GeoQoS: Delivering Quality of Services on the Geoprocessing Web

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ABSTRACT
Geoprocessing is a basic element in spatial data infrastructure (SDI). As more and more geoprocessing functions are available as Web Services in SDI, the quality of geoprocessing services has become an important concern in providing effective geoprocessing in a distributed environment. This paper introduces the design and implementation of GeoQoS to support QoS-aware geoprocessing on the Web. Key issues, including QoS attributes, QoS evaluation for geoprocessing services, and QoS-aware optimization of geoprocessing chains, are addressed. The results are published as an open source tool to facilitate QoS-aware geoprocessing on the Web.

Keywords
Quality of Service (QoS), Geoprocessing Web, Geoprocessing Services, Workflow, GIS.

1. INTRODUCTION
Geoprocessing is increasingly used in the Web environment to meet the demand on information extraction and knowledge discovery in geospatial information infrastructures, such as Spatial Data Infrastructure (SDI), e-Science, or Cyberinfrastructure. Conventional siloed geoprocessing functions are exposed as Web Services and shared for worldwide open use. Often, these services are chained as scientific workflows to solve complex geoscientific problems [1]. The emerging concept of Geoprocessing Web is characterized by the wide sharing of, access to, and collaboration of distributed geoprocessing services [2-3]. By evaluating the Quality of Service (QoS) and enabling QoS-aware optimization of geoprocessing chains, Geoprocessing Web could provide high quality of services for geospatial applications.

From the viewpoint of Geoprocessing Web, geoprocessing follows the publish-find-bind paradigm. The individual geoprocessing services are published in a Web service registry. A geoprocessing requestor is able to find geoprocessing services through the registry. When the appropriate services are located, using both functional (e.g. inputs, outputs, and operations) and non-functional (e.g. QoS) properties of geoprocessing services, the requestor can bind the services and assign geoprocessing tasks. In a distributed environment, a complex geoprocessing task may require different geoprocessing services to work together as a service chain. The orchestration of geoprocessing services into chains includes both the service discovery and composition. In the service discovery process, QoS could be applied in selecting a service from multiple services with the same functionality [4]. In the service composition, user satisfaction could be maximized by expressing it as a utility function over QoS attributes, while at the same time QoS constraints set by users are still satisfied [5].

This paper introduces an approach to support QoS-aware geoprocessing on the Web. It presents a set of QoS attributes for geoprocessing services by complementing general QoS attributes with geospatial attributes. The quality of output data products is incorporated as a geospatial attribute for QoS. Various QoS attributes could be plugged into the quality evaluation model based on users' preference. The values of these QoS attributes are gathered using commonly used QoS measurements such as average response/flow time. In particular, provenance could be used to evaluate the quality of output data products, which consequently contributes to the evaluation of quality of geoprocessing services. All measurements are normalized, and an analytic hierarchy process (AHP) [6] is applied to determine weights of QoS attributes. Finally, the QoS result of geoprocessing services can be derived using the combination of weighted values of QoS attributes. Once QoS of individual geoprocessing services is determined, QoS-aware optimization of geoprocessing service chains is proposed. The goal is to ensure the best of global QoS indicator for geoprocessing chains, while at the same time satisfying QoS constraints specified by users. The optimization also includes both off-line and on-line planning. In the former case, the static QoS measurement is used. In the latter case, the dynamic measurement of QoS is incorporated to accommodate runtime exceptions of geoprocessing services.

The results are implemented as an open source tool, named GeoQoS. It can evaluate the quality of geoprocessing services with users' feedback and other quality factors including availability and reliability. QoS for each geoprocessing service can be visualized in a Virtual Globe environment to facilitate service selection. Users can set QoS constraints for processing nodes in geoprocessing workflows, and then optimize workflows with constraints. The tool has been incorporated into to an existing geoprocessing modeling tool to facilitate geoprocessing on the Web.

The rest of this paper is organized as follows. Section 2 introduces related work in the literature. Section 3 presents the architecture design and key issues of GeoQoS. Section 4 describes details of the system implementation. Conclusions and pointers to future work are given in Section 5.

2. RELATED WORK
QoS can be understood in the following two perspectives [7]: the first is how measurable characteristics of services satisfy a fixed specification, i.e. conformance to specification; the second is the services' capability to meet customer expectations. The first one is related to the objective aspect of QoS, while the second one

concerns about the subjective aspect of QoS. Some work uses objective measurements including invocation failure probability, response time, and throughput performance, to provide large-scale quality evaluations of real-world Web services [8]. Others focus on users' experience and expectation in QoS-aware Web Service selection [9-10]. Both objective and subjective aspects are addressed in this paper. In particular, the system developed in this paper allows users to selectively set preferences on QoS attributes, which later can be taken into the evaluation model of QoS.

QoS is a broad concept that can address many attributes of Web Services, including availability, accessibility, integrity, performance, reliability, regulatory, and security [11-12]. Among them, the performance, reliability, and availability are the major questions in the quality of geoprocessing services, as suggested by existing work in the geospatial domain [13-15]. By considering the diverse use requirements, the unique character of spatial data, and QoS related constraints on complex geoprocessing, Onchaga defines a QoS model that covers performance, cost, reliability, availability, security, reputation, interactive support, location, and health of services [16]. Geoprocessing services process input data and output high-level spatial data products. The quality of geoprocessing services also depends on the quality of processing results. Thus the quality of service output could also be used a metric for QoS [17]. In addition to common processing and output quality factors, Gui et al. integrated dynamic features of services, such as data size and network bandwidth into a QoS assessment model for geoprocessing services [18]. The work in this paper is not limited to the QoS model. It goes further to propose QoS-aware optimization of geoprocessing chains. The final goal is a practical and easy-to-use tool to promote the QoS-aware geoprocessing.

In terms of measurement of QoS attributes, some work proposes to monitor availability and response time of geospatial services [19-20]. Technically, the geoprocessing services are implementation and algorithm specific. The ability to dynamically generate quality information for the results of spatial analysis is important for quality aware geoprocessing services. Donaubauer et al. demonstrate such a case, and propose to use Geographic Markup Language (GML) and ISO 19139 to encode data quality by means of metadata [21]. In the Open Geospatial Consortium (OGC) Web Services (OWS) testbeds, data quality and provenance are captured in WPS and encoded also using the ISO standards-compatible XML format [22]. Provenance records the processing steps and inputs that contribute to the processing results [23]. It provides an information context to assist users in evaluating not only quality of geospatial data but also quality of geoprocessing services. The work in this paper tries to provide provenance based quality evaluation. Although the quality evaluation is case-specific due to the specific nature of geoprocessing algorithms, similar quality evaluation process could be developed and plugged into the system for different types of geoprocessing.

3. GEOQOS: SYSTEM DESIGN AND KEY ISSUES

GeoQoS is designed to not only support the QoS evaluation of individual geoprocessing services, but also enable the QoS-aware optimization of geoprocessing service chains. Figure 1 shows the system architecture of GeoQoS. It couples the existing service-oriented architecture in Geoprocessing Web.

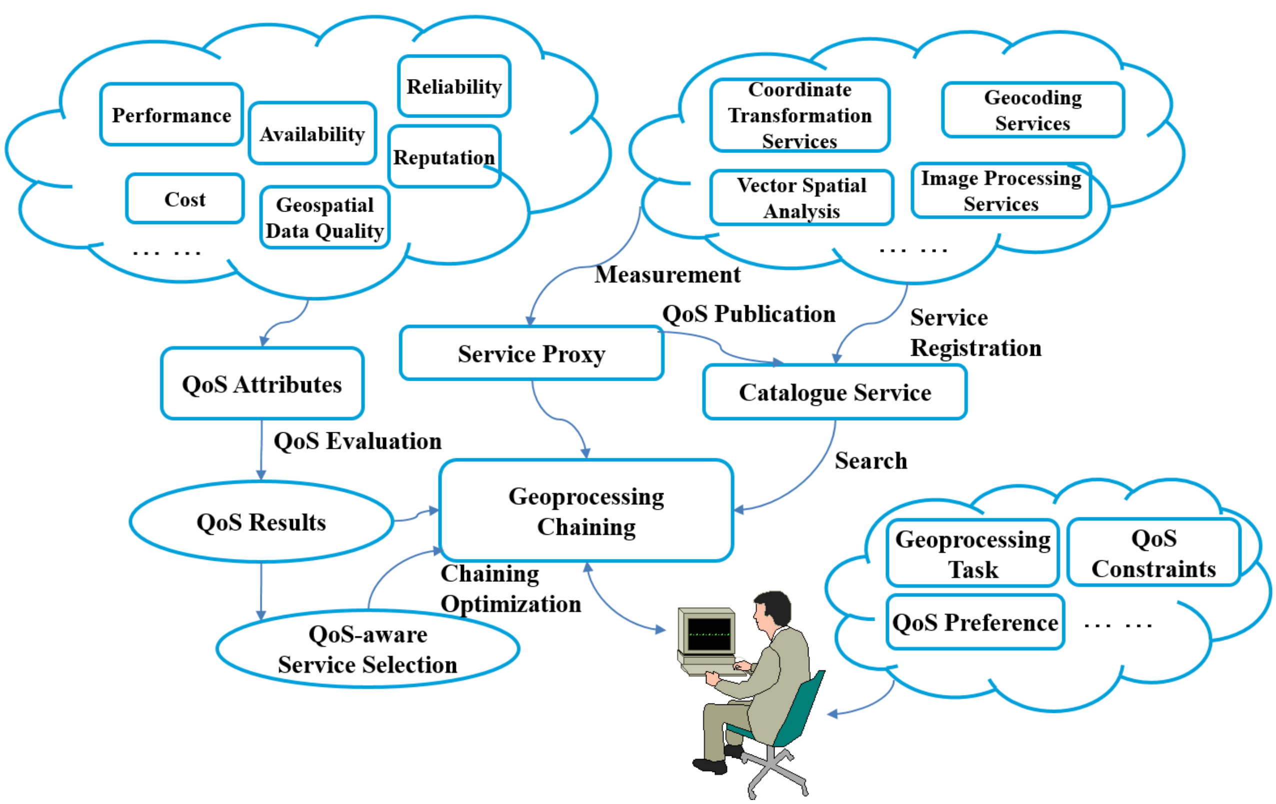


Figure 1. System architecture of GeoQoS

There are five key actors in GeoQoS (Figure 1): service users, service registration center, service proxy, service providers, and service chaining tool. Existing geoprocessing services from different providers are registered in a geospatial catalogue service. The service proxy tests and monitors geoprocessing services. It can also summarize users' rating results. The test reports can be published in the catalogue service. Conventionally, a geoprocessing chaining component is capable of searching, chaining, and running services. Here the component is enriched with provenance and quality related capabilities. First, it is able to do QoS evaluation using a selected set of QoS attributes and measurements from the service proxy. Second, it can do QoS-aware optimization of geoprocessing service chains. Third, it is able to trace the execution of chains, and adjusting selected services during the run-time. The tracing results, captured as the provenance, can also contribute to feedback evaluation of quality of services or chains. The whole process is illustrated using an UML sequence diagram in Figure 2. When developing these capabilities, the following key issues are addressed.

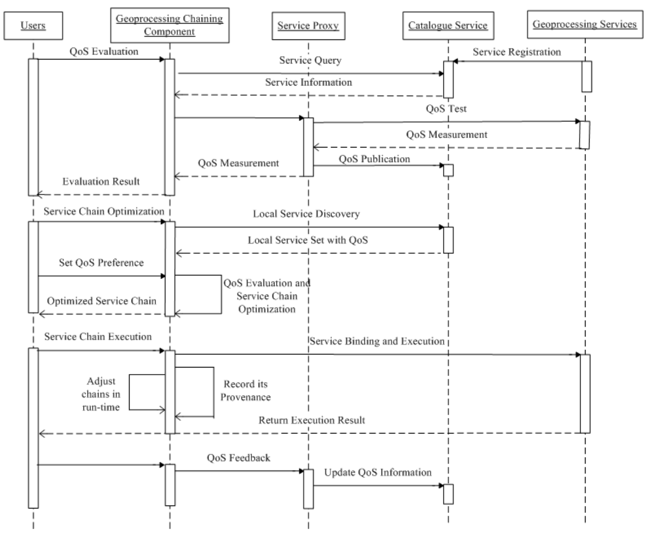


Figure 2. A sequence diagram for GeoQoS

3.1 QOS ATTRIBUTES FOR GEOPROCESSING SERVICES

To provide a better QoS, it is primarily necessary to identify all possible QoS requirements for geoprocessing Web Services. Requirements for general Web Services have been proposed before. The World Wide Web Consortium (W3C) have set a comprehensive list of QoS requirements for Web Services: performance, reliability, scalability, capacity, robustness, exception handling, accuracy, integrity, accessibility, availability, interoperability, security, network-related QoS requirements. However, the geoprocessing Web Services differ from the general ones in that they have their particular emphasis, i.e. the data they are processing is geospatial data. As a result, the quality of geospatial data can be one of the most important factors for evaluating the quality of geoprocessing Web Services. Figure 3 shows the QoS attributes adopted in GeoQoS. In addition to data quality, others are typical attributes often used in the literature. Their definitions are provided in Table 1. More attributes can be added according to the application requirements.

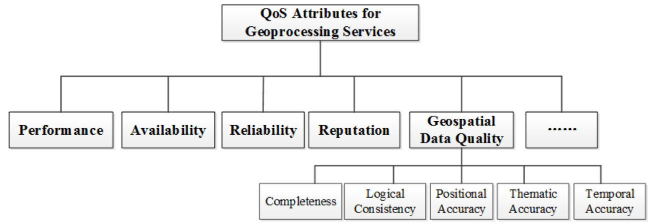


Figure 3. Typical QoS attributes

Table 1 illustrates methods for estimating values of the QoS attributes. Since the existing service registers do not support the QoS evaluation, a third-party notary, like the service proxy in Figure 1, is necessary to provide QoS tests. QoS values on attributes such as performance, availability, and reliability can performed using the service proxy. It is like available QoS monitoring services on the Web, yet emphasizing the testing of geoprocessing services using benchmark geospatial datasets. In addition, once a user experienced with a geoprocessing service, he/she could also publish his/her rating into the service proxy. Thus the service proxy is also capable to collect users' ratings on geoprocessing services, which can help measure the reputation of services.

Table 1. Measurement of typical QoS attributes

Name	Definition	Measured by
$q_{performance}$	Representing how fast a geoprocessing request can be completed? $q_{performance} = Throughout/Time$, where *Throughout* represents the number of geoprocessing requests in a given time period, and *Time* denotes the latency.	Service proxy
$q_{availability}$	The probability that a service is available. $q_{availability} = T/t$, where T is the time that the service is up in the given time period t.	Service proxy
$q_{reliability}$	The probability that a service is performed successfully for a specified time interval. $q_{reliability} = N/n$, where N is the number of successful executions in a given number (n) of executions.	Service proxy
$q_{reputation}$	Users' rating on geospatial services	Users' rating
$q_{spatial}$	Quality of geospatial data	Direct or indirect evaluation

Table 2. Elements for data quality: a case on map conflation

1st Level Quality Element	Weight (W_i)	2nd Level Quality Element	Weight (W_{ij})
Completeness	W_1	Feature Density	W_{11}
		Feature Density Improvement	W_{12}
		Measured percent change in attributes	W_{13}
Logical Consistency	W_2	Topological consistency	W_{21}
		Conceptual consistency	W_{22}
		Format consistency	W_{23}
Positional Accuracy	W_3	Absolute or external positional accuracy	W_{31}
		Change in accuracy	W_{32}
		Hausdorf Distance	W_{33}
Thematic Accuracy	W_4	Classification correctness	W_{41}
		Non-quantitative attribute correctness	W_{42}
		Quantitative attribute accuracy	W_{43}
Temporal Accuracy	W_5	Accuracy of a time measurement	W_{51}
		Temporal validity	W_{52}

The evaluation of geospatial data quality follows the guideline by ISO 19157 Geographic information — Data quality [24]. There are two types of data quality evaluation methods, direct and indirect. The direct evaluation methods determine data quality through the comparison of the data with reference information. Indirect evaluation methods infer or estimate data quality using provenance. The quality of geospatial data is generally measured by their completeness, logical consistency, positional accuracy, thematic accuracy, and temporal accuracy [24]. However, each type of geoprocessing has its own specific requirements. Table 2 lists specific requirements for map conflation. The map conflation is to integrate data from different sources into one dataset using some procedures such as alignment of features or attributes using specific conflation logics [25]. The goal in this paper is to adopt a template design pattern [26] for quality analysis. The skeleton for the first level quality element is defined, deferring specific requirements to the second level using plugins or configuration files.

3.2 QOS EVALUATION FOR GEOPROCESSING SERVICES

The evaluation of QoS for geoprocessing services includes three major steps: normalization of QoS values, determination of weights for QoS attributes, and selection of mathematical evaluation models.

Normalization of QoS values: Due to the inconsistency of dimension and scope on geoprocessing QoS attributes, QoS values need to be normalized. There are two categories for QoS values: positive and negative. For positive ones, the higher the value is, the better the quality is. The negative ones are reverse. The normalization of positive and negatives ones follows the formula (1) and (2) respectively.

$$q' = \begin{cases} \dfrac{q - q_{min}}{q_{max} - q_{min}} & (q_{max} - q_{min} \neq 0) \\ 1 & (q_{max} - q_{min} = 0) \end{cases} \quad (1)$$

$$q' = \begin{cases} \dfrac{q_{max} - q}{q_{max} - q_{min}} & (q_{max} - q_{min} \neq 0) \\ 1 & (q_{max} - q_{min} = 0) \end{cases} \quad (2)$$

Determination of weights for QoS attributes: The determination of weights for QoS attributes not only affects the result of QoS evaluation but also reflects users' preference. Existing methods on determining weights for multi-factors include subjective experience method, experts mark method, Delphi method and analytic hierarchy process (AHP). The subject experience method requires rich user experience. The experts mark method and Delphi method are not easily operational in practice. AHP is a widely used scientific analysis method, having logical analysis on pairwise comparison between QoS attributes and normal mathematical processing steps. Users' QoS preferences can be enforced when doing pairwise comparison. It is adopted in this paper for determining weights in both data quality evaluation (Figure 4) and QoS evaluation (Figure 5). It is noted that users' QoS preferences can be reflected not only by weighting methods/attribute selection, but also by setting preferred QoS constraints in service selection and service chain optimization.

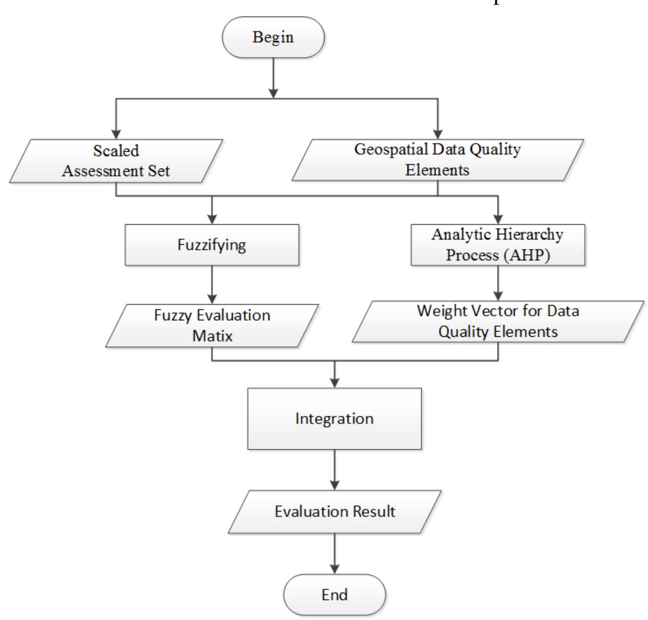


Figure 4. A sequence diagram of data quality evaluation

QoS evaluation model: The evaluation model borrows approaches from mathematical evaluation. Two models, a linear model for weighted integration and fuzzy comprehensive evaluation model are adopted. The latter one is more suitable for factors with unclear referential boundary and quantified fuzzy indicator. It is adopted in data quality evaluation, since some elements of data quality often have such characteristics. Figure 4 shows the sequence diagram for data quality evaluation using the fuzzy comprehensive evaluation model. The weighted linear integration model is a commonly used multi-factor comprehensive evaluation method. It is simple and effective, and easy to be operational in practice. The model is adopted in QoS evaluation, as shown in Figure 5.

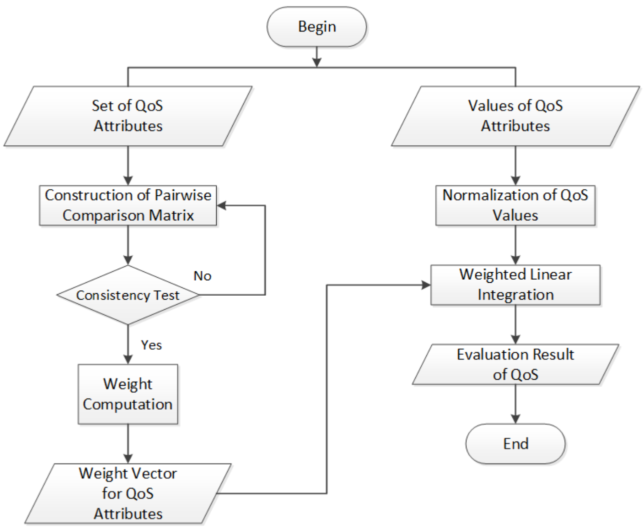


Figure 5. A sequence diagram of QoS evaluation

3.3 QOS-AWARE OPTIMIZATION OF GEOPROCESSING CHAINS

In the Geoprocessing Web, a geoprocessing task often needs several geoprocessing services to be chained together. QoS based service selection focuses on maximizing the local QoS, while the goal of optimization for geoprocessing chains is to select a best set of services to maximize the global QoS. To be more specific, it will select the suitable candidate service for each geoprocessing, taking into the consideration of QoS constraints and user preferences, and furthermore, adjust the candidates according to runtime status.

The global QoS is often represented as a utility function, shown in Formula (3)

$$\max f(\mathrm{g}) = W_{performance} \bullet Q_{performance} + W_{availability} \bullet Q_{availability} + W_{reliability} \bullet Q_{reliability} + W_{reputation} \bullet Q_{reputation} + W_{spatial} \bullet Q_{spatial} \quad (3)$$

Where $W_{performance}+W_{availability}+W_{reliability}+W_{reputation}+W_{spatial}=1$, and $W_{performance}$, $W_{availability}$, $W_{reliability}$, $W_{reputation}$, and $W_{spatial}$ denote weights for each QoS attribute respectively. These weights can be derived using AHP. $Q_{performance}$, $Q_{availability}$, $Q_{reliability}$, $Q_{reputation}$, $Q_{spatial}$ denote QoS values for the geoprocessing chain. The QoS of the service chain is an aggregation of qualities of component services. The aggregation function is modelled over the structure of service chains, such as sequence, choice, parallel, and loop. Table 3 lists aggregation functions of each structure for typical QoS attributes.

Table 3. QoS derivation for geoprocessing chain

QoS Attributes	Sequence	Choice	Parallel	Loop
$Q_{performance}$	$\sum_{i=1}^{n} q_{performance}(s_i)$	$\sum_{i=1}^{m} p_i q_{performance}(s_i)$	$\sum_{i=1}^{n} q_{performance}(s_i)$	$k \cdot q_{performance}(s_i)$
$Q_{availability}$	$\prod_{i=1}^{n} q_{availability}(s_i)$	$\sum_{i=1}^{m} p_i q_{availability}(s_i)$	$\prod_{i=1}^{n} q_{availability}(s_i)$	$[q_{availability}(s_i)]^k$
$Q_{reliability}$	$\prod_{i=1}^{n} q_{reliability}(s_i)$	$\sum_{i=1}^{m} p_i q_{reliability}(s_i)$	$\prod_{i=1}^{n} q_{reliability}(s_i)$	$[q_{reliability}(s_i)]^k$
$Q_{reputation}$	$\sum_{i=1}^{n} q_{reputation}(s_i) / n$	$\sum_{i=1}^{m} p_i q_{reputation}(s_i)$	$\sum_{i=1}^{n} q_{reputation}(s_i) / n$	$q_{reputation}(s_i)$
$Q_{spatial}$	$\sum_{i=1}^{n} q_{spatial}(s_i) / n$	$\sum_{i=1}^{m} p_i q_{spatial}(s_i)$	$\sum_{i=1}^{n} q_{spatial}(s_i) / n$	$q_{spatial}(s_i)$

Assuming users set the QoS constraints as formula (4):

$$cons = \left(cons_{performance}, cons_{availability}, cons_{reliability}, cons_{reputation}, cons_{spatial}\right) \quad (4)$$

The QoS-aware optimization of geoprocessing chains can be modelled as formula (5):

$$
\max f(\boldsymbol{g}),\ \ \mathrm{s.t.}\begin{cases} Q_{performance} \geq cons_{performance} \\ Q_{availability} \geq cons_{availability} \\ Q_{reliability} \geq cons_{reliability} \\ Q_{reputation} \geq cons_{reputation} \\ Q_{spatial} \geq cons_{spatial} \end{cases} \tag{5}
$$

The global optimization is a NP-hard problem in service composition. Existing heuristic approaches such as Genetic Algorithm (GA), Particle Swarm Optimization (PSO), and Ant Colony Optimization (ACO) can be used for optimization.

The aforementioned approach can be classified as an offline planning approach, since it is based on the past QoS information retrieved from the catalogue service. Another strategy adopted in GeoQoS is to monitor and detect the status of services at runtime, or named online approach. When meeting service failure, abnormal connections, load imbalances, or some other runtime exceptions, the system will replace the bad one with candidate services to guarantee the service chain can perform successfully. In the meantime, the system will also record the trail of geospatial data in the execution process, which later can support provenance based evaluation of geospatial data quality.

4. IMPLEMENTATION AND RESULT ANALYSIS

4.1 IMPLEMENTATION

The results are implemented as a tool named GeoQoS. GeoQoS provides a wizard to guide users for QoS evaluation and chaining optimization. The five major QoS attributes, performance, availability, reliability, reputation, and data quality, are supported. More specific QoS attributes, such as conformity with OGC-standards, can be easily added when necessary. The AHP and fuzzy comprehensive evaluation model are implemented in QoS evaluation. The genetic algorithm is implemented in QoS-aware geoprocessing chaining. Other optimization algorithms can be plugged in.

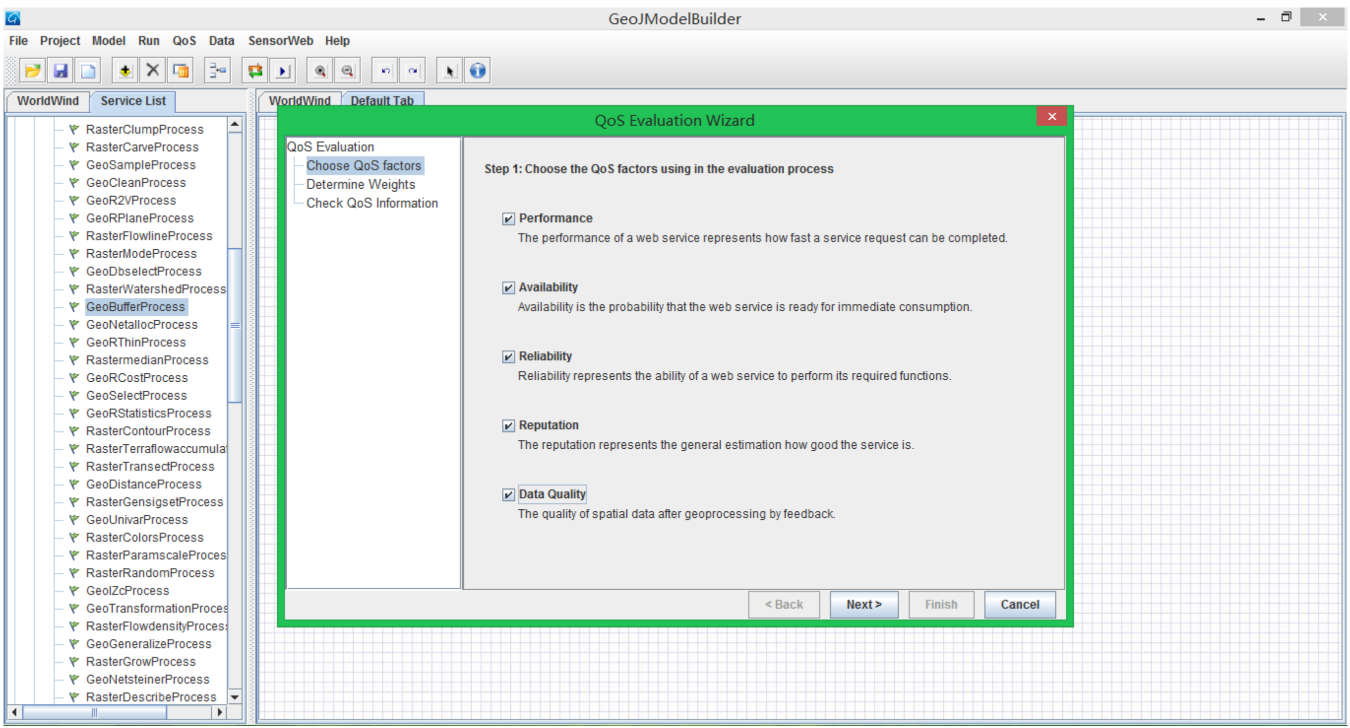


Figure 6. Wizard for QoS evaluation

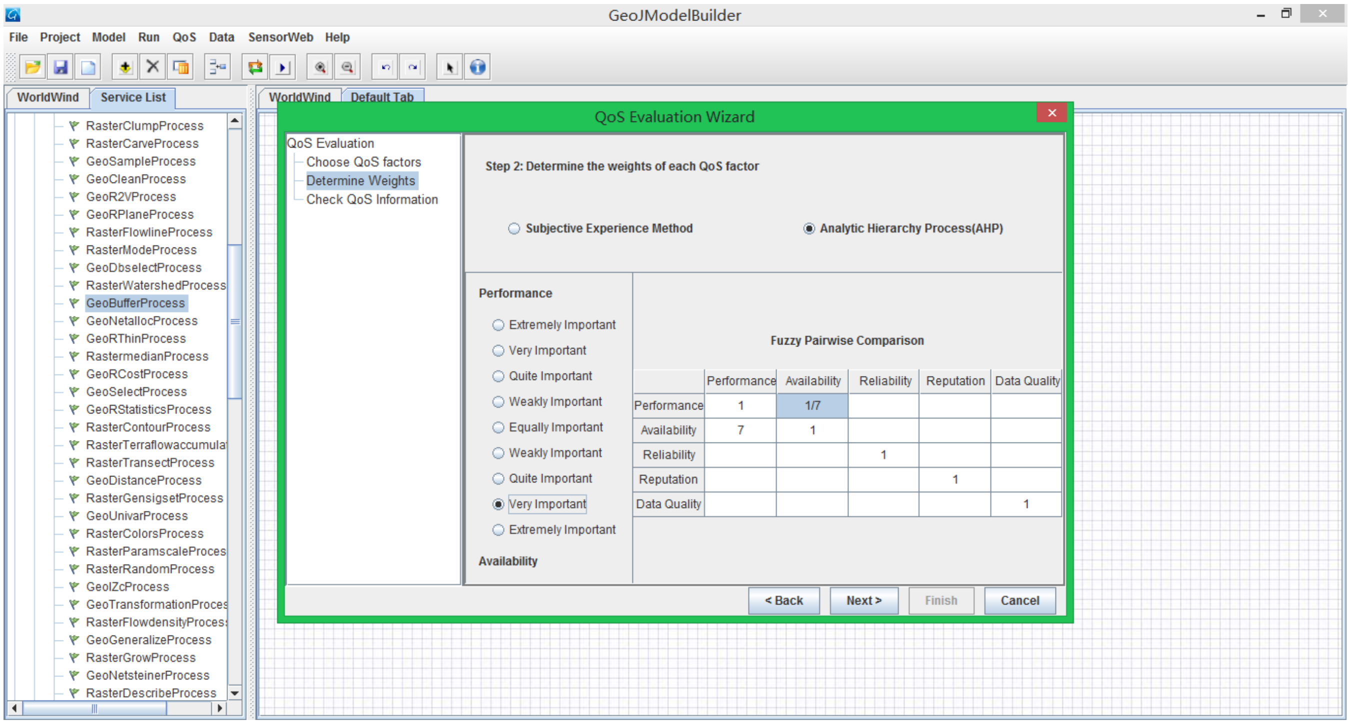


Figure 7. AHP for determining weights

GeoQoS is implemented as an extension to an existing open source geoprocessing chaining tool, i.e. GeoJModelBuilder [27]. GeoJModelBuilder is written in Java for cross-platform support. Java Swing and NASA World Wind Java technologies are used to realize the graphical user interface (GUI) of GeoJModelBuilder. The geoprocessing chaining models will be drawn on the JPanel as graphics using native libraries from the Java runtime environment. Basic operations, such as zoom, redo, and undo, are supported. NASA World Wind is embedded into the GeoJModelBuilder for the visualization of input data, results, sensors, and geoprocessing services. Users can click each geoprocessing service in the panel to evaluate its QoS. Example geoprocessing services include those from GeoPW, which provides near two hundred geoprocessing services on the Web [2]. The tool has been published as an open source tool (under the GNU General Public License version 2, http://sourceforge.net/projects/geoqos/) in the NASA World Wind Europa Challenge 2014 in Bremen, Germany.

Figure 6 illustrates the wizard for QoS evaluation of individual geoprocessing services. Figure 7 shows the analytic hierarchy process for determining weights. Users' preference can be enforced when doing pairwise comparison. Existing values for different QoS factors can be viewed in Figure 8. Figure 9 shows the indirect method for evaluating data quality.

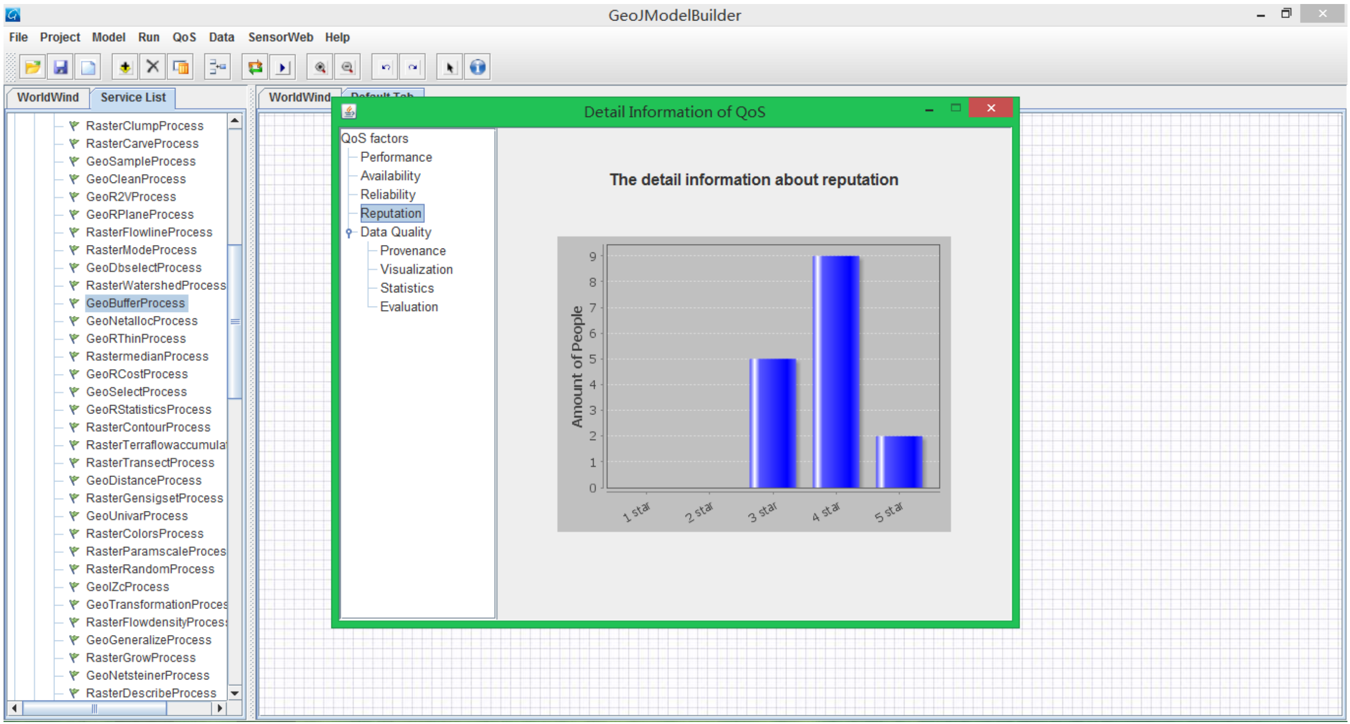
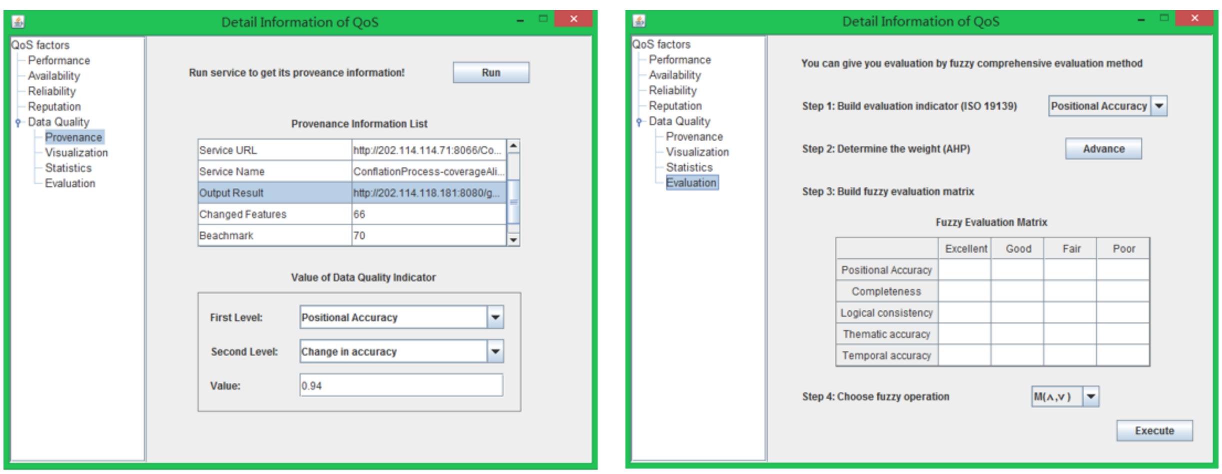


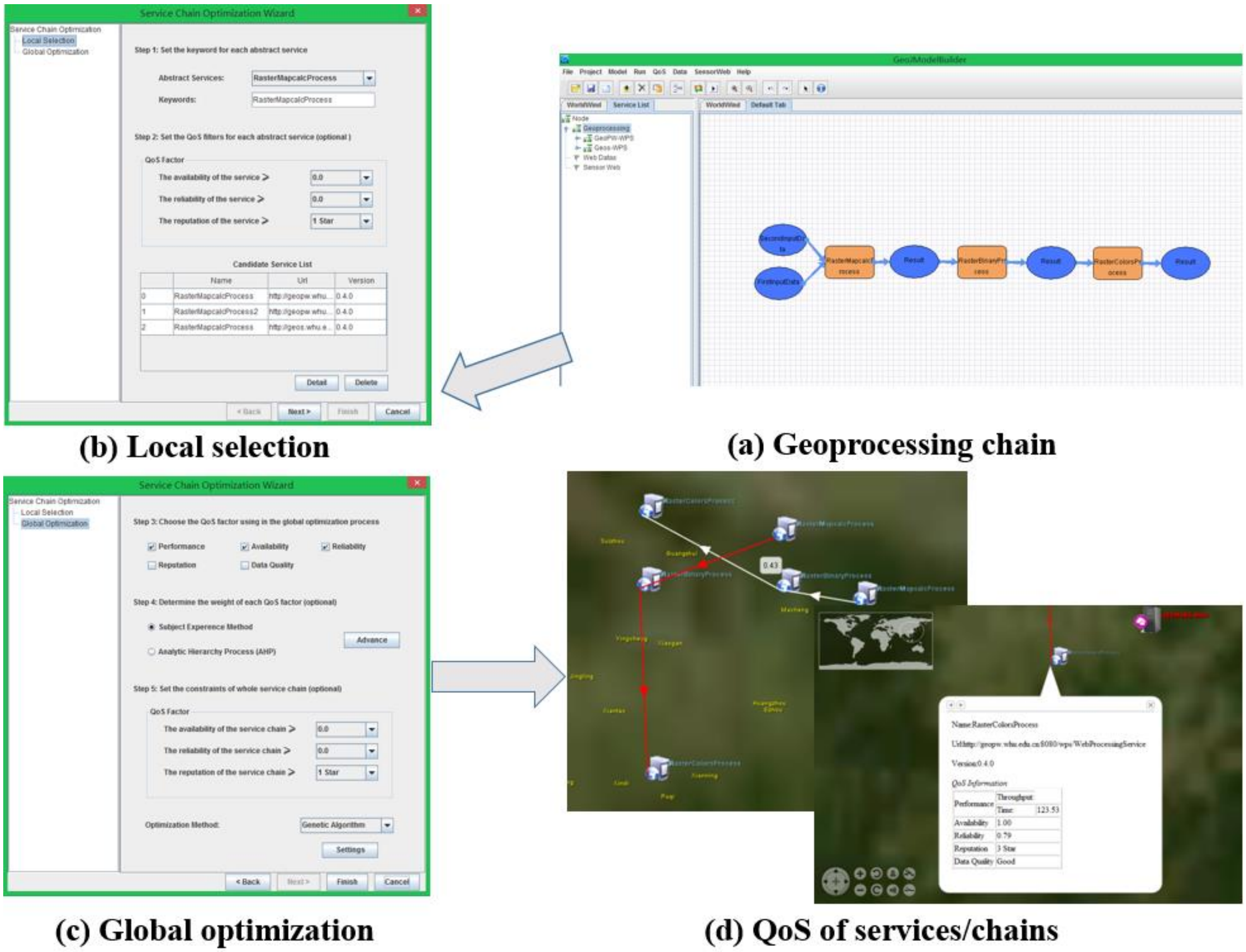
Figure 8. Reputation statistics



(a) Provenance **(b) Data quality evaluation**

Figure 9. Data quality evaluation

Figure 10 illustrates the optimization for geoprocessing chains. It includes local selection and global optimization. The local selection is to select a set of candidate services, while the global optimization will determine the best combination of services.



(b) Local selection

(a) Geoprocessing chain

(c) Global optimization

(d) QoS of services/chains

Figure 10. Optimization of geoprocessing chains

Figure 10d shows the optimization result using the genetic algorithm. The optimization result (the red line) is visualized in the WorldWind. Users can change service bindings by selecting alternative services, and then check the global QoS value when moving the mouse pointer to the updated chain (the white line).

It is noted that some steps in wizards are optional. Some of them are designed to be advanced options. Users can edit default values of them when necessary.

4.2 RESULT ANALYSIS

The applicability of the approach is demonstrated by an open source software that is capable of doing QoS evaluation and geoprocessing chaining optimization. Users' preference and constraints on QoS are supported in selection and composition of geoprocessing services. The software is coupled with a geoprocessing chaining tool to facilitate the QoS-aware geoprocessing on the Web.

Through the research and implementation experiments, several issues that are important for the practical use of QoS-aware geoprocessing services have been identified:

(1) A practical set of QoS attributes and monitoring: During the evaluation process, we found that some QoS attributes are hard to measure or determine. Some of them are fuzzy and without clear referential boundary. Also some of them are based on past information, and cannot reflect the current status. Due to the dynamic and unpredictable nature of the Web environment, the runtime status of services, often continuously monitored, is important for robust execution of services or chains. At present, availability is the primary issue in QoS in most cases. In the data quality evaluation, although we offer various methods such as comparison with reference data and provenance-based evaluation, the most practical solution is to prepare benchmark datasets for different types of geoprocessing services. Using the same benchmark dataset, it is then possible to compare output data quality of services that provide the same function using different algorithms. This provides an objective way for quality evaluation in terms of geoprocessing functions.

(2) Standardization of process quality: The quality requirements for various geoprocessing functions are different, such as the second level quality elements in Table 2. These quality requirements could be regulated and formalized. For example, a set of quality elements for map conflation services could be formalized as a profile to the general quality requirement.

Similarly to the rationale for developing WPS profiles, quality profiles for WPS processes could be a promising approach in supporting interoperability of process quality.

(3) Interactive GUI for QoS-aware geoprocessing: The full automation of QoS-aware geoprocessing is still an ongoing research activity. However, human-involved QoS evaluation is practical for sophisticated domain applications. Sometimes it is better to provide recommended information such as a set of candidate geoprocessing services with QoS to assist users in selecting services. Users might want to compromise their initial QoS requirements when aligning existing services for their geoprocessing tasks. Thus an easy-to-use interactive GUI could significantly facilitate QoS-aware geoprocessing.

5. CONCLUSIONS AND FUTURE WORK

This paper presents approaches and development towards the QoS-aware geoprocessing on the Web. As more and more geoprocessing functions are available in a Geoprocessing Web environment, QoS-aware selection and composition of geoprocessing services will be a key issue in providing effective geoprocessing in a distributed environment. The paper discusses QoS attributes for geoprocessing Web Services, describes methods for measurement and evaluation of geoprocessing services, and proposes strategies for optimization of service chains when developing geoprocessing workflow. By adopting different evaluation methods for different QoS attributes, the QoS results can assist users in selecting the most suitable geoprocessing service. When combined with past and current QoS measurements, GeoQoS can not only generate a service chain with best QoS in the workflow generation step, but also ensure that the service chain works smoothly at runtime.

GeoQoS is being developed to provide more evaluation models and optimization algorithms. In addition, interactive and user-friendly GUI is being designed to facilitate the use of GeoQoS. We will investigate more cases on process quality to promote the interoperability of the quality of geoprocessing services. The experience in developing GeoQoS also helps enhance the previous work on semantics-based service discovery, chaining, and geoprocessing modeling, by fully considering data, functional, execution, and QoS semantics of geospatial services [28].

6. ACKNOWLEDGEMENTS

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