and workflows of added-value applications so as to support decision making in case of emergency [1]. Natural disasters pose a great threat to people's lives and their properties while they present a negative impact to the economies. However, in order to efficiently handle, forecast, mitigate and prevent such disasters, new open scalable and distributed service platforms need to be created [2]. Such Service Oriented Architectures enable integration of heterogeneous geospatial data of different types and format, real time geospatial data streaming and filtering, as well as incorporation of a plethora of new added-value services that allow, not only mash-ups of geospatial data (useful towards an event-based presentation and prediction), but also simulation of natural phenomena and decision making mechanisms. All these issues are addressed in this paper by proposing a novel Service Oriented Information System proper for Environmental Information Management, as well as for planning and decision support in case of emergency. The proposed architecture is in close collaboration with real world stakeholders in civil protection and environmental crisis management, and has been implemented as a real system, currently into production, use for planning and decision support in forest fire crisis management.

In general, environmental modeling is a time consuming task of high complexity. This task usually requires long iterative processes of mathematical computations along with analysis, reformatting and integration of the heterogeneous geospatial data, generally an arduous task due to the existence of multiple models, formats and protocols [3]. Typical examples of environmental modeling include wild fire dispersion simulation, gas flow simulations, oil spills detection and so on. Such tasks are performed by appropriate models, whose choice is based not only on the performance requirements of each specific case, but also on data processing considerations. The traditional monolithic centralized approaches present a series of disadvantages such as limited scalability, isolation and high cost to integrate geospatial datasets coming from diverse sources and independent entities; emphasis is often given on integrating the disparate information instead of supporting the main objective which is decision making and

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doi:10.1016/j.future.2011.03.010

disaster handling [4]. In other words, when client–server is chosen as the architectural style, quality attributes like performance or maintainability are typically the primary architectural concerns; in the context of SOA, the scope of service pools, the runtime behavior of services, the cooperation with external stakeholders and governance issues become major concerns that need to be dealt with [5], which are key issues in decision making. For this reason, heterogeneous, distributed and scalable service platforms are introduced for environmental modeling [6,7].

The distributed geospatial services and components are integrated using the open framework of Service Oriented Architecture (SOA), or Web services in case of an TCP/IP Internet implementation. Service Oriented Architecture is a flexible set of design principles that enable the development of distributed applications and loosely-coupled solutions whereby service providers advertise the services they offer, and solution providers and software developers access the service repositories to search for suitable services to invoke for a given purpose. Web services is one of the currently available options for the development of a scalable, open, distributed and platform-independent environmental information management system, since it allows for consumption and composition of ready-to-use services, coming from different providers, that they have to be integrated to implement real world applications. Such systems, in their turn, can be available as new services for invocation by end-users or further integration.

Geospatial services are different from the "traditional" computing services, because of the nature of the geospatial information (data) on which they operate [8]. Geospatial data and services are much more complex to integrate due to the variety of existing data models, data formats, data semantics and spatial relationships, which in practice are limiting factors to the interoperability. For this reason, the Open Geospatial Consortium (OGG) [9] has introduced an interface for implementing web services using geospatial data. This interface includes several specifications the most important of which are the Geography Markup Language (GML), the Web Feature Service (WFS) and the Web Map Service (WMS). The Geography Markup Language (GML) is "an XML grammar written in XML Schema for the modeling, transport, and storage of geographic information including both the spatial and non-spatial properties of geographic features" [10]. It is developed as an implementation specification by the Open GIS Consortium to foster data interoperability and exchange between different systems. The WFS is an OpenGIS implementation specification [11] that allows a client to retrieve geospatial data encoded in GML from multiple Web Feature Services. Finally, the Web Map Service Interface Standard (WMS) provides a simple HTTP interface for requesting georegistered map images from one or more distributed geospatial databases [12]. Using these specifications, one can create geospatial service oriented architectures, which retain the main principles of web services using, however, different data description languages able to handle geospatial properties, which are a key element in environmental information management systems.

Another main aspect for an effective environmental information management system is *its real time properties*. In many cases, geospatial information data such as environmental measurements should be transmitted in real time for an efficient decision making. Real time services are data processing or analysis applications exposed as Web Services and connected with each other via a publish/subscribe messaging substrate. Real time data and messages *collected from distributed environmental sensors* are processed using these services. It is clear that real time access in a streaming fashion requires software architectures that are able to fulfill all the performance, availability and reliability requirements of an information management application.

Considering current technology advances, real time sensor measurements are becoming the most popular type of data sources; high spatial density of such sensors which can be achieved as their cost decreases, presents us the requirement to ensure that the capacity to produce and transfer tremendous amount of measurements is available. Such measurements may require more than the processing capacity that "reasonably budgeted" systems can handle. This imposes new challenges in the design principles of a real time geospatial service oriented architecture, since methods for data filtering, visualization and presentation should be incorporated. Processing of huge amounts of data sets requires new architectures due to the large computing resources, network bandwidth, and storage challenges.

Finally, computational methods are used to transform the acquired data to new geospatial datasets that contain new attributes useful for the information management system, such as simulation results. The models can be retrieved from a wide set of available models, using intelligent service selection mechanisms that exploit the current contextual information provided by the real time data sets, together with performance requirements. To do this, context adaptation methodologies are needed not only for the efficient data filtering and simulation model selection, but also for efficient presentation of the geospatial data sets. Although available options are many, integration of all current possibilities in a complete, reliable system with a cost-effective architecture, that can provide added-value services as decision support, remains a challenging research issue.

1.1. Previous works

In geospatial domain Alameh was one of the first attempts at addressing the problem of geospatial service chaining or composition [13], following by other methods, such as the work of [14], where distributed components can be created using Common Object Broker Architecture (CORBA) [15], Remote Method Invocation (RMI), or Web Services technologies, which enable components at different geographic locations to communicate. CORBA based technology for geographical distributed applications has been reported in [16]. However, the CORBA model presents a series of limitations such as difficult implementation. For this reason, OGC Web mapping specifications are currently used in the design and implementation of a environmental crisis management system [9].

Chang and Park present an XML web service model for distributed GIS systems [17]. In this paper, the distributed geospatial service are described as XML web services and integrated by client when necessary. OGC specifications are used for interoperably describing geospatial data. However, still many open interoperability issues arise when different tools from different providers are to integrate together [18]. Risk management issues using service oriented architectures have been reported in [19]. The use of distributed geospatial services in *Digital Earth* have been reported in [20]. In particular this paper uses geospatial information processing (DGIP) methods that enable easy integration of widely distributed geospatial resources. In the same frame [21] proposes a Spatial Data Infrastructure (SDI) framework for creating geospatial services by concentrating all the required functionalities in a single, publicity accessible geospatial component. Finally, [22] presents an evaluation of the OGC web processing services as well as a road map for a future integration. Reusability issues are presented in [3].

The main drawback of all the aforementioned approaches is that they concentrate on an integrating framework for collecting distributed geospatial services but not in a real time framework for geographical information systems by exploiting the principles of the service oriented architecture. These issues are addressed in [23]. A publish/subscribe framework has been introduced in [24] for handling real time geospatial data. Publish/Subscribe is a protocol that produces/declares the topics of interest and subscribes registers for the topics of interest. A sensor