

ADAPTIVE ARCHITECTURE OF GEOSPATIAL INFORMATION SERVICE OVER THE INTERNET WITH QOGIS EMBEDDED

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ABSTRACT:

The coming is a new era featured by intelligent geospatial information service. This paper introduces a new theoretical and technical philosophy to meet this intelligence. The core of this intelligence is best described by a recently emerging concept, QoGIS, which is proposed to umbrella all matters concerning the improvement and guarantee of geospatial information service quality. The purpose of QoGIS is to make the final client serviced with best quality under the restriction of computing resources and network capability. This paper discusses the contents of QoGIS. A research framework and major research issues of QoGIS pursuing the next generation intelligent geospatial information service is outlined. Technical requirements of geospatial information service are concluded into five features: Internet, Integration, Intelligent, Interactive and Interoperability. An adaptive architecture of a prototype geospatial information service with QoGIS enabled was further designed to meet this requirement. Five critical points were discussed in detail.

1. INTRODUCTION

1.1 General Instructions

The greatest technologies are those disappeared in research agenda and become part of our daily life. Network and the Internet is one of great inventions witnessed in the past decades. Along with the development of network technology, architecture of geographical information system (GIS) becomes more and more closely connected with the Internet. Web services and XML technologies make it possible to transplant local GIS to geospatial information service over the globally distributed computing environment.

There are academic and commercial geospatial information services available over the Internet now. Some of them provide a variety of professional services including query and model-driven analysis. Some of them provide simple query services that are most popularly required by the non-professional users. Due to topological complexity of geospatial data, most recent research works are conducted to improve the interoperability between systems. OpenGIS consortium has been dedicating standards for geospatial technology in all levels including data model and service model (<http://www.opengis.org>).

However, research works on currently deployed geospatial information services seldom involve quality aspects of service from the viewpoint of end users (Hu etc., 2004). Recently a new concept, Quality of Geospatial Information Service (QoGIS), was proposed to umbrella all aspects concerning how good the end user is served with geospatial information (Wu etc., 2004a). Based on this concept and service philosophy, this paper proposes an adaptive architecture that promises the best service of geospatial information under constrains from client, server and the network.

The remaining part of this paper is organized in 4 sections. Section 2 introduces the QoGIS philosophy of geospatial

information service. Section 3 analyses technical requirements of geospatial information service carrying this philosophy. Section 4 introduces an architectural design of a prototype system of geospatial information service with QoGIS embedded. Section 5 briefly concludes this paper.

2. QOGIS, A PHILOSOPHY OF ADAPTIVE GEOSPATIAL INFORMATION SERVICE

Let first review the history of the technology of browsing image over the Internet. There was one day we were not able to view images over the Internet. Partially because the bandwidth of the Internet at that time was not broad enough, the critical reason is that there was not available compression technology with enough ratio for reducing the data size transferred over the Internet. Now, JPEG and other image compression technologies have almost become a technology melted in people's daily lives.

With the release of the new generation still image compression standard JPEG2000, browsing image of very large size via the Internet becomes feasible. JPEG2000 compressed image bit-streams have many desirable merits which make them very suitable for progressive transmission. Through adding various useful independent truncation points in one single bit-stream, JPEG2000 provides various progressive modes including resolution, quality, and SNR. Images no longer need be compressed multiple times to achieve a target bit-rate. Instead, the target bit-rate is not known at the time of compression and can be achieved by simply truncating the bit-streams at suitable truncation points (<http://www.jpeg.org/jpeg2000/>).

Image information is only one type of geospatial information. These achieved in image service are what QoGIS thinks indispensable philosophy for geospatial information services. Due to the massive size of geospatial data, compression technologies are to be taken into consideration. Further more,

technologies of progressive compression and transmission are also necessary to be incorporated. Some other measures that make the client user more appreciable are research issues. Innovative theories are required for better service and assessment of the quality of service.

QoGIS, Quality of Geospatial Information Service, is a general term proposed to umbrella all efforts that improve satisfaction of the final users being served with geospatial information. These efforts can be either in theoretical, technical or even algorithmic level. QoGIS can be concluded into an optimization problem: with the same size of geospatial data and stable or unstable network bandwidth, how to make the final client feels serviced with best quality? How to assess QoGIS in quantity is also a research issue.

According computation resources used in geospatial information service, there are three types of computation resource restrict QoGIS: client visualization capability, network quality and server computation capability. So, the above optimization problem is equivalent to any one of the followed three problems:

- Based on client's capability, transfer data as less as possible with more visualized geospatial information
- Based on client's visualization capability, exploit the network bandwidth as much as possible, in order to provide geospatial information as more as possible
- Based on the server's computational power, pre-process geospatial data and response the client in its best

The research framework of QoGIS consists of 5 hierarchical components with lower theoretical levels support higher application levels. Figure 1 shows this framework.

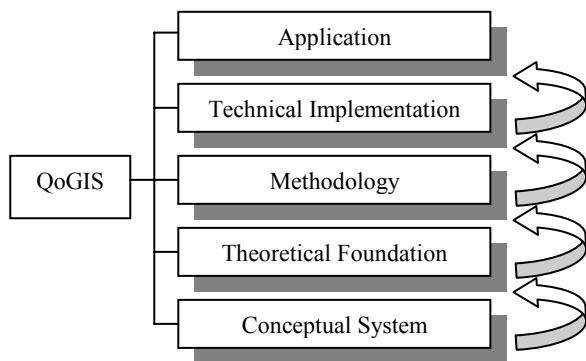


Figure 1. Research Framework of QoGIS

The conceptual system of QoGIS includes all entities that govern QoGIS. Examples of these concepts include geospatial data, visual information measurement, and data features in frequency domain. Theoretical foundation of QoGIS includes optimization theory, cybernetics and quantity analysis. Research on methodology of QoGIS include information theory, frequency analysis, multi-representation and multi-resolution technologies. Technical implementation of QoGIS includes system architecture, embedded streaming, compression, and load balance etc. Application of QoGIS includes how to incorporated QoGIS with engineering projects.

Within this research framework of QoGIS, there are a lot of research topics covering all aspects of geospatial information service. A partial list of these research topics is:

- Geospatial recognition, geospatial interface
- Measurement of geospatial information
- Quantitative relationship between data size of information size
- Assessment of QoGIS
- Adaptive architecture of geospatial information services
- Data organization and cache in client- and server-side for QoGIS
- The optimization of server-side computing resources management for geospatial information service
- Transfer strategy above route
- Protocol and standard for geospatial information service considering QoGIS
- Geospatial data compression and appropriate structure for transfer data over stateless network
- Integration service for multi-source geospatial data
- Seamless visualization in both spatial and frequency domain
- Test bed and benchmark for QoGIS

3. REQUIREMENT ANALYSIS OF QOGIS

There are two types of architectures for geospatial information service in general. One is so called thin client that the server implements computational functions and all response to the client is a map in image format. Another is so called thick client that the server only prepares and sends geospatial data while the client decides how to display the map and implement query and analysis functions.

No matter what types of architecture deployed, most of them provides static services. In architecture of static services, geospatial servers passively response to client's request by generating a map in image format for each request. And all the client-side does is to get the image and display it. There is no consideration of interactivity taken to reduce data size between two subsequent requests according to data correlations between two correspondences. There is also no consideration taken to adjust data size in order to match the real-time network state. There is also no measurement is taken to adapt to the client's capability of visualization and computation.

Compared to static services, the kernel of architectural consideration of QoGIS is adaptive services. In an architecture that embedded QoGIS within its geospatial services, we identify five essential requirements.

- Internet. Research of QoGIS should be on systems deployed in a stateless network. The typical example is the Internet. The Internet is not only a ubiquitous computing environment, but also a computing environment that does not promise any stable connectivity. The most widely used TCP/IP protocol is based on best-effort principle regarding to the data transmission and neglects client's satisfaction. QoGIS should best exploit the network bandwidth and provide the client with visual information as more as possible.

- Integration. Geospatial data are of more than one type and they are better visualized together to provide more synthesized information. Vector map with satellite image as background is easier for understanding than pure 2D vector map. If DEM is also integrated, slopes in a perspective project view make unprofessional client a very intuitive image of real world. So, architecture powered with QoGIS must have the ability of integrating known and unknown types of geospatial information. Integration also requires the synthesized service of multi-resolution, multi-source information from hetero-structured servers.
- Intelligence. The essence of QoGIS is to make the geospatial information service intelligent. The amount of geospatial information increases with the amount of geospatial data. However, as spatial and colour resolutions are limited, more geospatial data does not mean more information (Wu etc., 2004b). This intelligence is exhibited by that the client visual quality always keeps largest amount of information provided if network bandwidth is not broad enough. However, if network bandwidth is broad enough, this intelligence enables the least occupation of network bandwidth while client's visual requirement is best satisfied.
- Interactive. Interactivity is essential to geospatial information service, however to what extent and by what kind of interface that service architecture supports interactivity differs. QoGIS requires swift response to client's input and gives the client a feeling of very smooth operation. An example of this response is to zoom in and out the client map by rolling the mouse wheel without any feeling of delay.
- Interoperability. Geospatial information, especially vector format data, is of complicated topological relationship and cartographic projection. Different systems have different data format. So it is very important for geospatial information service to conform to interoperability standards (<http://www.opengis.org>).

In order to meet above requirements, the feature of adaptive service mechanism should exploit all possible computation resources. The following strategies are very important in design architecture of geospatial information service with QoGIS taken into consideration.

- The maximum size of data should be decided by the client-side visualization capability: resolution, view size and colour space.
- The actual size of data should be decided by the network bandwidth and stability.
- What kinds of geospatial data can be send to the client side should be decided by the server side database according to client's computing environment.
- The actual data send to the client side should be estimated by the server computation capability. However, this strategy is less important partially because the server side computation capability is usually less critical compared to the network bandwidth, which is the bottleneck of geospatial information service.

To implement above strategies, some measures should be conducted. Possible samples of these measures are:

- An independent thread is needed to detect the network status in real-time. The result will dynamically steer the quantitative control of data size and contents transferred via the network.
- Both indexes in space and frequency domain are essential.
- Correlation between two sequential responses and compression are ways to reduce data size.
- Caches in both server side and client side are measures to decrease time in I/O.
- Network protocols should be specially designed for QoGIS.
- Consideration of multi-server cascading to increase server power.

4. A PROTOTYPE DESIGN OF ADAPTIVE GEOSPATIAL INFORMATION SERVICE WITH QOGIS

Figure 2 and Figure 3 are client and server architecture of a prototype of geospatial information service with QoGIS implemented. With geospatial data model supported, both client and server side have a cache designed to accelerate computing efficiency. The client side cache is a dynamically managed snapshot of the geospatial database in the server side.

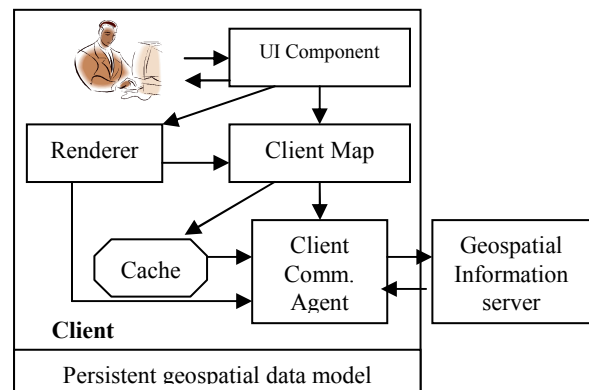


Figure 2. Client Architecture of prototype system of QoGIS

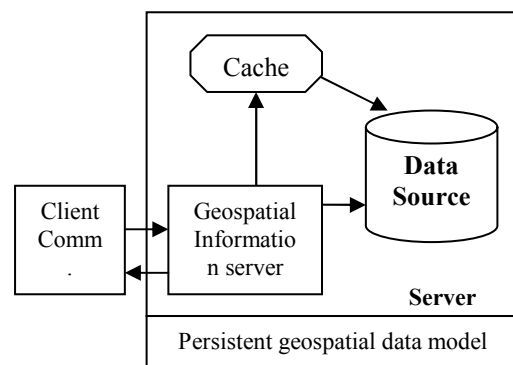


Figure 3. Server Architecture of Prototype of QoGIS

4.1 The Amount of Geospatial Information Controls the Data Size

What the end user most concerning about is mount of the information received from the service. The relation between geospatial data and information carried is not pure positive linear. The amount of information contained in data increases with growing of data size, but when this reaches a peak, this amount decreases even more data is acquired. The visual capacity of the client screen is not only limited by the number of pixels, but also limited by resolution and colour space (Wu etc, 2004b).

The design of this prototype sends geospatial data request to the server with a bounding box as well as other parameters that character the client visualization capability. The server then prepares and sends appropriate data set to the client with selected layers, selected objects with best resolution in frequency domain.

4.2 Persistent Geospatial Data Model

OpenGIS released simple feature specification (OpenGIS, 1999) for object-oriented modelling of vector geospatial data. However the specification only defined standard interfaces that vector geospatial object must implement. How to serialize these objects are left to implementation. Though object-oriented programming languages implemented object serialization, they are not appropriate to geospatial data. Geospatial objects are of complex topological relationship, general serialization always over-serialize geospatial objects. This will significantly decrease efficiency of object to bit stream and bit stream to object transformation while this transformation is frequently called in B/S architecture.

The prototype design extends the persistent design of vector data model to all geospatial data types (Wu etc., 1999). We design a bit array for any vector object. The bit array is in a format the same as object record in ERSI shape file. Whenever a call is required to access internal points or other information, the object provides a member function to read the bits and interpret them on the fly. This format is almost the same as OGC WKB and WKT format and we keep the same whenever appropriate either in internal memory and external storage. This persistent structure is further extended to image, DEM and 3D model. This persistent structure also maintains pyramid of all geospatial data types introduced in the followed subsection.

4.3 Hybrid-pyramid Structure for Multi-source Data Organization

Another design for reducing external I/O operation is pyramid structure that is extensively used in image service. It is well know that spatial index, such as R tree or simple grid index can greatly reduce the I/O operation in server. However, on frequency domain we can also do the same as spatial domain. Taken image as an example, an image pyramid is created that a series of images with downscaled images are pre-generated and stored. Further more, these images are cut into tiles of regular size, e.g. 256x256. Whenever the client requests a view, the server responses with best resolution and right tiles. The latest progress in this field is the hierarchical and progressive compression technique such as JPEG2000.

It is intuitive to extend this structure to DEM data. This paper does more and proposes the same design to vector data. These

different scales of vector data are generated before deployed in the data server. Vector data in each scale is cut to square tiles that match visual resolutions of the client request. A problem arises when neighbour tile does not reach the client side. The prototype designed in this paper remains this problem dissolved by the client design, which guarantees that all views in the client side must show tiles of the same scale.

4.4 Multi-thread and Data-driven Rendering Mechanism

There are 4 independent threads designed in the client side to make the client visualization and interactivity smoothly. The UI thread is in charge of user's input and the renderer thread controls the best display to response to user's input. Client map is container of map data organized in object-layer-map structure, however it only keeps this structure with pointers point to persistent data blocks in client cache. Client cache thread organizes data received from the server in persistent format. It maintains data by accepting data from sever and deleting data most probably not used in the near future. The client communication agent is a thread that deals with all communications to the server.

To make visual effect smoothly transit from one frame to another frame, besides some common techniques such as morphing are applied, the data driven rendering mechanism is a unique design in this prototype. In the client side, data requested is the critical element that makes the user feel smooth. Usually the data requested for answering pan, zoom operations comes from the server should wait for a time gap including the transmission process in the network.

The data-driven mechanism is built in the client communication agent. It not only sends requests to and receives data from the server, it also controls reactions to any arrival of new data from the server. Whenever there is new data received, this thread checks whether the arrived data is within the current view (both in spatial domain and frequency domain). This check is necessary because there are a large proportion of situations that the data comes too late to display in the current view. If the check answers yes, client commutation agent sends message to renderer asking for updating current view. No matter whether this update is done or not, all data received are sent to the client cache, which will manage all data by deleted the most unused data according to frequency or other criteria.

4.5 Data Cache for Fast Data Accessing

Both client side and server side are equipped with cache. The memory size of cache is pre-allocated compatible with the computation resources and is designed to dynamically grow whenever needed.

The data stored in cache is in persistent format. The bit stream is self-interpretable. When the renderer displays this data, it decodes the bit stream on the fly. Whereas the geospatial information server directly forward this bit stream to the encoding module and send to the client communication stream.

The cache is managed dynamically by inserting objects and deleting objects. The deleting criterion is critical to increase cache's efficiency. Generally they are two way of designing this criterion. One is neglecting geospatial characters and deleting objects by the principle of time "longest time not used, first deleted". Another is deleting objects that are farthest from the current view, both in spatial domain and frequency domain. The

cache always keeps a local database that fit the current view with a certain buffer of space and frequency.

Generally memory resources in the server side are far better than the client. So, cache design in the prototype is that server side cache is managed by time criterion while the client cache is managed distance principle.

4.6 Interfaces Reserved and Experimental Results

The prototype also reserves some interfaces for further extensions. One of these is interface for compressed and progressively compressed data. For data progressively compressed in a JPEG2000 style, the prototype provides functions of encoding, decoding and progressive decoding.

As this project is still working on, there are only some very simple experimental results. However from initial demonstration of prototype system, the architectural design and new ideas added to the architecture proved the philosophy of QoGIS and the architecture is feasible.

5. CONCLUSIONS

The coming is a new era featured by intelligent geospatial information service. The core of this intelligence is best described by the philosophy, QoGIS, proposed by this paper. The purpose of QoGIS is to make the final client serviced with best quality under the restriction of computing resources and network capability.

Based on detailed discussions of QoGIS, this paper outlined a research framework and major research issues of QoGIS

pursuing the next generation intelligent geospatial information service. This paper further concluded technical requirements of geospatial information service into five features: Internet, Integration, Intelligent, Interactive and Interoperability.

An adaptive architecture of a prototype geospatial information service with QoGIS enabled was further designed to meet this requirement. Five critical technical points in the architecture were discussed in detail.

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