10

Develop a Spatial Decision Support System based on Service-Oriented Architecture

Chuanrong Zhang
Department of Geography and Center for Environmental Sciences and Engineering, University of Connecticut, USA

1. Introduction

A Spatial Decision Support System refers to a computer system that assists decision-makers to generate and evaluate alternative solutions to semi-structured spatial problems through integrating analytical models, spatial data and traditional geoprocessing software so that individuals or groups can make feasible decisions (Armstrong 1993; Densham 1991; Malczewski 1996). It can allow easier decision-making by providing an easy access to geospatial data and analytical models. Many Spatial Decision Support Systems (SDSSs) have been developed for environmental and natural resources decision-making in recent years (e.g., Carver 1999; Jankowski et al, 1997, 2001, 2006; Van Der Perk et al., 2001). However, an important limitation of the SDSS applications is that they are not interoperable. The geospatial data and geoprocessing resources distributed by them cannot be shared and interoperated. While there is an increase in the number of SDSS applications over the past two decades, most of them did not take advantage of the Internet's distributed nature by sharing spatial data and geoprocessing software (Ostländer 2004; Rinner 2003). Several issues prevent the further development of SDSS applications.

One issue is that most SDSSs were developed independently of one another and they are typically standalone systems incapable of sharing and reusing existing data and processing functions. They have their own proprietary system designs, database storage structures, and process models. Thus, it is difficult to communicate and exchange spatial information among these systems, and decision-makers usually cannot integrate data and geoprocessing resources from these systems. Instead of direct integration, they have to spend a lot of money and time on taking a complex procedure to convert the heterogeneous information together. The integration of data and modelling software from disparate sources was beyond the technological capabilities of many potential users (Sengupta & Bennett 2003).

The second issue is the duplication problem caused by current SDSSs' incapability of sharing and reusing existing data and geoprocessing. Because of the lack of interoperability, accessibility and availability of data and information, redundant efforts are commonplace in the development of SDSS applications. While there is a massive increase in the number of SDSS applications over the past two decades, it is often the case that these applications were built with little knowledge of other applications with which they could share information. As a result, many agencies and companies are trying to maintain the databases and

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processing functions that coexist but are not integrated. There are many duplicate data and geoprocessing that occur in separate departments and applications. For example, to make a trip planning decision, a county transit agency may need replicate the street network that is managed by the state highway department and the utility data that is maintained by a local natural resource government agency. The costs attributed to the redundant and duplicated efforts are huge. There is a need to flexibly manage systems and processes and eradicate duplication efforts inside and between different departments and organizations. Further, duplication may cause inconsistency of replicated data.

Thirdly, it is time-consuming to obtain geospatial data when implementing SDSSs. Geospatial data capable of supporting desired analyses often did not exist or was too expensive to acquire (Sengupta & Bennett 2003). Although many geographical databases have been developed, geospatial data sharing and acquisition is still a big problem because of the heterogeneity of existing systems in terms of data modeling concepts, data encoding techniques, storage structures, and other related reasons (Devogele et al. 1998). In order to exchange information and share computational resources among heterogenous systems, conversion tools have to be developed to transfer data from one format into another. However, data conversion is costly and time consuming and may lead to inefficiencies and ineffectiveness in many time-critical decision-making applications, such as real time traffic management, which needs real-time access to diverse data to make quick decisions and take instantaneous actions (Zhang & Li 2005). For the development of a SDSS, the issue of how to aquire data rapidly from different sources becomes important. Decision supports demand that the right information be available at the right time for making the right decision.

Fourthly, while it is recognized that maintaining the most up-to-date geospatial information is important to aid in right decision making, it is difficult to keep consistent updated data in SDSS applications. To facilitate data sharing in SDSS applications, when data are updated at one source the change should be automatically updated in other closely associated applications. However, in current SDSS applications, automatically updating databases from disparate sources produced by different agencies cannot be realized with conventional database management.

Finally, it is costly and time consuming to develop a new SDSS from scratch. Although many small companies and government agencies want to develop SDSSs to make decision-making easier, they cannot afford it because of limited or declining resources. It is often more cost effective to reuse existing data and software via interoperable SDSSs than to develop new databases and custom software. A solution that builds on existing data and geoprocessing rather than starting a new one from scratch is needed. There is an increasing demand for the development of interoperable SDSSs to reuse geographical data and geoprocessing.

The emergence of OGC web services provides a way to overcome the heterogeneity problem of spatial databases and geoprocessing (Peng & Zhang 2004; Zhang et al. 2003a; Zhang & Li 2005). Users can "wrap" existing heterogeneous data into a web service and enable many potential clients to use the service. OGC’s web services represent an evolutionary, standards-based framework that may enable seamless integration of a variety of online geospatial data and geoprocessing (OGC Interoperability Program White Paper, 2001). Power (2003) suggested that the next generation of decision support systems should be primarily service-based. Rinner (2003) and Sugumaran and Sugumaran (2005) proposed web services and the Service-Oriented Architecture (SOA) to be the next generation infrastructure supporting decision-making. Realizing the great potential of web services, researchers began to move towards developing SDSS applications using OGC web services (Bernard et al. 2003; Keßler et al. 2005). In spite of this growing interest, little has been published about how to design and implement a workable interoperable SDSS using OGC web services.

The main objective of this chapter is to propose a framework of web services-based SDSSs for decision-making. The framework enables decision-makers to reuse and integrate geospatial data and geoprocessing from heterogeneous sources across the Internet. Based on the proposed framework, a prototype has been implemented to demonstrate how OGC web services and the SOA overcome the aforementioned issues and contribute to the development of interoperable SDSSs. The implemented prototype addressed how to find and integrate existing heterogeneous data from diverse sources for decision-making.

2. Proposed framework

2.1 Framework structure

A framework for web services-based decision-making system is proposed as shown in Figure 1. The main objectives of the framework are: (a) to enable geospatial data and geoprocessing sharing over the web; (b) to maximize productivity and efficiency with geospatial data and geoprocessing sharing; (c) to overcome data duplication and data maintenance problems; and (d) to make it easy to integrate with other SDSS applications. The framework is based on independent OGC web services and the SOA. It is essentially a collection of OGC web services, which communicate with each other by simple data passing or coordinating some activities.

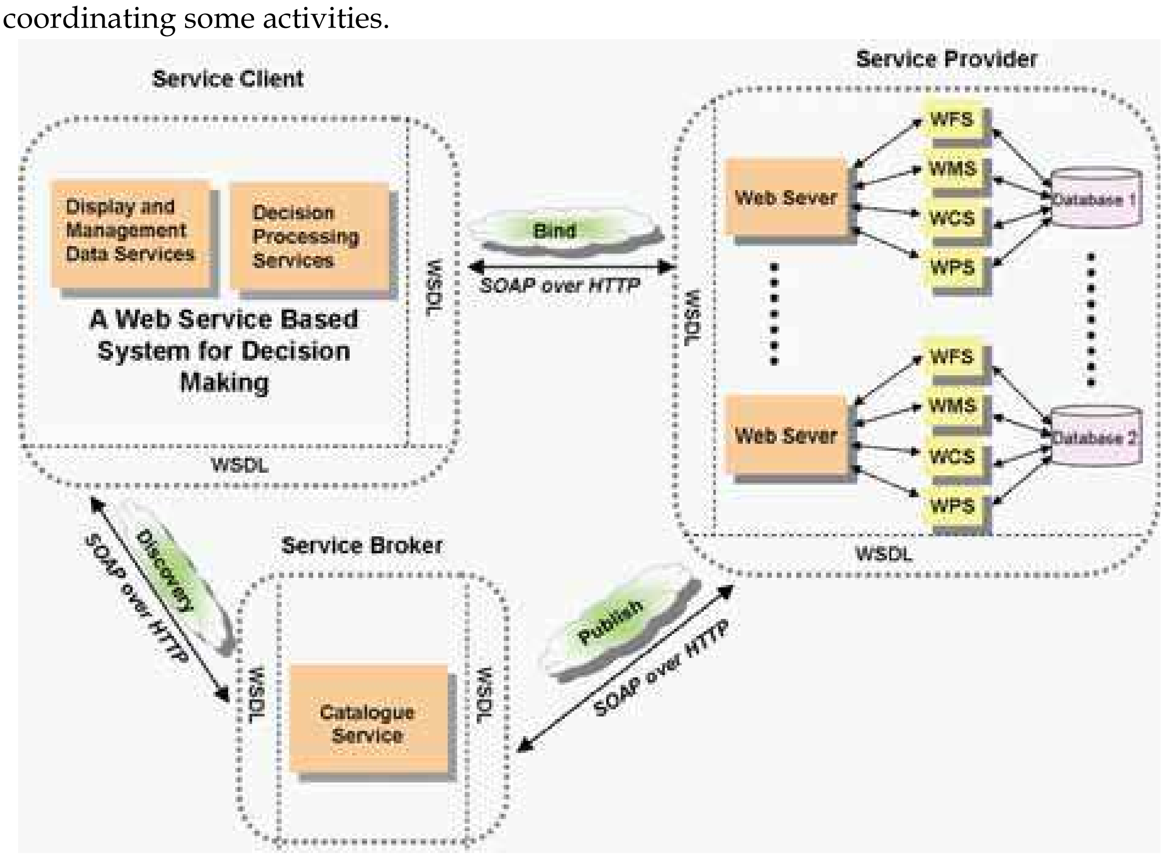


Fig. 1. A framework proposed for web services-based decision-making system.

The framework is composed of three elements: service provider, service broker and service client. Service provider supplies heterogeneous geoprocessing and geospatial data from disparate sources via OGC Web Processing Services (WPS) and data services such as Web Feature Services (WFS), Web Map Services (WMS) and Web Coverage Services (WCS). The OGC data services provide a basis to share spatial data with different data models and from different sources without data conversion. The decision geoprocessing services can be chained to build specific spatial decision support services. Service client helps decision-makers display and manage data services and access decision processing services to generate and evaluate alternative solutions to semi-structured spatial problems. Service client offers an easy interface to allow users to search and integrate geospatial data and geoprocessing from various service providers. Service broker provides a registry for available services. Service broker uses OGC Catalogue Services (CS) to register and manage the data and processing services and allow users to search for these services. Service clients search contents of catalogue services to find the datasets and services of interest, and they also can combine the data or processing services found through catalogue web services. The web services are connected via Web Service Description Language (WSDL) among the service provider, the service broker and the service client. The Simple Object Access Protocol (SOAP) binding over HTTP is employed for communication between web services via the Internet. SOAP essentially provides the envelope for sending web services messages. In general, the proposed framework ensures interoperability through open web services, which offer basic conditions for interoperability by using a standard exchange mechanism between diverse spatial data sources connected over the web.

The main benefit of the proposed framework is its capability of sharing and reusing existing data and geoprocessing from heterogeneous sources across the web. In the framework, different software vendors can be the sources of the data or geoprocessing environments. Decision-makers need not have prior knowledge of the original formats of the data and the original programming language of the geoprocessing. They can transparently exchange and integrate the heterogeneous data and geoprocessing over the web. Thus, the proposed framework may enable many existing proprietary legacy databases or geoprocessing to be reused and shared across application, enterprise, and community boundaries. The SOA employed by the proposed framework allows the system decomposed into several services that enable receiving a system of relatively independent distributed applications. With this loosely coupled nature, the proposed framework permits smart and fast modification of the system's obsolete data and geoprocessing, and quick integration of new data and geoprocessing into the application system, thus enhancing the flexibility in the reuse of geospatial data and geoprocessing. Therefore, it reduces investments in different SDSS applications by avoiding overlapping or repeatedly creating the same data, and leverages an organization's existing investment in data and applications by taking advantage of current resources. Since the solution is based on open standards, it has the potential to be a way of getting to the interoperability. The following sections introduce major concepts in the proposed framework - OGC web services and SOA.

2.2 OGC web services

Web services are described as reusable software components that interact in a loosely coupled environment, and they are designed to interoperate in a loosely-coupled manner. A web service can be discovered and used by other web services, applications, clients, or agents. Web services may be combined or chained to create new services. And they may be recombined, swapped or substituted, or replaced at runtime. Due to the fact that web services are based on XML standards, they are currently being used by enterprises for interoperability. Web services provide the interoperable capability of cross-platform and cross-language in distributed net environments (Anderson & Moreno 2003). As a result, companies may convert their applications to web services to make disparate applications interact.

OGC web services deal with geographic information on the Internet. OGC web services can be grouped into three different categories: data services, processing services and registry or catalog services (Figure 2). Data services are tightly coupled with specific spatial data sets and offer access to customized portions of the spatial data. Examples of data services include WFS (Web Feature Services), WMS (Web Map Services) and WCS (Web Coverage Services). WFS (OGC document 04-094 2005) allow a client to retrieve, query, and manipulate feature-level geospatial data encoded in GML (Geography Markup Language) from multiple sources. They are written in XML (Extensible Markup Language) and use an open-source standard GML (OGC document 02-023r4 2003) to represent features. GML data are stored in a universal format-- text format. Due to the universal format GML data can be easily integrate into other data across a variety of platforms and devices (Zhang et al. 2003a). As a standard data exchange format GML reduces the costly conversion processes among different format databases and can deliver vector data over the Internet (Zhang et al. 2003a). In proprietary systems, such as ESRI's ArcGIS, support of GML in WFS is through a DataStore. The DataStore can transform a proprietary data format such as Shapefile into the GML feature representation. There are two types of WFS - basic and transaction. "Basic" WFS only implement operations for describing and retrieving features over the web, and "transaction" WFS also implement operations for locking and modifying (creating, updating, and deleting) features across the web. One important property of WFS is that they can serve multiple feature types. Different features from different data stores can be integrated with WFS and clients do not realize that the features are retrieved from several sources (Zhang & Li 2005). WMS are capable of creating and displaying maps that come simultaneously from multiple heterogeneous sources in a standard image format such as SVG, PNG, GIF or JPEG (OGC document 04-024 2004). WMS provide three operation protocols: GetCapabilities, GetMap, and GetFeatureInfo. GetCapabilities allows a client to instruct a server to expose its mapping content and processing capabilities and return service level metadata. GetMap enables a client to instruct multiple servers to independently craft "map layers" that have identical spatial reference systems, sizes, scales, and pixel geometries. GetFeatureInfo enables a user to click on a pixel to inquire about the schema and metadata values of the feature(s) represented there. Unlike WFS which enable users to access specific feature DataStores in GML, WMS permit users to display spatial data and produce images of the data rather than to access specific data holdings. WCS provide access to potentially detailed and rich sets of geospatial information in forms that are useful for client-side rendering, multi-valued coverage, and input into scientific models and other clients (OGC document 03-065r6 2003). Rather than static maps (server-rendered pictures), WCS deliver coverage data (e.g. multi-spectral imagery or elevation data) in response to queries from HTTP clients. A WCS client can issue a GetCoverage request to obtain these numeric values for further processing or rendering on behalf of the user. WCS offer one or more layers, just like WMS, but do not render them for the user and therefore do not offer styles.

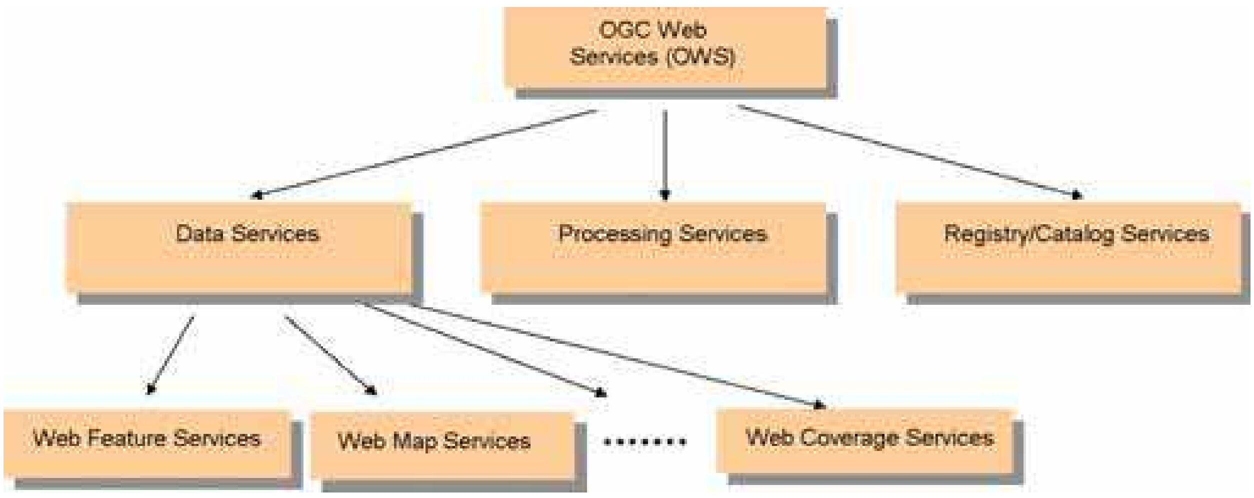


Fig. 2. OGC web services.

OGC WPS provide decision-makers access across the web to decision models that operate on spatially referenced data and help decision-makers achieve a higher effectiveness of decision-making while solving a complex and ill-defined spatial decision problem. WPS have mechanisms to identify the geospatial data required by the decision models, execute the calculation of the models, and manage the output from the calculation so that they can be accessed by the decision-makers. Both vector and raster data can be processed by WPS. The data can include image data formats such as GeoTIFF, or data exchange standards such as GML or Geolinked Data Access Service (GDAS). Three operations are required for a WPS interface (OGC document 05-007r4 2005): GetCapabilities operation allows decision-makers to request and receive back service metadata (or Capabilities) documents that describe the abilities of the implemented decision models; DescribeProcess operation grants decision-makers to request and receive back detailed information about one or more decision model(s) that can be executed, including the input parameters and formats, and the outputs; Execute operation allows decision-makers to run a specified decision model implemented by the processing services, using provided input parameter values and returning the outputs produced. To achieve interoperability, service providers must specify the specific implemented decision models in a separate document called an Application Profile.

OGC Catalog Services allow decision-makers to classify, maintain, register, describe, search and access information about web services. The Catalog Services provide catalogues for the above introduced OGC data services and processing services and support the ability to publish and search collections of descriptive information (metadata) for data, services, and related information objects (OGC document 04-021r2 2004). The essential purpose of a catalogue service is to enable decision-makers to locate, access, and make use of resources in an open, distributed system by providing facilities for retrieving, storing, and managing many kinds of resource descriptions. A catalogue service has two main functions -- discovery and publication. Discovery means that decision-makers seek to find resources of interest through simple browsing or by sophisticated query-driven discovery that specifies simple or advanced search criteria. The catalogue performs the search and returns a result set which contains all registry objects that satisfy the search criteria. OGC Catalog Services support distributed search. When decision-makers perform a distributed search, the request message is forwarded to one or more affiliated catalogues to enlarge the total search space.

In general, OGC web services conceal complexity of heterogeneous geospatial data and geoprocessing. They enable SDSS developers to integrate data and geoprocessing models into their applications without having to host the spatial data locally or build the models completely by themselves, and they also make possible to utilize many valuable existing legacy databases and geoprocessing to develop SDSSs.

2.3 Service oriented architecture

The concept of web service is based on the Service-Oriented Architecture (SOA). A pure architectural definition of SOA might be "an application architecture within which all functions are defined as independent services with well-defined invokable interfaces which can be called in defined sequences to form business processes" (Kishore et al. 2003). In another word, the SOA can be defined as a system in which resources are made available to other participants in the network as independent services that are accessed in a standardized way. The SOA provides for more flexible loose coupling of resources than traditional system architectures. With SOA, applications can access web services through the web without concern how each service is implemented. The interaction among various services in the SOA relies heavily on the standardized interface described by the WSDL and the web communication message protocol SOAP. WSDL defines all of the information necessary to invoke a web service such as what a web service can do, where it resides, and how to invoke it (W3C 2001). The WSDL provides a way for service providers to describe the basic format of web service requests over different protocols or encodings and thus helps improve interoperability between applications (OGC 04-060r1 2004). SOAP messages are encoded using XML and it is a simple XML based protocol for accessing a web service (W3C 2003) and is used for communication between applications running on different operating systems, with different technologies and programming languages.

In the SOA, three components - service provider, service client and service broker work together. A Service Provider publishes services to a Service Broker. A Service Client finds required services using a Service Broker and bind to them. The binding from the Service Client to the Service Provider should loosely couple the service. This means that the service requester has no knowledge of the technical details of the provider's implementation, such as the programming language, deployment platform, and so forth. The SOA aims to improve the ability of organizations to quickly create and reconfigure a SDSS to support new and rapidly changing situations. The key idea is to move away from monolithic systems, towards systems which are designed as a number of interoperable components, for enhanced flexibility and reuse. With SOA, each SDSS application can be built without a priori dependencies on other applications. The services in an application can be added, modified, or replaced without impacting other applications. This results in very agile systems, which can be flexibly adapted to changing requirements and technologies.

3. Prototype implementation

3.1 Prototype

The Lunan Stone Forest, or Shilin, is the World's premier pinnacle karst landscape. Located among the plateau karstlands of Yunnan Province, in southwest China, it is widely recognized as the type example of pinnacle karst, demonstrating greater evolutionary complexity and containing a wider array of karren morphologies than any other example

(Zhang et al. 2003b). The area is designated as a national park covering a protected Shilin area of 350 km2, and is organized into three zones with different protection levels. But no much evaluation work was done when the protected-area boundaries were delimited in 1984. The designation of these boundaries are mainly based on the scenery beautiful values of the Stone Forest Landscape, and it has no relationship with the karst landscape itself or its natural values. Further the boundaries are drawn on a small scale (1:1,000,000) geological map. They almost have no relationship with the topography characteristics such as road, river, topography line, or geological character. Thus, to a great extent it is even difficult for the administrative officials to know the direction of the boundaries and to find out their exact location, not to say for the public and local residents. This brings difficulty to carry out the accordingly conservation regulations.

An web-based SDSS for Lunan Stone Forest Conservation has been developed to provide a way to establish rational protective boundaries based on a variety of environmental and social criteria and render the location of the boundaries clear to the public (Zhang et al. 2005). However, the developed web-based SDSS was based on traditional Client-Server architecture and was implemented using traditional computer technologies such as Visual Basic 6.0, ESRI Mapobjects 2.1 and ESRI Mapobjects IMS 2.0 and ASP (Active Server Pages) (Zhang et al. 2005). Thus it is not an interoperable SDSS and has limitations for share and reuse of geographical data and geoprocessing although it indeed increased the public access to information and involvement in the decision-making processes for protective boundary designation decision-making processes. The objective of this case study is to develop an interoperable SDSS prototype to assist in protective boundary delimitation for Lunan Stone Forest Conservation based on the proposed framework shown in Figure 1. The interoperable SDSS prototype should render the location of the boundaries clear to the public. The prototype also should facilitate share and reuse of heterogeneous geographical data and geoprocessing over the web. The prototype covers several components in the proposed framework, such as using OGC WFS and WMS services to access the heterogeneous spatial data connected to heterogeneous legacy GISystems, using OGC WPS to access the multiple criteria decision model for delimitation of the protected-area boundaries, using OGC CS to register and discover the published WFS, WMS and WPS services, using WSDL as service interface to connect service providers, service brokers and service clients, using SOAP over HTTP for communication between web services over the web. Figure 3 illustrates the architecture of the prototype. The architecture consists of:

1. Data Service providers:
   - ESRI ArcGIS and PostGIS, which provide different format spatial data;
   - Geoserver (http://geoserver.sourceforge.net/html/index.php), an open-source software which enables full implementation of the OGC WFS and WMS specifications and serves ShapeFile and PostGIS data using WFSs and WMSs;
   - Java 2 Platform, Enterprise Edition (J2EE), the supporting environment for GeoServer;
   - Apache HTTP server, which serves as a web server for WFS and WMS;
   - Tomcat, a java servlet container, which provides web developers with a simple consistent mechanism for extending the functionality of a web server and for accessing web application GeoServer.
2. Web process service providers:
   - A Multiple Criteria Decision Model to incorporate the interacting biophysical and social-economic criteria such as geology, geomorphology, soil, vegetation,

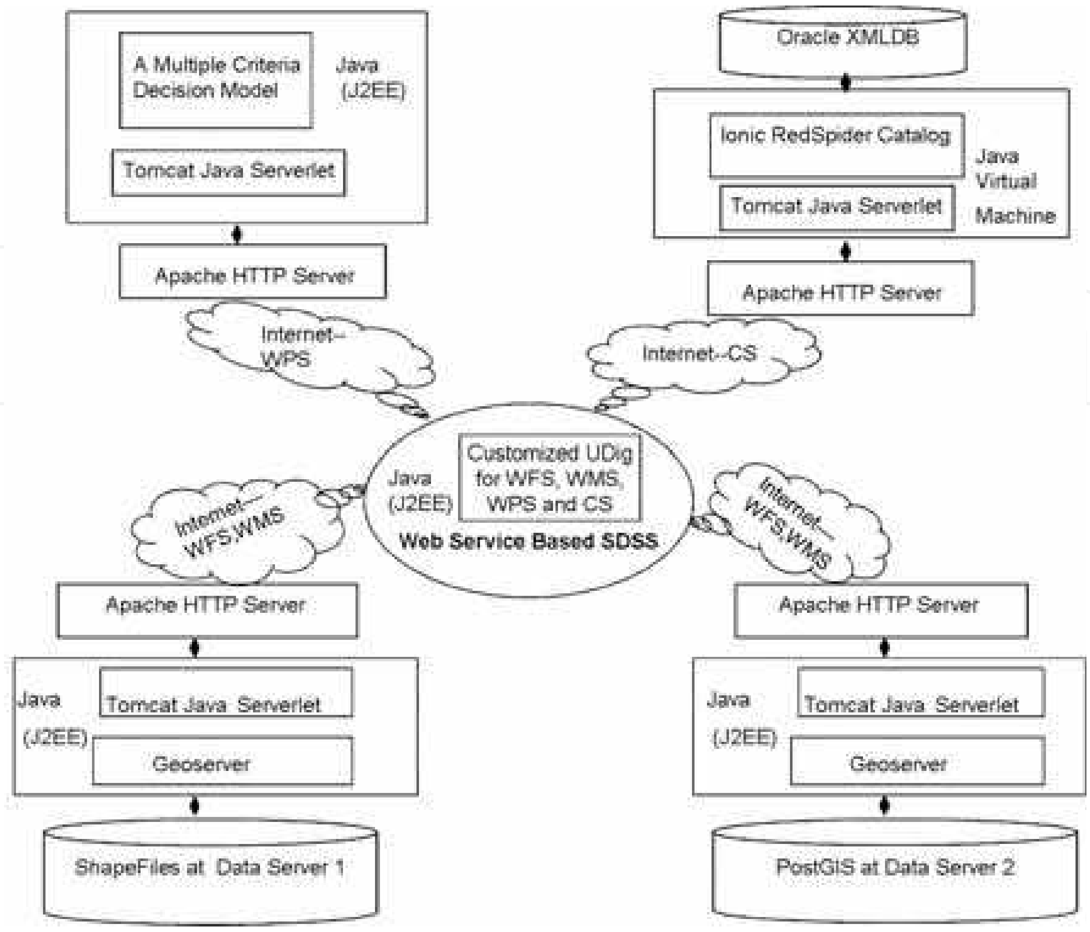


Fig. 3. Architecture of the implemented prototype.

population etc., into the delimitation of the protected-area boundaries, which is implemented as WPS using Java computer programming language;
- Java 2 Platform, Enterprise Edition (J2EE), the underlying developing environment for the Multiple Criteria Decision Model;
- Apache HTTP server, which serves as a web server for WPS;
- Tomcat, a java servlet container, which provides web developers with a simple consistent mechanism for extending the functionality of a web server and for accessing WPS.

3. Service brokers:
   - Ionic RedSpider Catalog software, which allows full implementation of the OGC CS specifications;
   - Oracle XMLDB, which provides capabilities for the storage and management of XML data for Ionic RedSpider Catalog;
   - Apache HTTP Server, which serves as a web server for catalogue services;
   - Tomcat Java Serverlet, which allows for accessing Ionic RedSpider Catalog;
   - Java Virtual Machine, the supporting environment for Ionic RedSpider Catalog.
4. Service clients:
   - Customized UDig software, which provides a user-friendly interface for decision-makers to query and access to web services such as WFS, WMS, WCS and WPS.

The same multiple-criteria decision model applied in the previous web-based SDSS (Zhang et al. 2005) was employed in this prototype but was recoded using Java computer programming language as web processing services. The multi-criteria evaluation approach was widely used in GIS literature (e.g. Carver 1991; Eastman et al. 1993). Among the many ways to integrate decision criteria, the weighted linear combination method is a popular one (Berry 1993; Hopkins 1977; Malczewski 2000) and was used to delimit different protected-area boundaries in this study. To rank the different protection level alternatives, the following formula was used:

$$S = \sum_{i=1}^{n} W_i C_i \tag{1}$$

where S is the suitability score with respect to the protection objective, W_i is the weight of the criterion i, C_i is the criterion score of i, and n is the number of criteria. The model has its own algorithm to make sure that $\Sigma W_i = 1$. By using formula (1), overall protective suitability scores were determined and the whole area was divided into several different level protection zones.

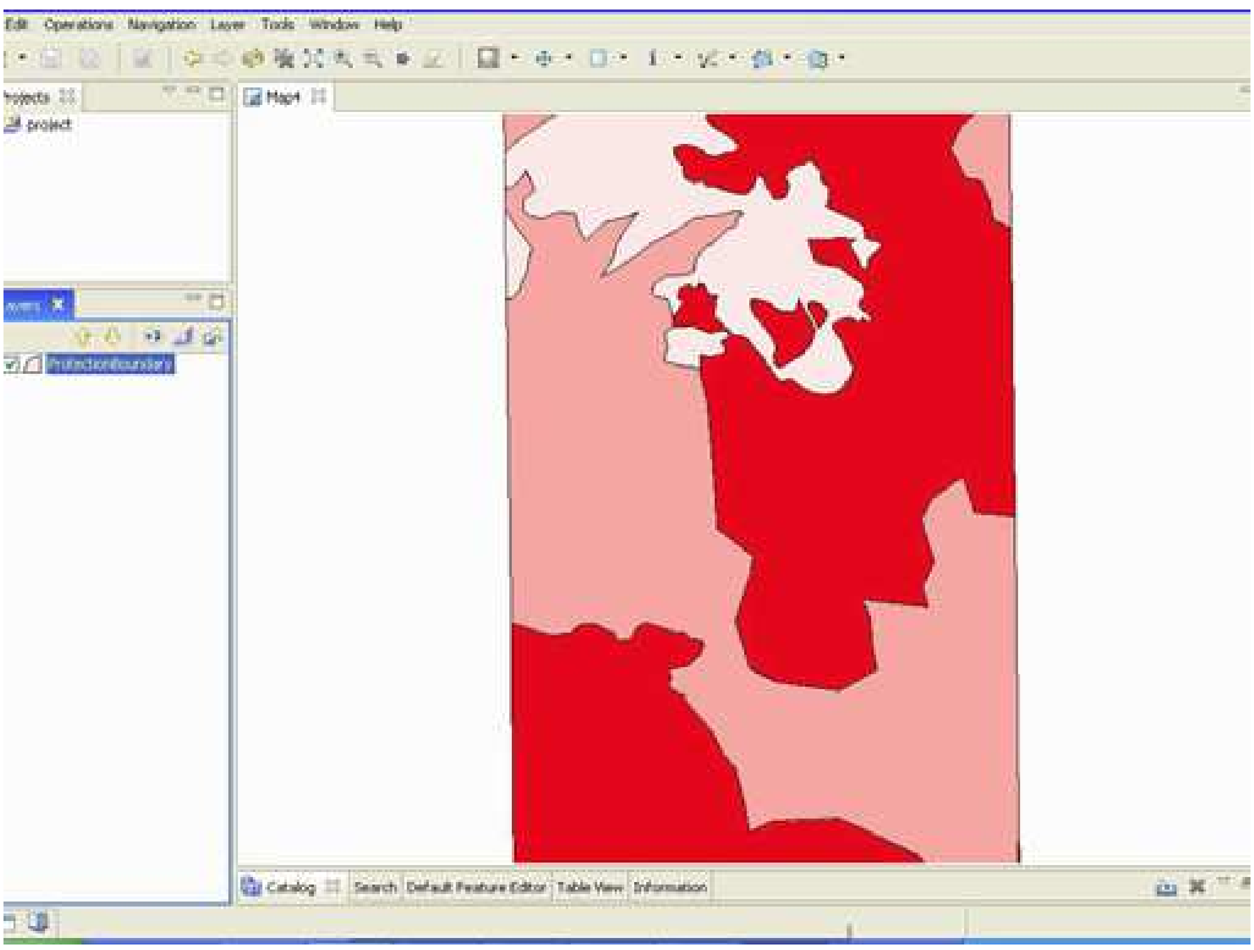


Fig. 4. One scenario of three different level protection areas delimited by using the prototype system.

3.2 Some experimental results

Through the prototype, decision-makers can delimit protective boundaries using the multiple criteria decision model based on a variety of biophysical and social economic criteria by employing OGC WFS, WMS, WPS and CS. Figure 4 shows one scenario of three different level protection areas that was delimited by using the prototype system. Note: in the prototype, the criteria data are stored in two different format databases (Shapfile and PostGIS) on two remote servers (http://140.146.179.29 and http://172.16.1.34). The multiple criteria decision model and the Ionic RedSpider Catalog software are held in the remote server (http://172.16,1.34).

Using the implemented prototype, decision-makers also can render the location of the boundaries clear to the public by aligning them with conspicuous landscape features such as water bodies, roads or buildings via employing WFS, WMS and CS (Figure 5). Note: in Figure 5 lake data (original format is Shapefile) come from the WMS from a remote server (http://172.16.1.34) and road data (original format is ArcSDE) come from the WFS from another remote server (http://140.146.179). The protective boundary data (original format is GML) come from WPS located at the same remote server with lake data (http://172.16.1.34).

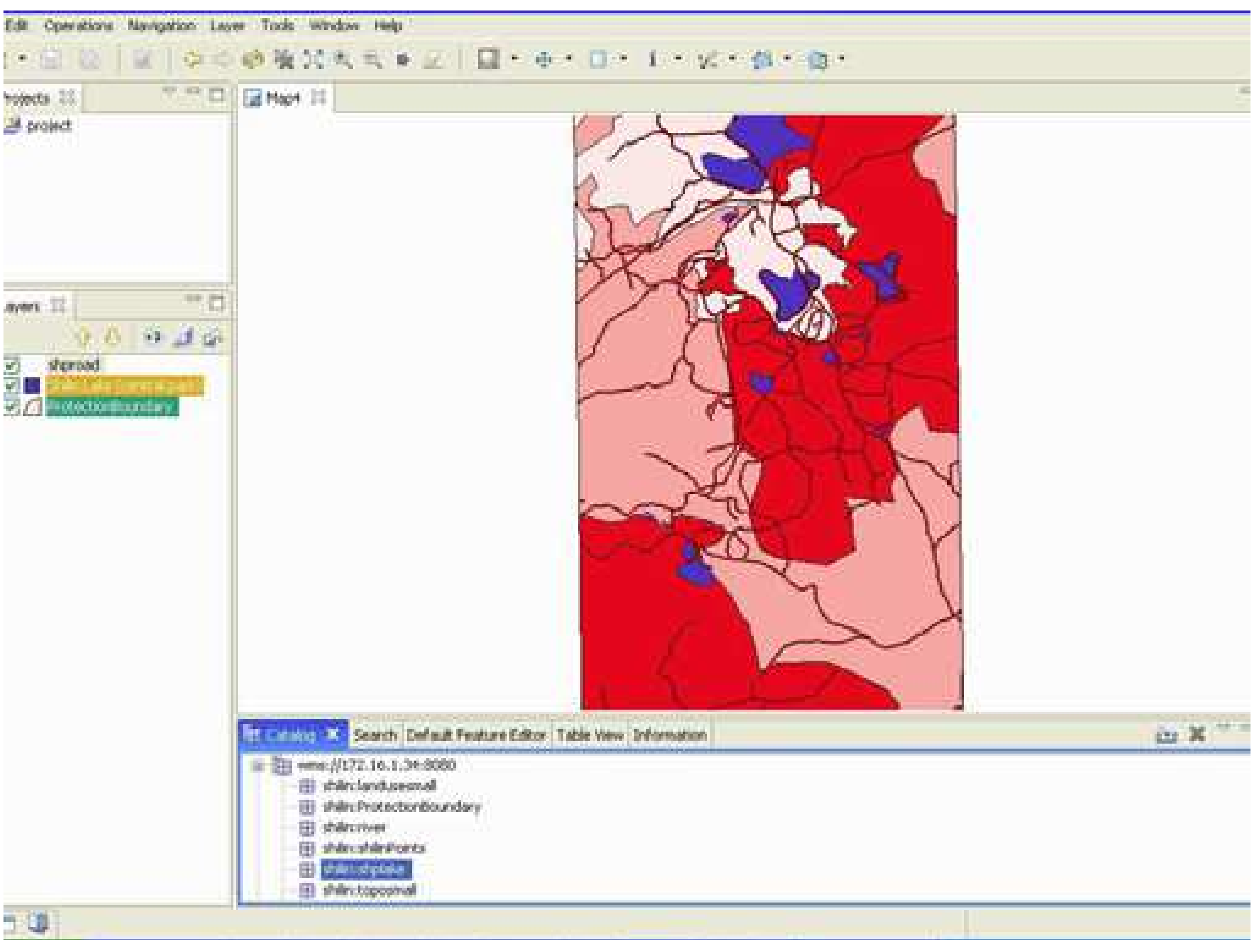


Fig. 5. Roads and lakes overlain on protective areas.

The following experimental results demonstrate some advantages of the web services-based prototype SDSS:

(1) The prototype system provides decision-makers with the ability to access and analyze heterogeneous criteria data in order to make better decisions for protected-area delimitation.

It allows the decision-makers access the heterogeneous criteria data from a variety of sources on the Internet. The criteria data, such as soil, vegetation, hydrology, geomorphology, land use, social and economic data, are stored in different databases with different formats. However, decision-makers can directly access these heterogeneous data sources without having to know specifically who might provide the data they want and the format of the data. They need not contact data providers by email or mail to get the files and convert them into a format they need to start the decision-making task. Figure 6 illustrates seamless and dynamic integration of geology data (original in Shapefile format) located at the data server http://140.146.179.29 and topography data (original in PostGIS databases) located at the data server http://172.16.1.34 by invoking the WFS and WMS services with little or no knowledge about the heterogeneous environments of the data providers. By seamless data integration the web services-based system not only promotes remote access and potential collaborative decision support applications. It also can reduce developing and maintenance costs and minimize data conflicts by avoiding redundant data.

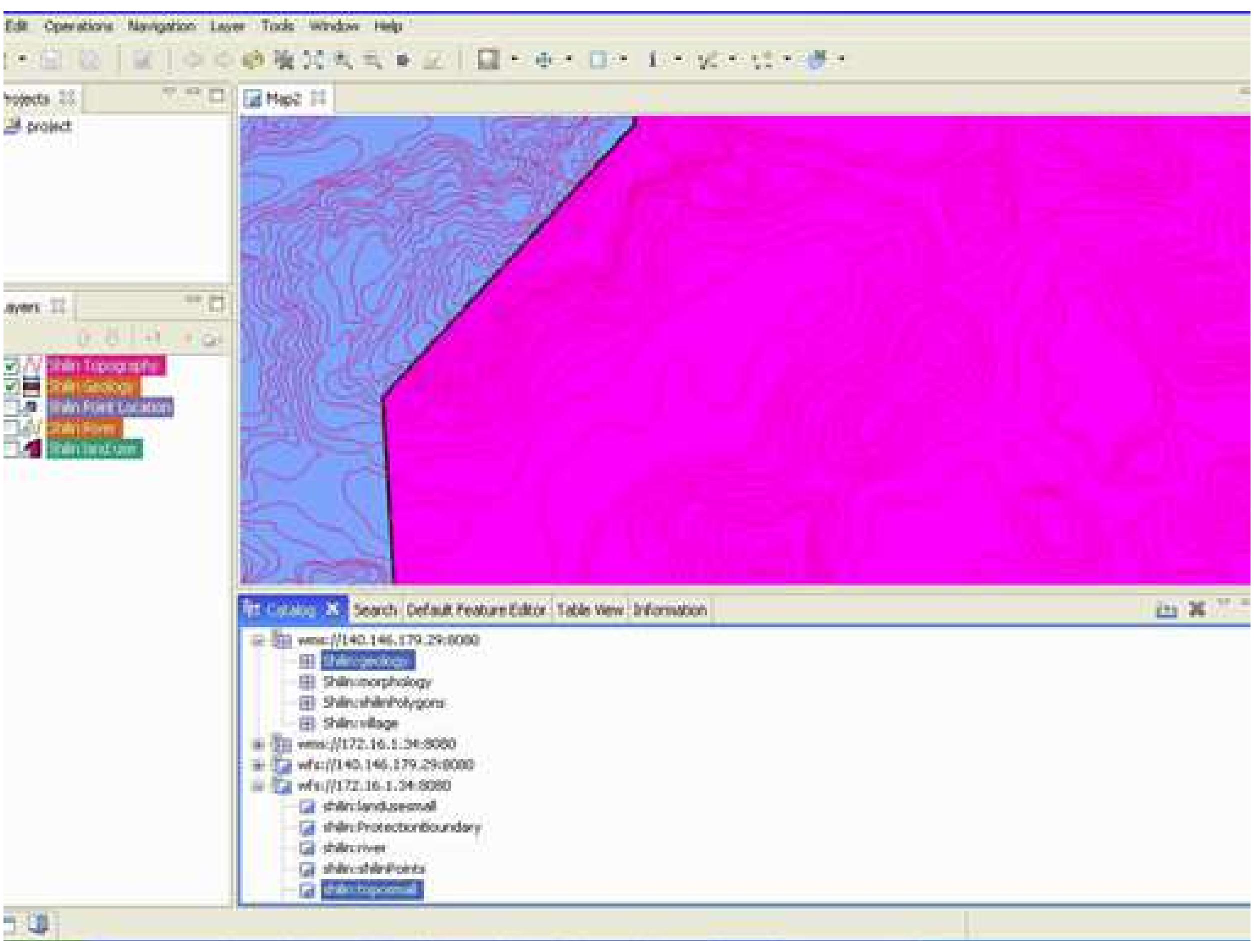


Fig. 6. Integrate different format data from disparate servers by invoking WFS and WMS services.

(2) The prototype system provides decision-makers with the ability of feature-level data search, access, and exchange in real time over the web. In some applications the actual

information needed by the decision-makers may be a subset of the information available. Decision-makers may need only several features of a data file or have interests only in a small area of a data file. Downloading entire datasets or data files will increase the time of data acquisition and analysis and affect the speed of decision-making. Because WFS deliver GML representations of simple geospatial features, decision-makers can access geographic feature data through WFS by submitting a request for just those features that are needed for a decision-making application. Figure 7 shows copy one geology polygon feature (the small polygon referred by two arrows) and paste it in GML format in a WordPad file over the web by WFS. Note: the original geology data format is a shapefile located in a remote data server http://140.146.179.29. The downloaded GML features may serve as input to decision models for small area decision-making processes.

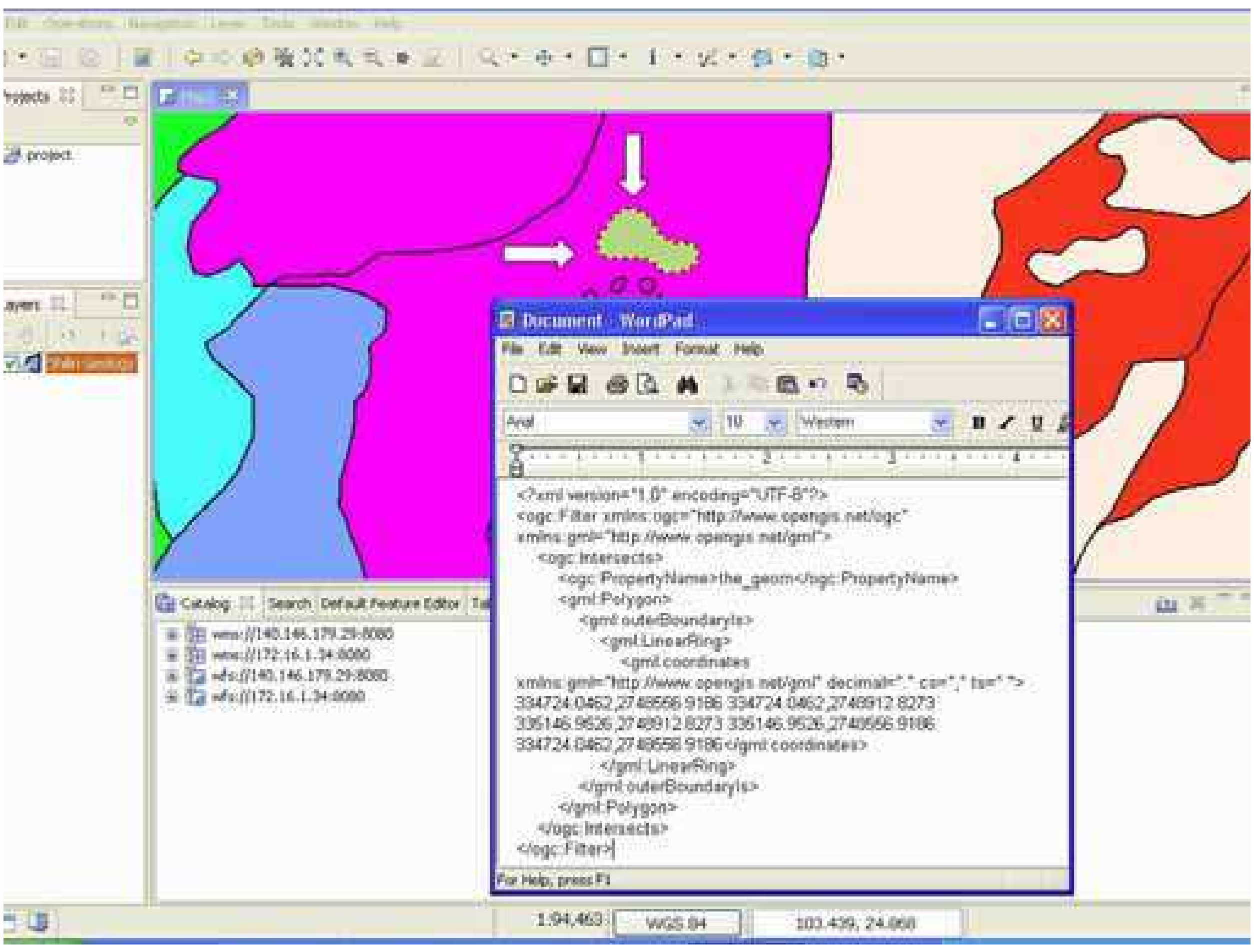


Fig. 7. Copy one geology polygon feature (the small polygon referred by two arrows) and paste it in GML format in a WordPad over the web by WFS.

(3) The prototype system allows decision-makers access the multiple-criteria decision model across the web via WPS. The WPS dynamically conduct spatial data analysis, compute the evaluation value and pass the evaluation results as input to WFS. The input and output data for the implemented WPS is in GML format, which are connected with WFS. Figure 4 displays one scenario of the different level protected-area boundaries calculated by WPS. In

this scenario, the first protection level (dark) covers almost all the limestone pinnacles and the lakes, which are considered by the karst scientist to be of great importance to the landscape; the second protection level (grey) includes nearby forests which have important influences on the local ecosystem; and the third protection level (white) contains less important protection targets including villages, farmlands, and tourism facilities, such as hotels, commercial stores, roads and parking lots. Since the multiple-criteria decision model is employed as web services, it provides the interoperable capability of cross-platform and cross-language and can be accessed and reused by other applications and organizations.
(4) The web services-based prototype system facilitates decision-makers access to the most up-to-date criteria data. With the WFS and WMS data maintenance of the prototype system becomes easy. Because the criteria data reside in the original databases, they are always updated. Unlike traditional SDSSs the data updated from one source have to be delivered or downloaded manually to its applications to maintain the changed data, the web services based prototype system automatically propagates the change or update of data. In the web services-based prototype system developers or decision-makers also can change or update criteria data or alternative solution maps remotely in disparate sources cross the web. They

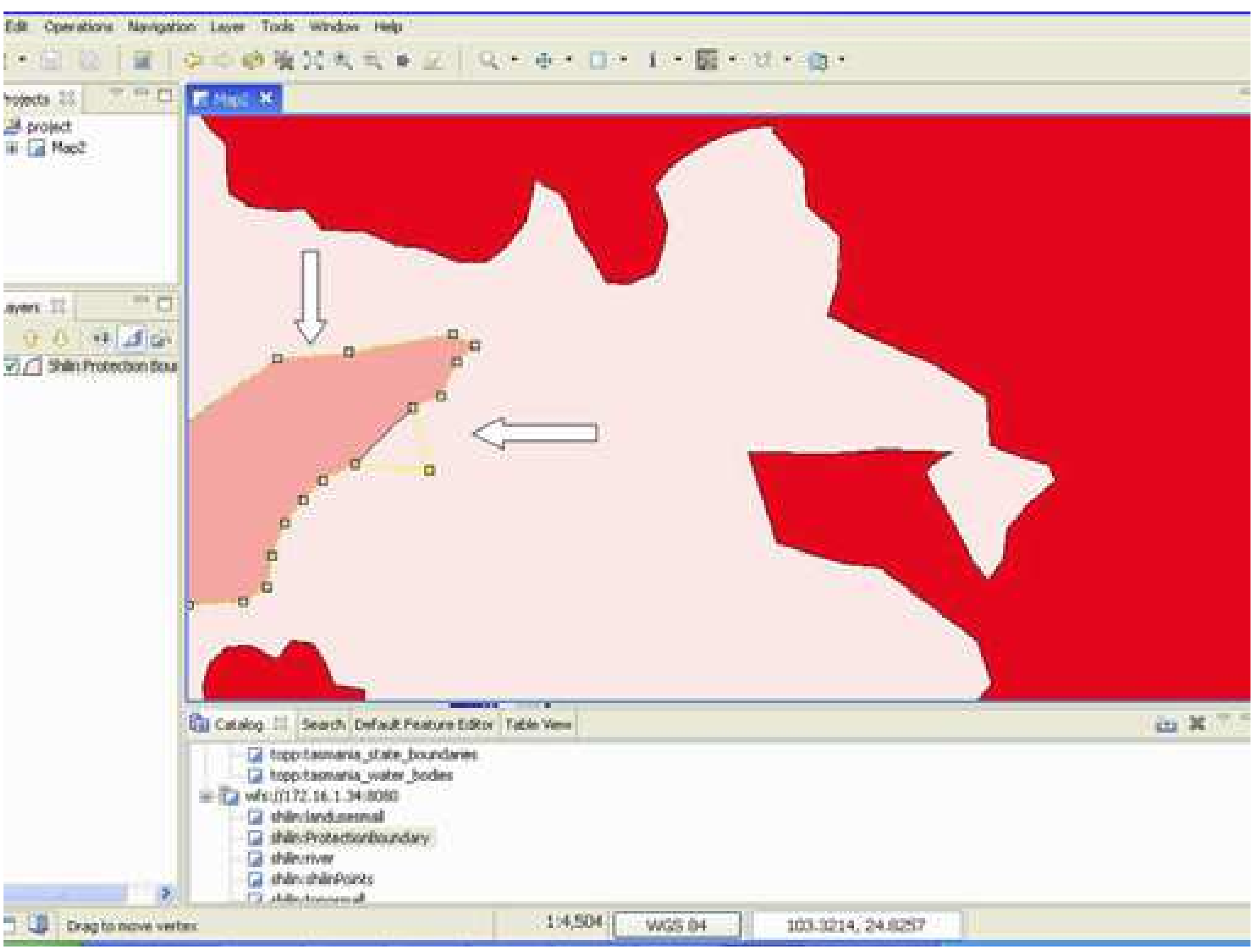


Fig. 8. A decision-maker changes one scenario of protective boundaries created by another decision-maker in a remote server (http://172.16.1.34) over the web.

can create, delete and update geographic features in a remote database over the web using WFS. Figure 8 shows an example that a decision-maker changes one scenario of protective boundaries created by another decision-maker in a remote server (http://172.16.1.34) over the web. Changes to the protective boundaries are instantaneously relayed to other decision-makers and applications. This instant access to the most up-to-date information enables decision-makers avoid the tedious process of transferring data and facilitates the decision-making process. In this way inconsistencies generated by updates are minimized and enterprises collaboration for a specific joint project is supported.

(5) The catalogue services in the implemented prototype system enable decision-makers to dynamically discover and communicate WFS, WMS and WPS with a suitable resource provider. Decision-makers can search needed criteria data for the multiple criteria model from various resource providers in the registry by using keywords. Figure 9 illustrates the query results using keyword “shilin”. All the service providers having “shilin” in their metadata, data or services are listed.

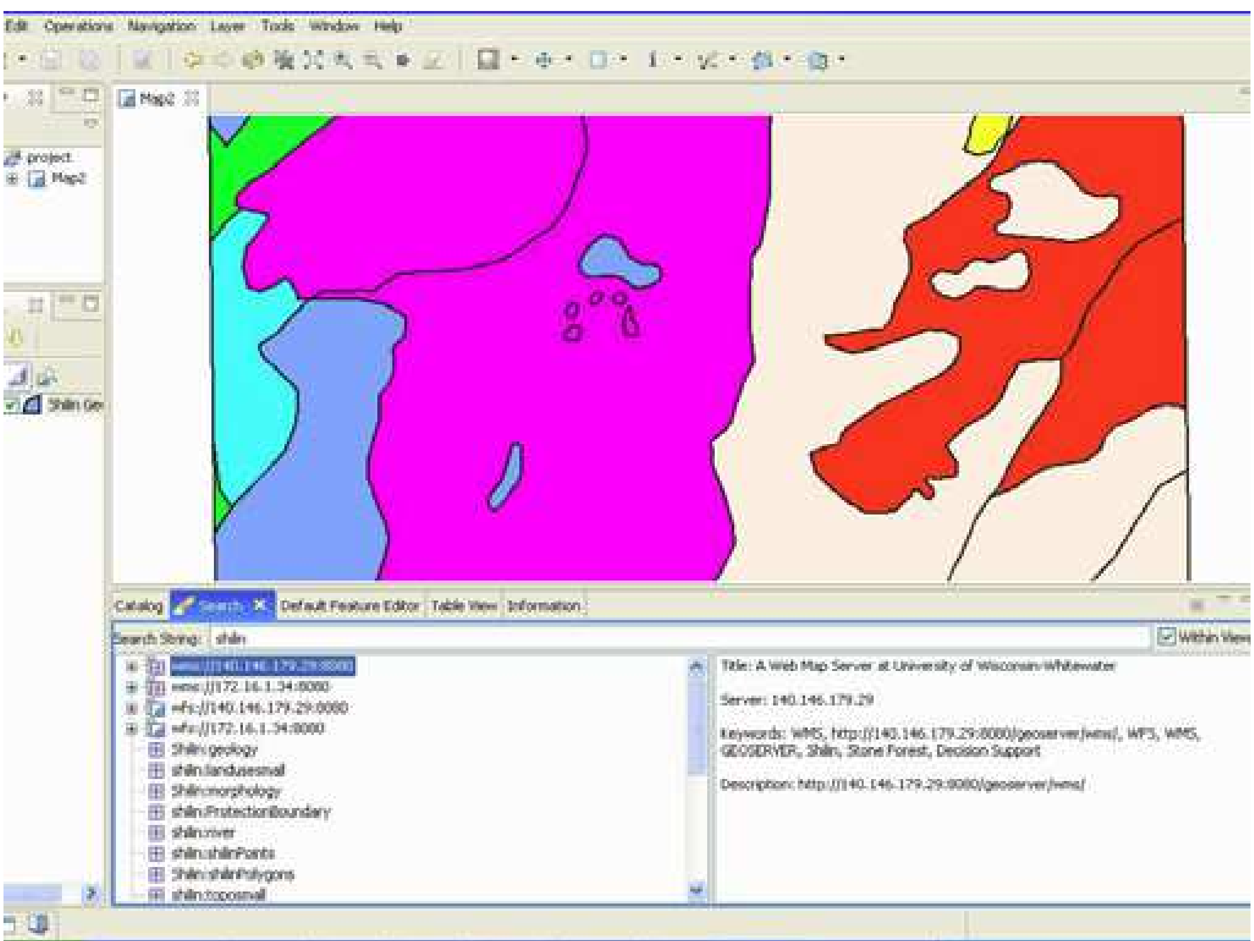


Fig. 9. Query web services using keyword “shilin”.

Besides the aforementioned advantages, the web-services based prototype system has basic GIS functions enabling data investigation. For example, decision-makers can display and overlay different data layers, and can zoom in, zoom out, pan or query the attribute table of these data layers. Also, decision-makers can make different style maps for the WMS and WFS by changing styles inside the system or importing SLD (Style Language Descriptor) files from outside. Figure 10 illustrates different views of the same WFS data by importing different SLD files.

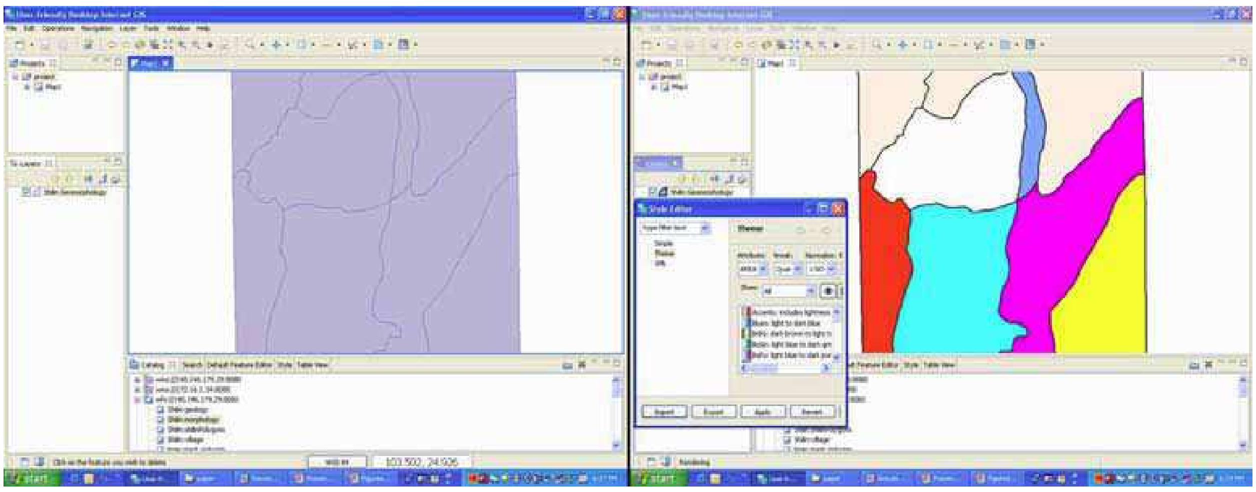


Fig. 10. Different views of the same WFS data by importing different SLD files.

4. Discussions and conclusions

This paper proposed a framework for web services-based spatial decision-making systems. A prototype has been implemented to demonstrate how to build an interoperable SDSS using OGC WFS, WMS, WPS and Catalogue Services based on the SOA. OGC WFS and WMS were used to access the heterogeneous spatial data and WPS were used to access the multiple criteria decision model. OGC Catalog Services were employed to locate geospatial data and processing services wherever they are located, and provide information on the services they find for the decision-makers. Results from the implemented prototype showed that the proposed framework provided an environment for interoperability technically via web services and standard interfaces. Information from any source may serve as input to the decision-making process in such systems. Decision-makers can access necessary geospatial information no matter where it resides, what format it takes and how quickly it changes. By reusing existing heterogeneous data and geoprocessing plus update and maintenance of data remotely across the web, the web services-based system provides a potential way to alleviate duplication problem and reduce related costs.

The proposed framework is particularly useful for organizations with scare resources such as limited time, expertise and finances to implement a SDSS. It is cost effective because it makes easier to distribute geospatial data and applications across platforms, operating systems, and computer language, and SDSS developers can find, access and use the information needed over the web. They no longer have to address the technical side of the SDSS to exploit its value because they do not need to develop and maintain whole databases and geoprocessing by themselves and can integrate existing geospatial data and functionality into their custom applications online.

Although the proposed framework offers the aforementioned advantages, it still has several issues which need further investigation. One issue is semantic interoperability. The proposed framework only resolves technical interoperability via web services and standard interfaces and it cannot resolve semantic heterogeneity problem in composition of web services. None of the XML-based standards such as WSDL and SOAP used by web services provide a means to describe a web service in terms of explicit semantics. Thus web services alone will not be sufficient to develop a real interoperable SDSS. Integration of web services and ontologies may offer a potential solution to the semantic heterogeneity problem. The second issue is performance. The framework uses WFS to deliver spatial vector data in GML format. However, the size of the GML files tends to be large especially when there are a large number of features included. The network and processing overhead associated with GML makes it inefficient for processing and storage performances. More research would greatly benefit from file compression algorithms and highly efficient parsing methods. The third issue is security. Using an identification and authentication that requires users to employ a login authentication may provide the first level of information security access control. One also can use the standard Secure Socket Layer and firewall based rules for security control at the transport level and digital signatures and/or encryption to protect specific parts of an XML/SOAP message at the application level. In addition, the Web Services Security Specification, which provides a complete encryption system, may be employed to add more security features to web services by using methods such as credential exchange, message integrity, and message confidentiality. Except for the three major issues discussed above, other issues such as the privacy issue, copyright issue and the data quality issue also need further study.

5. References

Anderson, G. & Moreno, S.R. (2003). Building web-based spatial information solutions around open specifications and open source software, *Transactions in GIS*, Vol. 7, pp. 447-66

Armstrong, M.P. (1993). Perspectives on the development of group decision support systems for locational problem solving, *Geographical Systems*, Vol.1, pp. 69-81

Bernard, L.; Ostländer, N. & Rinner, C. (2003). Impact Assessment for the Barents Sea Region – A Geodata Infrastructure Approach, *Proceedings of AGILE – 6th Conference on Geographic Information Science*. Lyon, France, pp. 653-661

Berry, J.K. (1993). Cartographic modeling: The analytical capabilities of GIS, In: *Environmental Modeling with GIS*, Goodchild M F, Parks B O and Steyaert L T (ed). New York, Oxford University Press, pp. 58-74

Carver, S.J. (1991). Integrating multi-criteria evaluation with geographic information systems, *International Journal of Geographical Information Systems*, Vol. 5, pp. 321-339

Carver, S.J. (1999). Developing Web-based GIS/MCE: Improving access to data and spatial decision support tools, In: *Spatial Multicriteria decision-making and analysis:*

A geographic information sciences approach, Thill JC(ed) New York, Ashgate, pp. 49-76

Devogele, T.; Parent, C. & Spaccapietra, S. (1998). On spatial database integration, *International Journal of Geographical Information Science*, Vol.12, pp. 335-352

Densham, P.J. (1991). Spatial decision support systems, In: *Geographical Information Systems: Principles and Applications*, Maguire D J, Goodchild M F and Rhind D W (ed) New York, John Wiley and Sons, pp. 403-412

Eastman, J.R. (1993). *IDRISI: A Grid Based Geographic Analysis System Version 4.1*, Worcester, MA: Clark University Graduate School of Geography

Hopkins, L.D.(1977). Methods for generating land suitability maps: A comparative evaluation, *Journal of the American Institute of Planning*, Vol. 43, pp. 386-400

Jankowski, P.; Nyerges, T. L.; Smith, A., Moore, T.J. & Horvath, E. (1997). Spatial group choice: a SDSS tool for collaborative spatial decision making, *International Journal of Geographic Information Science*, Vol.11, pp. 577-602

Jankowski, P.; Andrienko, G.L. & Andrienko, N.V. (2001). Map-Centered Exploratory Approach to Multiple Criteria Spatial Decision Making, *International Journal of Geographical Information Science*, Vol.15, pp. 101-127

Jankowski, P.; Robischon, S.; Tuthill, D.; Nyerges, T. & Ramsey, K. (2006). Design considerations and evaluation of a collaborative, spatio-temporal decision support system, *Transaction in GIS*, Vol.10, pp. 335-354

Keßler, C.; Rinner, C. & Raubal, M. (2005). An Argumentation Map Prototype to Support Decision-Making in Spatial Planning, *Proceedings of AGILE 2005 - 8th Conference on Geographic Information Science*, Toppen F and Painho M (ed). Estoril, Portugal, pp.135-142

Kishore, C.; Kerrie, H. & Edward, T.M. (2003). Migrating to a service-oriented architecture. www document, http://www-128.ibm.com/developerworks/library/ws-migratesoa/

Malczewski. J. (1996). A GIS-based approach to multiple criteria group decision-making, *International Journal of Geographical Information Systems*, Vol. 10, pp. 955-971

Malczewski, J. (2000). On the use of weighted linear combination method in GIS: common and best practice approaches, *Transactions in GIS*, Vol. 4, pp. 5-22

OGC document 02-023r4 (2003). OpenGIS Geography Markup Language (GML) implementation specification, version 3.00, www document, http://www.opengeospatial.org/ specs/?page=specs

OGC document 03-065r6 (2003). Web Coverage Service (WCS), Version 1.0.0. www document, http://www.opengeospatial.org/specs/?page=specs

OGC document 04-021r2 (2004). OpenGIS catalogue service specification, www document, http://www.opengeospatial.org/ specs/?page=specs

OGC document 04-024 (2004). Web Map Service, Version 1.3., www document, http://www.opengeospatial.org/specs/ ?page=specs

OGC document 04-060r1 (2004). OWS 2 Common Architecture: WSDL SOAP UDDI. www document, http://www.opengeospatial.org/ specs/?page=specs

OGC document 04-094 (2005) Web feature service implementation specification, version 1.1.0., www document, http://www.opengeospatial.org/specs/?page=specs

OGC document 05-007r4 (2005). OpenGIS Web Processing Service. www document, http://www.opengeospatial.org/specs/?page=discussion

OGC Interoperability Program White Paper (2001). Introduction to OGC Web Services. www document, http://ip.opengis.org/ows/010526_OWSWhitepaper.doc

Ostländer, N. (2004). Interoperable Services for Web-Based Spatial Decision Support. www document, http://www.agile-secretariat.org/Conference/greece2004/papers/P-13_Ostlander.pdf

Peng, Z.-R. & Zhang, C. (2004). The Roles of Geography Markup Language, Scalable Vector Graphics, and Web Feature Service Specifications in the Development of Internet Geographic Information Systems, *Journal of Geographical Systems*, Vol. 6, pp. 95-116

Power, D.J. (2003). Defining Decision Support Constructs, *Proceedings of the Seventh International Conference on Decision Support Systems (ISDSS'03)*, Ustron, Poland

Rinner, C. (2003). Web-based Spatial Decision Support: Status and Research Directions, *Journal of Geographic Information and Decision Analysis* Vol.7, pp. 14-31

Sengupta, R.R. & Bennett, D.A. (2003). Agent-based modeling environment for spatial decision support, *International Journal of Geographical Information Science* Vol.17, pp. 157-180

Sugumaran, V. & Sugumaran, R. (2005). Web-based Spatial Decision Support System (WebSDSS): Evolution, Architecture, and Challenges. www document, http://mis.temple.edu/sigdss/icis05/fullProgram.htm

Van Der Perk, M.; Burema, J.R.; Burrough, P.A.; Gillett, A.G. & Van Der Meer, M.B. (2001). A GIS-based environmental decision support system to assess the transfer of long-lived radiocaesium through food chains in areas contaminated by the Chernobyl accident, *International Journal of Geographical Information Science*, Vol. 15, pp. 43-64

W3C. (2001). Web Services Description Language (WSDL), 1.1, www document, http://www.w3.org/TR/wsdl

W3C. (2003). SOAP Version 1.2 Part1: Messaging Framework. www document, http://www.w3.org/TR/soap12-part1/

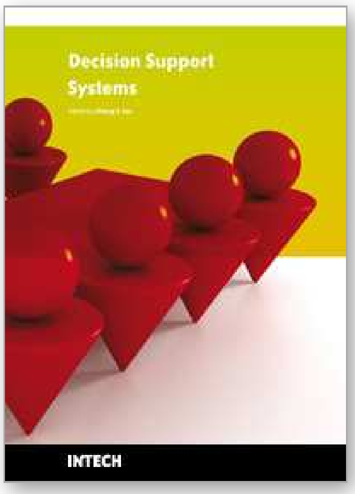
Zhang, C.; Li, W.; Peng, Z.-R. & Day, M. (2003a). GML-based Interoperable Geographical Database, *Cartography* Vol. 32, pp. 1-16

Zhang, C, Day, M. & Li, W. (2003b). Land use and Land Cover Change in the Lunan Stone Forest, China, *Acta Carsologica*, Vol.32, pp. 161-174

Zhang, C. & Li, W. (2005). The Roles of Web Feature Service and Web Map Service in Real Time Geospatial Data Sharing for Time-Critical Applications, *Cartography and Geographic Information Science*, Vol.32, pp. 269-283

Zhang, C.; Li, W. & Day, M. (2005). Towards Establishing Effective Protective Boundaries for the Lunan Stone Forest Using an Online Spatial Decision Support System, *Acta Carsologica*, Vol.34, pp. 178-193

Zhang, C.; Li, W. & Day, M. (2006). Towards Rationalizing Protected-Area Designation in China Using a Web-Based Spatial Decision Support System, *Journal of Spatial Science*, Vol.51, pp.33-46



Decision Support Systems

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Decision support systems (DSS) have evolved over the past four decades from theoretical concepts into real world computerized applications. DSS architecture contains three key components: knowledge base, computerized model, and user interface. DSS simulate cognitive decision-making functions of humans based on artificial intelligence methodologies (including expert systems, data mining, machine learning, connectionism, logistical reasoning, etc.) in order to perform decision support functions. The applications of DSS cover many domains, ranging from aviation monitoring, transportation safety, clinical diagnosis, weather forecast, business management to internet search strategy. By combining knowledge bases with inference rules, DSS are able to provide suggestions to end users to improve decisions and outcomes. This book is written as a textbook so that it can be used in formal courses examining decision support systems. It may be used by both undergraduate and graduate students from diverse computer-related fields. It will also be of value to established professionals as a text for self-study or for reference.

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InTech Europe
University Campus STeP Ri
Slavka Krautzeka 83/A
51000 Rijeka, Croatia
Phone: +385 (51) 770 447
Fax: +385 (51) 686 166
www.intechopen.com

InTech China
Unit 405, Office Block, Hotel Equatorial Shanghai
No.65, Yan An Road (West), Shanghai, 200040, China
中国上海市延安西路65号上海国际贵都大饭店办公楼405单元
Phone: +86-21-62489820
Fax: +86-21-62489821