The Design of Scalable Web GIS Microservice Framework for Undergraduate Education

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ABSTRACT:

As an interdisciplinary integration of GIS theory and network technology, Web GIS is of great significance for the comprehensive development of students' GIS capability. Therefore, this paper targets undergraduate GIS education and presents a novel approach to designing a scalable Web GIS microservices framework, which consists of three essential components: scalable Web GIS microservices using RESTful APIs, scalable geographic data source provider using PostGIS, and scalable Web mapping and symbolization using JavaScript. In the GIS practice, students are expected to utilize Python, PostGIS, and JavaScript programming languages to develop RESTful microservice APIs, access geographic data, and perform mapping and symbolization using Web browser. Furthermore, they are encouraged to adjust the workload of GIS spatial analysis and algorithms based on the needs of the development environment, and implement different GIS applications. Ultimately, by guiding students to use this framework and participate in GIS practice, the aim of improving their GIS capability is achieved. The experimental results show that through the design and practice of the scalable Web GIS microservices framework, the relevant contents of Web GIS, GIS Software Development, GIS Principle, GIS Algorithm, and GeoDatabase courses are integrated. Students participate in GIS practice in various forms, such as open experiments, innovation projects, and professional competitions, which enhance their GIS capability at the undergraduate level and achieve favorable results.

1. INTRODUCTION

Geographic Information Science (referred to as GIS) is a discipline on the theory and method of geographic data management, spatial analysis, visualization and mapping, etc., which is comprised of a bundle of GIS algorithms and tools [1-4]. With the rapid development of internet technologies, GIS is extended with wings of the Web and become "Web GIS" [5-6], which has dramatically prompted the socialized development of GIS, and makes it accessible from GIS experts to common users [7-9]. With the development of service-oriented architecture (referred to as SOA), web-based applications are becoming more and more widespread, among them is the Web-based GIS service [10-11]. The Open Geospatial Consortium (referred to as OGC) has specifically proposed a series of map service standards, including Web Mapping Service (referred to as WMS), Web Feature Service (referred to as WFS), Web Processing Service (referred to as WPS), etc., which have become industry standards for Web GIS services [11-12]. In terms of Web GIS services, REpresentational State Transfer (referred to as REST) Web GIS services have the advantages of lightweight, simple, and efficient, and can be built scalable Web GIS services and applications [11]. Moreover, the use of RESTful Web GIS services allows for the implementation of complex visualization and processing, such as Web Mapping and spatial analysis, using an Internet browser [13-14]. Spatial Database Engine (referred to as SDE) has been developed for traditional databases like PostGIS, enabling general spatial operations and creating the GeoDatabase [14-15]. With the rapid development of Web GIS, it has become essential to master GIS tools and programming skills to implement Web GIS services and further promote the socialization and popularization of GIS development [8, 12]. Therefore, helping people to acquire GIS capability and master GIS skills to solve geographic problems in social lives has become an urgent issue, especially in undergraduate education. However, the current GIS education system often focuses solely on building comprehensive GIS knowledge and training software skills [1-2]. This lack of integration among multiple courses results in insufficient logical coherence in the knowledge system, inadequate practical hands-on abilities, and a lack of integration between multiple courses in students' GIS scientific system training from theory to practice [4, 8]. Additionally, students often struggle to understand and master the logical relationships between each GIS course, hindering their ability to transition from GIS learning to GIS practice.

To address the issue, a scalable Web GIS microservice framework is designed for undergraduate education, which is aimed to instruct students in GIS practices of multi-courses, including Web GIS, GIS Software Development, GIS Principle, GIS Algorithm, and GeoDatabase. Through the GIS practice, students are expected to gain an understanding of the inter-relationship between different courses within GIS disciplines, build a cognitive process from theory to application, and develop practical abilities and problem-solving skills.

2. SCALABLE FRAMEWORK DESIGN

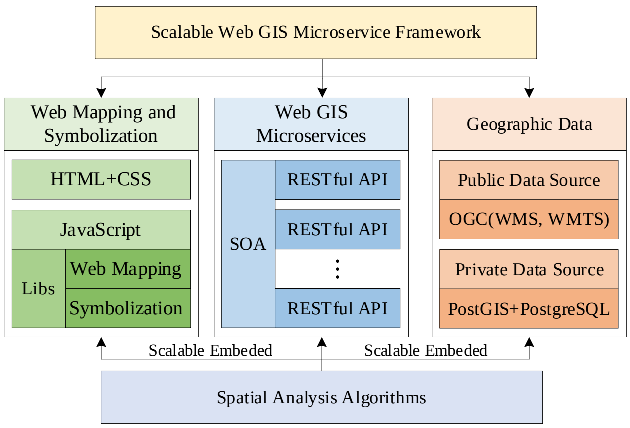


Figure 1. The scalable Web GIS microservice framework

The Scalable Web GIS microservice framework is intended to conduct the GIS query and spatial analysis by mashup several different data sources, ranging from the private data source to public data provider (for example, the Open Street Map, referred to as OSM), and provide the visualization of the geographic dataset in the Web browser. Using SOA, GIS algorithms are encapsulated as isolated GIS microservices, and the GIS dataset is treated as a resource according to the REST standard. The framework is composed of following three modules, as depicted in Figure 1.

2.1 Scalable Web GIS microservices using RESTful APIs

Based on the Model-View-Controller (referred to as MVC) pattern, GIS data is isolated from Web browser, and GIS operations on GIS data is conducted by the Controller at the Web server. GIS data stored in the GeoDatabase is accessed via the Model, while the operation result is returned to the browser as the View. To make services independent to specific applications and more accessible to invoke, the Web GIS service is further packaged as a microservice and encapsulated as RESTful APIs. Hence, as independent scripts, different GIS spatial analysis algorithms are scalable embedded in each microservice. When invoked by parameters from browser, then GIS Web services are called via the RESTful APIs, and can be scalable assembled with different requirements. In addition, Web GIS microservices can also be scalable deployed at different physical machines in a distributed network environment. Details of the scalable Web GIS microservices are illustrated in Figure 2.

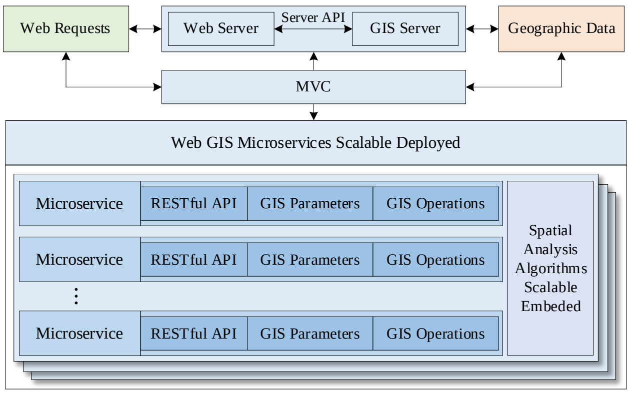


Figure 2. Scalable Web GIS microservices using RESTful APIs

2.2 Scalable geographic data source provider using PostGIS

The geographic data typically consists of spatial and semantic information, whose semantic information can be stored in the traditional relational database, and spatial information needs to be stored in the spatial database. In the design of scale framework, the geographic data source for each Web GIS microservice is provided by the PostGIS, which is further connected to the PostgreSQL database. The spatial information is provided by the scalable geographic data source, processed by the GIS algorithms in Web GIS microservice, and returned to the browser in JSON format. Besides, since GIS extensions have already been included in PostGIS, some spatial analysis operations, such as buffer analysis and overlap analysis, can be scalable implemented via the PostGIS. In addition, the geographic data source can also be deployed at different physical machines, using the feature of distributed geographic databases. Details of the scalable geographic data source provider are illustrated in Figure 3.

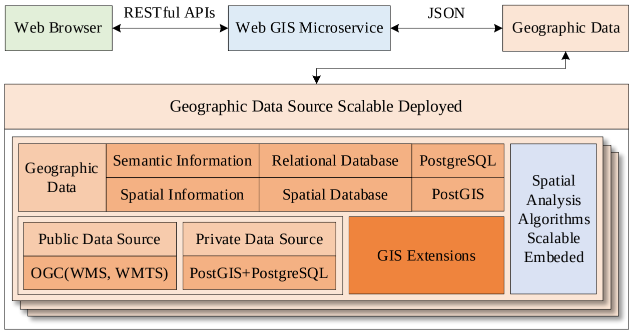


Figure 3. Scalable geographic data source provider using PostGIS

2.3 Scalable Web mapping and symbolization using JavaScript

The geographic data transported to the Web browser can be processed in different ways. The base map is usually provided by the public data source, such as WMS, WMST from OSM, Google Map, and can be visualized directly using JavaScript. While the thematic map provided by the private data source, as the aforementioned scalable geographic data source, is hosted locally or from remote private server, and this kind of data source needs to be further processed with some spatial analysis operations. In the design of scalable Web GIS microservice framework, private geographic data acquired from Web GIS microservice is transported to the Web browser, and the data is further processed and visualized with JavaScript libraries, such as Leaflet, OpenLayers, and D3. Additionally, with different kinds of JavaScript libraries, GIS spatial analysis operations can be conducted in the Web browser, making it scalable to mashup various GIS features on demands, for example, Web mapping and thematic symbolization. Details of the scalable Web mapping and symbolization are illustrated in Figure 4.

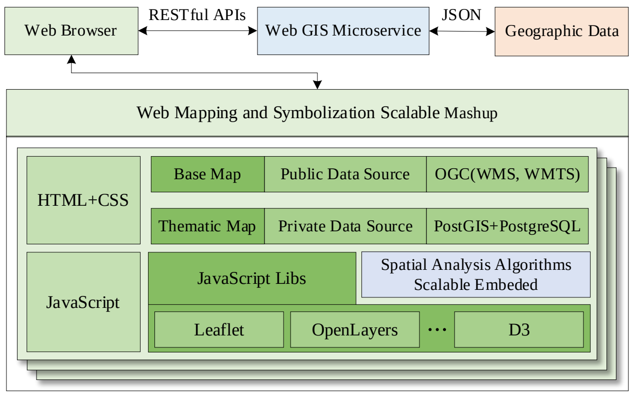
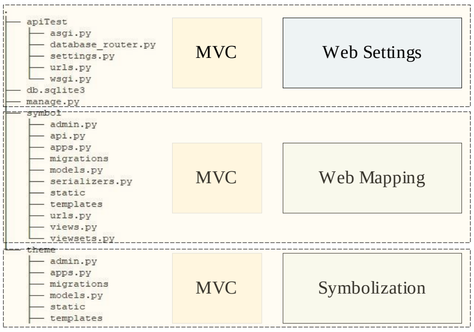


Figure 4. Scalable Web mapping and symbolization using JavaScript

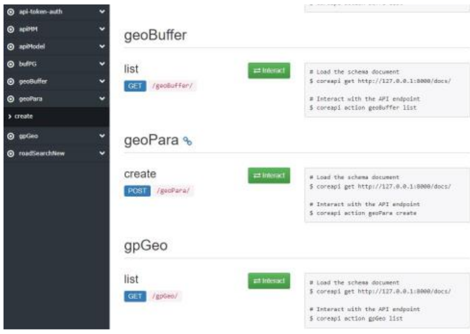
3. EXPERIMENTS AND DISCUSSIONS

To improve the GIS capability of undergraduate students, experiments are conducted using the Scalable Web GIS microservice framework, which is designed and implemented in GIS practices. Students are required to design Web GIS microservices using the Python Django framework, develop RESTful GIS APIs, access geographic data sources using PostGIS, and visualize geographic information through web mapping and symbolization using JavaScript. Development structure of the framework is depicted in Figure 5(a).

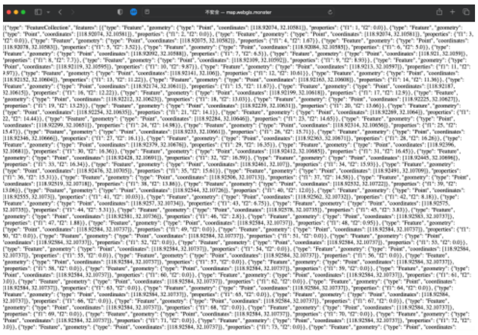
3.1 implement of the scale Web GIS microservice framework



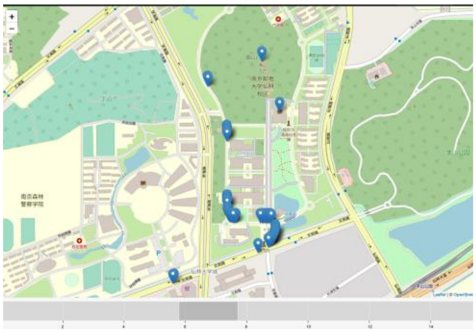
(a) development structure of the framework



(b) RESTful APIs by microservices



(c) JSON data provided by Geodatabase



(d) Web mapping and visualization

Figure 5. Implement of the scale Web GIS microservice framework

Based on the design, the scale Web GIS microservice framework is implemented in three aspects:

(1) microservices using RESTful APIs.

Web GIS microservices are implemented using the Python Django framework, based on the MVC pattern. The geographic data accessed in Django is designed as the Model and processed by the Controller. GIS spatial analysis algorithms are programmed using Python and embedded into the Controller. To invoke the RESTful APIs, requests from the web browser are conducted in the View. Finally, the Web GIS microservice is deployed using Nginx, based on Web Server Gateway Interface (referred to as WSGI). Moreover, API documents are generated to illustrate the specific usage of each API, as depicted in Figure 5(b). To make the Web GIS service independent, RESTful APIs using Python Django are further packaged using Docker, which can be scalable deployed with different loads and environments.

(2) data source provider using PostGIS

While thematic information is predefined by the public data provider, spatial analysis operations are conducted using the private data source provider, which is hosted at the local physical machine or remote private server. The private data source is stored in GeoDatabase, which is hosted by the PostgreSQL with PostGIS as the SDE. Since the spatial extension has been assembled in PostgreSQL, spatial analysis operations can be conducted using SQL queries. Hence, with database connections stored in the configuration of Python Django, requests from the Web browser can be transformed into SQL queries and operated on the GeoDatabase. In addition, some simple data source can be just stored as isolated file and processed directly by the Django Controller. The sample application via JSON data is depicted in Figure 5(c).

(3) Web mapping and symbolization using JavaScript

Request for different GIS operations are sent from the Web browser based on RESTful APIs, and operations are completed using JavaScript. The geographic data is further visualized using JavaScript, with different JavaScript libraries, such as Leaflet, OpenLayers, D3, etc. What's more, various GIS spatial analysis algorithms, including buffer analysis, shortest path analysis, spatial interpolation analysis, etc., are implemented in these JavaScript libraries. Therefore, GIS operations can be scalable deployed on the Web browser. In addition, with the abundant visualization features and multimedia mashup ability provided by the JavaScript libraries, geographic data can be visualized in different kinds of themes, for example, color-rendered map. The sample application using different data sources is depicted in Figure 5(d).

3.2 GIS practices conducted based on the framework

Specific GIS trainings are conducted in the form of open experiment, in-course experiment, concentrated practice, innovation ability cultivation program, graduation design, and different kinds of awards are achieved by students. The goal of these practices is to improve GIS capability for undergraduate education, and the process is as follows:

(1) open experiment. This is the bottom level of the practice and aims to pre-build the general impression of Web GIS, which is with few difficulties. Students are instructed to visit different Web GIS websites, and invoke the Web mapping and symbolization tools provided by public GIS data providers. During the practice, the process of Web GS microservice framework is illustrated in different sections, from the GeoDatabase, RESTful Web GIS service, to Web GIS applications.

(2) in-course experiment. This level of GIS practice is conducted after the open experiment, and operated during the Web GIS learning process. With the pre-build impression of Web GIS, students have already been familiar with background and have a

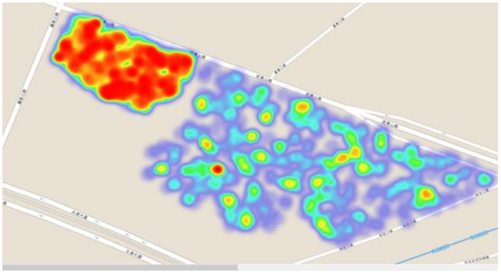
better understanding of related GIS courses. Hence, difficulties at this level are improved, and students are required to finish each part of the Web GIS microservice framework with few programming tasks, based on the prepared instructions.

(3) concentrated practice. This level of GIS practice aims to build a comprehensive understanding of GIS course system, and conducted after the course learning of Web GIS. Knowledge of Web GIS, GIS Software Development, GIS Principle, GIS Algorithm, and GeoDatabase are thoroughly invoked, since students are required to build a complete scalable Web GIS microservice framework with all kinds of GIS features, such as geographic data collection, data storage, spatial analysis, data modeling and visualization. What's more, GIS spatial analysis algorithms are encouraged to be implemented and embedded into the framework.

(4) innovation ability cultivation program. The difficulty of the practice keeps increasing, and this level aims to integrate all related GIS skills in GIS innovation ability cultivation. Students are encouraged to design a thematic GIS system based on the scalable Web GIS microservice framework, with the specific purpose of solving a real-world problem, for example, design a story description system by combining public data source and private data source.

(5) graduation design. This is the highest level of the practice and aims to build a comprehensive understanding of the undergraduate GIS education. Not only the scalable Web GIS microservice framework, students are encouraged to build a complete system and solve a real problem, without any instruction or cookbook. Hence, students have to design the GeoDatabase and create spatial constraints, complete the programming using different programming languages, design the Web mapping and symbolization, and even propose a new geographic model.

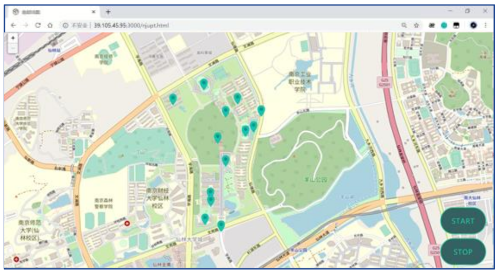
During the last three years, the GIS practice has been conducted many times, and different awards are achieved, including the Provincial Excellent Graduation Project, Innovation and Entrepreneurship Awards, Surveying and Mapping Geographic Information, etc. GIS practices conducted based on the framework are depicted in Figure 6.



(a) open experiment & innovation ability cultivation program

(b) in-course experiment on Web GIS service invoking

(c) concentrate practice on Web mapping and visualization



(d) graduate design on Web GIS system programming

Figure 6. GIS practices conducted based on the framework

3.3 Interrelations between different courses

Based on the scalable Web GIS microservice framework, different courses are leveraged and the inter logical connections are built during the practice. Details of the interrelations are depicted in Table 1:

Table 1. Interrelations between different courses

courses	interrelations	GIS capabilities
Web GIS	background and main purpose	Web architecture, Internet protocol, geographic database, data visualization
GIS Software Development	basic computer programming skills	framework design, wrting development document, including the background, demand analysis, user interface design, and usage manual.
GIS Principle	fundamental course and basic concept	GIS theories and methods of data management, spatial analysis, mapping and symbolization
GIS Algorithm	implementation of GIS theory	spatial analysis methods, data management methods, and algorithm embedding
GeoDatabase	GIS data management	store and manage the GIS geographic data, geographic data modeling, database technique

(1) Web GIS. As the background and main purpose of the experiment, Web GIS playes a role of overall designer, which connect to each course and build the logical relation via the GIS practice. Specific techniques, such RESTful API, Web Framework, MVC, PostGIS, JavaScript libraries, are used to build the scalable Web GIS microservice framework, with the related knowledge of

Web architecture, Internet protocol, geographic database, data visualization, in the course.

(2) GIS Software Development. As one of the basic skills for the GIS undergraduate, the computer programming using C, C++, Java, Python, etc., has already been required throughout GIS courses. In the development practice, students are instructed to design the framework architecture, and finish the development document, including the background, demand analysis, user interface (referred to as UI) design, and usage manual. Hence, the GIS software development skills can be comprehensively trained and strengthened.

(3) GIS Principle. It is a fundamental course in GIS undergraduate education system, and focuses on the basic concepts of GIS and instructs the development of GIS capacity for each student, with principal theory and plenty of GIS applications. However, there is still a long way for students to become experts who can use computer programming to solve GIS problems. With the GIS practice of designing the framework, GIS theories and methods of data management, spatial analysis, mapping and symbolization, etc., can be experimented with and applied in practice.

(4) GIS Algorithm. It is the specific implementation of the theory in GIS principle, utilizing different kinds of computer programming languages that were learned in the pretrained GIS courses. As the scalability of the Web GIS microservice framework, spatial analysis methods, data management methods, and some other GIS methods can be applied in the sections of geographic data processing, RESTful GIS microservice, or Web GIS mapping and symbolization. In other words, GIS algorithms can be embedded throughout the framework design practice.

(5) GeoDatabase. As an important technique and theory of GIS data management, it is not only software to store and manage GIS geographic databases but also the combination of distributed object techniques, geographic data modeling, and database techniques. During the GIS practice of framework design, students are required to design the geographic data model and use it in the MVC framework, read and write the geographic information via the GeoDatabase, along with the design of geographic data constraints to guarantee data integrity and uniqueness.

4. CONCLUSIONS

To improve the coherence of GIS knowledge system and enhance the GIS capability of undergraduate students, the scalable Web GIS microservice framework is designed and implemented in three aspects: scalable Web GIS microservices using RESTful APIs, scalable geographic data source provider using PostGIS, and scalable Web mapping and symbolization using JavaScript. Students are encouraged to conduct the GIS practice and complete the Web GIS framework in different forms, including open experiments, innovation projects, and professional competitions. The results demonstrate that the GIS capability of undergraduate students is effectively trained and enhanced, and the interrelation of multi-courses is established during the practice.

ACKNOWLEDGEMENTS

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