Towards a Research Agenda for Geoprocessing Services

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ABSTRACT

Geoprocessing services are currently a hot topic in research and industry for enabling the dynamic generation of web-based geoinformation in Spatial Data Infrastructures. An overview and an in-depth analysis of this new approach are missing yet. However, they are necessary to support upcoming projects and to streamline research towards fully web-based geoinformation. Thus, this paper provides a detailed overview about recent publications and projects concerning geoprocessing services. Research commonalities among these works are extracted. Based on this analysis, a research agenda for geoprocessing services is formulated and discussed. The research agenda identifies three major research issues, which are promising for enabling web-based geoinformation: Semantic descriptions of geoprocessing services, orchestration of geoprocessing services and approaches for performance enhancements.

Keywords. OGC WPS, Geoprocessing Service, Research Agenda, Semantics, Orchestration, Performance, Geoprocessing.

1. INTRODUCTION

Increasing network capabilities and processing power enable distributed geoprocessing on the web. It thereby becomes a promising application to provide web-based geoinformation. Web-based geoprocessing is the next logical step (Kiehle et al. 2007), as geodata has become largely available through Spatial Data Infrastructures (SDI) (Groot and McLaughlin 2000). Moreover, extracting geoinformation from web-based geodata is an important issue for applications in which decision makers have to integrate multiple sources to answer questions regarding a geospatial context. Web-based geoprocessing is also promising to establish distributed platforms for large scale computational calculations such as complex simulation models. In particular, interoperable geoprocessing services can be chained to create new value-added chains (Alameh 2003).

In this context geoprocessing services attracted various attentions by research and industry bodies (ESRI 2006). Geoprocessing services have been identified as the means for creating web-based geoinformation from available geodata. The first official release of the Web Processing Service (WPS) interface specification also indicates that geoprocessing services are becoming an integrative component of standardized geoservices (OGC 2007). Geoservices are the family of Web Services concerning any handling of geospatial data. These are usually subdivided into three categories: data services, processing services and registry or catalogue services (Alameh 2003).

Since several research projects, different vendors and Open Source projects carry out work in the context of geoprocessing services, an analysis of their results is promising to identify bottlenecks, future challenges and future applications. This paper provides an inventory of related projects and applications. Additionally, it structures the achievements and open issues. Finally, this paper will provide a research agenda, which identifies the main obstacles regarding geoprocessing services and can thereby serve as input for future projects of commercial or research bodies.

The presented list of project does not claim to be complete, but should rather provide a sufficient overview. The research agenda described in this paper is based on literature study and practical experience of the authors.

2. RELATED WORK

In the context of web-based geoprocessing, the WPS interface specification evolved as the de-facto standard (current version of specification 1.0.0). It provides a straight-forward approach to publish and execute geoprocesses on the Web using XML-technology. It is a step towards instant and on-demand transformation from geodata to geoinformation on the Web. The specification provides service and process metadata and a means to execute the desired process according to the parameter requirements of the specific client. The WPS interface specification features a communication mechanism for asynchronous message exchange, which is promising for implementing efficient client-server communication. The specification also provides a means for automated discovery of geoprocesses via profiles. These WPS profiles are common process descriptions, which can be referenced by service providers in order to specify a designated process as being similar. For instance, a buffer process could be annotated as a buffer process by referencing a profile for buffering.
Table 1 lists the currently available implementations of the WPS 1.0.0 interface specification.

Name	**Programming Language**	**Website**	**Literature**
52°North WPS	Java	www.52north.org/wps	Schaeffer and Foerster 2008; Brauner and Schaeffer 2008
PyWPS	Python	Pywps.wald.intevation.org	Cepicky and Becchi 2007

Table 1: Software implementations of the WPS interface specification version 1.0.0.

In the context of SDIs and geoprocessing services, several applications have been developed. Table 2 provides an overview of selected applications and groups them according to their specific aim.

In addition to the reported efforts regarding web-based geoprocessing applications, the drawbacks of current standardized geoprocessing on the Web have been analyzed. Friis-Christensen et al. (2007) examined the drawbacks regarding a Service-Oriented Architecture (SOA) based on GI-Services. They discovered that performance of web-based geoprocessing involving multiple processing instances is crucial. Thus, they propose to limit the data transfer between client and server. Following their proposal, data transfer can be limited by:

- using asynchronous client-server communication
- reducing the resending of data to the same processing service instance
- processing the data at their source by sending the processing code to the client instead of sending the data to the server.

These three options have been discussed in the context of the WPS interface specification. The authors suggested that enabling such features requires a fundamental change of the WPS interface specification.

Kiehle et al. (2007) also analyzed the drawbacks of web-based geoprocessing. They identified the lack of automatic service chaining capabilities (i.e. chaining of processes without human interaction) for complex processes. This lack results from missing semantic capabilities in the process descriptions. Semantic descriptions would not only enable automated service chaining but also enable intelligent processing of data using for instance self-organizing nets.

Bernard et al. (2005) developed a research agenda for SDI in general. They outline the importance of granularity for GI processing, semantic aspects, organizational and implementation issues for SDI, economics of GI and differentiation of SDIs versus other information infrastructures. Especially their statements concerning the granularity of GI processing (which leads to service orchestration) and the semantic of geodata and geoservices are relevant for geoprocessing services.

Category	**Project Name**	**Website**	**Selected literature**
Raster-based processing	AWARE	www.aware-project.net	Granell et al. 2007
Grid computing	GDI-Grid	www.gdi-grid.de	Baranski 2008; Lanig et al. 2008
	SEE-GEO	edina.ac.uk/projects/seesaw/seegeo	Koutroumpas and Higgins 2008
	ESDISP		Di et al. 2003
Automated Generalization	DURP ondergronden	www.durpondergronden.nl	Foerster and Stoter 2006
	WebGen	webgen.geo.uzh.ch	Neun 2007; Foerster et al. 2008
Schema Translation in INSPIRE			Lehto 2007
Wrapping existing (desktop) GIS			Díaz et al. 2008, Brauner 2008, Brauner and Schaeffer 2008
Spatial statistics	INTAMap	www.intamap.org	de Jesus et al. 2008; Henneböhl and Pebesma 2008
Client for workflow processing		www.52north.org/wps	Schaeffer and Foerster 2008
Integration into mainstream application		www.52north.org/wps	Foerster et al. 2009
Spatial Decision Support Systems (SDSS)	OK-GIS	www.ok-gis.de	Stollberg and Zipf 2007
	ORCHESTRA	www.eu-orchestra.org	Friis-Christensen et al. 2007
	AWARE	www.aware-project.net	Díaz et al. 2007
	ImmoSDSS_RLP	www.i3mainz.fh-mainz.de/Article300.html	Stollberg and Zipf 2008
SDSS / Multicriteria Evaluation	SoKNOS	www.soknos.de	Müller et al. 2009

Table 2: Overview of developed geoprocessing applications.

3. RESEARCH COMMONALITIES

Based on the related work shown above, this section provides a structured view of the different geoprocessing research efforts.

Research about geoprocessing services can be categorized into two types: First, the research focusing on generic problems of geoprocessing services, e. g. service orchestration or performance issues. Second, the research addressing specific application domains by the means of geoprocessing services (e.g. spatial decision support or spatial statistics). Three main research commonalities can be identified which are issues in different application domains: orchestration of Web Services providing geoprocessing functionality, their semantic descriptions and their performance.

The orchestration of Web Services to complex processing chains is especially relevant for geospatial applications, since their complexity (geospatial data and application problem) often requires the functionality of several geoprocesses. These orchestrated sets of Web Services are often referred to as workflows or service chains. Kiehle et al. (2007), Friis-Christensen et al. (2007) and Brauner and Schaeffer (2008) propose to use the Business Process Execution Language (BPEL) in combination with WSDL to execute such workflows. Schaeffer (2008) additionally proposes a transactional interface for the WPS (WPS-T) to offer the whole workflow as a single WPS process. Friis-Christensen et al. (2007) compare three possible chaining methods according to ISO (transparent, translucent and opaque chaining), and conclude that translucent chaining works best in combination with BPEL and in some cases this approach improves processing performance. Bernard et al. (2003) describe translucent chaining as “the way forward”. Stollberg and Zipf (2007, 2008) propose to use the WPS specification to realize complex processing chains over the BPEL approach due to missing WSDL descriptions for WPS processes. Brauner and Schaeffer (2008) present a first attempt to solve this problem by applying a dynamic XSLT transformation to create the WSDL documents. Sancho-Jimenez et al. (2008) used a proxy approach to address the same problem. Especially in the orchestration context, mainstream IT standards like SOAP/WSDL are often discussed to be applied to geoprocessing services in general (Kiehle et al. 2007; Friis-Christensen et al. 2007).

It is commonly agreed on that for finding and orchestrating geoprocessing services automatically, semantic descriptions are essential (Lemmens et al. 2007; Di et al. 2005; Bernard et al. 2005; Bucher and Jolivet 2008). Two approaches are mainly proposed: First, applying WPS profiles as a means to classify geoprocessing services into domain specific processes (Stollberg and Zipf 2007, 2008; Brauner and Schaeffer 2008; Müller et al. 2009; Nash 2008). Nash (2008) presents initial ideas on how to use them. Second, several publications suggest to explore the deep service descriptions of Lemmens et al. (2007) further (Brauner and Schaeffer 2008; Bucher and Jolivet 2008; Diaz et al. 2007; Kiehle et al. 2007). Lutz (2007) developed highly detailed ontology-based descriptions for semantic discovery and composition of geoprocessing services. Fitzner and Hoffmann (2007) try to integrate the approaches of Lemmens et al. (2007) and Lutz (2007) following the logical programming (LP) paradigm. Gone and Schade (2008) compare a semantic BPEL-based approach to OWL-S.

Performance is reported to be crucial in the context of geoprocessing services (Kiehle et al. 2007; Scholten et al.; Tu et al. 2004; Di et al. 2003, Baranski 2008, Bernard et al. 2005). Processing power and network bandwidth are identified as being the limiting factors which need to be tackled. Most often asynchronous service communication is proposed in the first place (Kiehle et al. 2007; Scholten et al; Tu et al. 2004). Secondly, applying Grid Computing or related methods and technologies as a means to solve large-scale problems is reported to be promising. Baranski (2008) and Lanig et al. (2008) extended the work of Di et al. (2003) and accomplished first experiments using Grid Computing technology for improving processing performance by distribution and parallel execution of processes. In the OWS-6 (OGC 2009) testbed, several WPS profiles for accessing applications in different Grid Computing environments are reviewed. Furthermore, it is often proposed to bring the algorithm to the data, in the sense of shipping code or executables from the server to the client (Bernard et al. 2005; Friis-Christensen et al. 2007; Granell et al. 2007). This is sometimes called the *moving code* paradigm. To our knowledge, this approach was never explored any further for geoprocessing services.

Besides the research related to generic problems of geoprocessing services, several activities address geoprocessing services in the context of different applications (Table 2). By doing so, these research areas touch certain generic problems, but their research focus is non-competitive regarding the research commonalities analyzed in this paper. In terms of standardized interfaces for geoprocessing services, the application-oriented research demonstrated already sufficiently that the WPS interface is indeed applicable in a universal manner. This has lately also been demonstrated by Foerster et al. (2009) using mass-market applications (i.e. Google Earth) to access geoprocessing services. However, most of the projects encounter a lack of performance when integrating geoprocessing services into their applications, especially in the case of large scale data sets (raster-based data or automated generalization processing). Additionally, semantic service descriptions are identified as relevant. WPS profiles are considered as a first attempt to enable automatic discovery, chaining and execution of geoprocessing services. For instance, Foerster et al. (2008) describe a WPS profile for automated generalization processing based on the WPS interface. Additionally, practical experience has shown that existing standards might sometimes be too complex for specific applications, as Stollberg and Zipf (2007) claim for the case of service chaining.

4. A RESEARCH AGENDA FOR GEOPROCESSING SERVICES

The review presented in the previous sections serves as a basis for the research agenda, which will be described below. The overview in Section 2 already indicates, that the use of geoprocessing functionality is adaptive in many different application scenarios ranging from simple schema translations for INSPIRE to more complex decision support in emergency situations. Therefore, the research agenda proposes strategies to improve generic web-based geoprocessing, which are important for a larger number of different application contexts.

After analyzing the research commonalities in the previous section, we propose three main research topics for a research agenda which are promising to enable web-based geoinformation by the means of geoprocessing services (Figure 1):

- Service orchestration
- Semantic descriptions
- Strategies to improve performance.

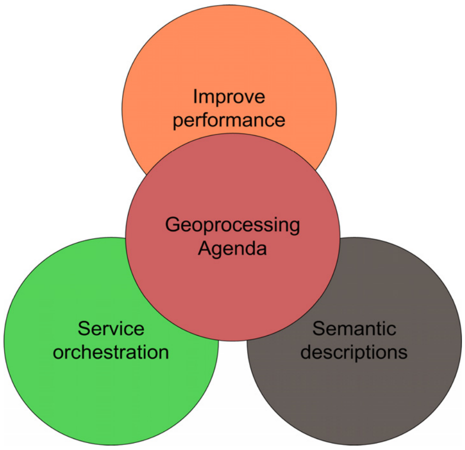

Figure 1: Identified components of the geoprocessing agenda.

In most cases, the complexity of geodata and the given application problem often require the functionality of several geoprocesses and have led to workflows, in which each element performs an isolated task while the whole workflow addresses a much broader problem (Gehlot and Verbree 2006). The workflow often reflects a business process (Leymann and Roller 2000) and supports it through an automated way (Chiu et al. 2002) (see Figure 2). In highly specialized fields such as geospatial applications, not every processing step can potentially be handled by a single entity. In addition, the delegation of certain processing steps of a business process to external partners fosters the quick adaptation of changing requirements (Weerawarana 2006) and leads to higher flexibility and scalability of those processes. Furthermore, it is often more cost-efficient to outsource highly specialized or seldom used tasks. This has been extensively studied in the Business Process Outsourcing (BPO see e.g. Halvey and Melby 2007) domain and should also be applied to the SDI field.

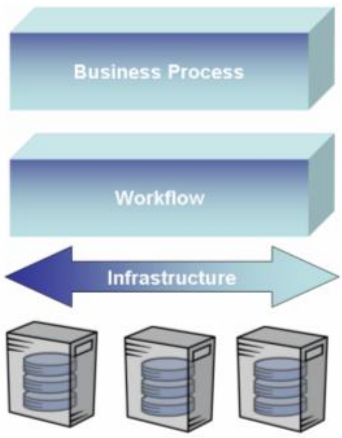

Figure 2: Mapping business processes to SDI service chains.

For the future, mapping of business processes to workflows in an SDI is promising to establish new business models. For instance, specialized geoprocesses could be offered as services. Amongst other things, dynamically negotiated Service Level Agreements (SLA) between service consumers and providers - and corresponding service quality guarantees - could be applied in that case. Constrained processes could be outsourced on an on-demand basis to specialized processing service providers which are able to guarantee certain Quality of Service (QoS) factors like service availability, service accessibility, the processing in a certain time frame or the processing until a specific quality (e.g. resolution for rasterization processes) is reached.

Grid Computing and related approaches from the field of High Performance Computing play a key role for service providers to allocate sufficient computational power to fulfil the needs of service users to perform large scale processing tasks satisfyingly. Integration of SLA in mature grid middleware and the application of Advanced Resource Reservation mechanisms in grid infrastructures will enable service providers to guarantee promised service qualities to service users (particularly processing performance).

The paradigm change comes along with *Cloud Computing* as one of the next hypes in mainstream IT technology. Cloud Computing is important for providing such scalable and failsafe environments on an on-demand and pay-per-use basis. This is also promising for geospatial applications to enable new and promising business models.

However, partners will only conduct business if their (geo) rights, trust relationships and security requirements are met. This crucial point becomes especially important, when partners need to know who accesses their services (Authentication), and if the requester is allowed to obtain the requested resource (Authorization) or if the requester has to pay for the requested resource (Accounting). This is typically known as AAA, but not yet completely addressed in current OGC specifications. To make OGC Web Services (OWS) and OWS-based SDI's ready for commercial usage, the OGC GeoRM Working Group aims at establishing a trusted infrastructure for purchasing, managing and protecting rights of digital content. In terms of mapping spatial related business processes (as for instance shown by Brauner and Schaeffer 2008) to geoprocessing workflows, the integration of secured services in a workflow as well as securing or even licensing such a workflow on an on-demand basis has not yet been studied. The problem of delegating rights and managing trust relationships becomes evident in those geospatial applications that enable new business models combining geoservices (hosted in an SDI) and the Cloud Computing paradigm.

This vision of instant chaining of geoprocessing services from different applications will only be feasible with the promised advent of the Semantic Web (Berners-Lee and Fischetti 1999). Semantic problems especially arise when an automated and problem-driven service discovery and orchestration has to be carried out. This case is envisioned by the Semantic Web and applied to SDIs by Bernard et al. (2005). Kiehle et al. (2007) even identify this problem as "one of the next frontiers in Geographical Information Science". Various research has been carried out concerning modelling semantic service descriptions by the means of ontologies (e.g. Lutz 2007). Mostly, semantic and syntactical descriptions are handled separately (Lemmens et al. 2007). Lemmens' deep service descriptions integrate the semantic and syntactic descriptions into another. We propose to follow this approach and make the semantic description operational at first and then integrate Lutz's (2007) more sophisticated approach. (Geo-)information becomes more and more important but at the same time the orchestration and data compatibility issues remain on the expert user side (Bernard et al. 2005). Automated service orchestration is the key approach to tackle these issues. Therefore, applications have to be able to read semantic descriptions and reason with them. This is a complex and sophisticated task and a research goal in the long term. In the meanwhile, we propose to reconsider the work of Tomlin (1983) and Albrecht (1996) and similar approaches, to create a taxonomy for GIS operators, this time taking geoprocessing services into account. Furthermore, an algebra (as we would like to call it) should be developed to concatenate geoprocessing services based on strict allegations for what is allowed and what is not. The work of Chakhar and Mousseau (2007) might be a starting point. They showcased an algebra for multicriteria spatial modelling. Special attention should be paid to eligible input and output data, including quality of data and service aspects. Several publications propose to consider WPS profiles (as defined in OGC's WPS specification) to overcome certain problems regarding meaningful descriptions of processes.

As instant and on-demand geoinformation is a overall goal for most of the applications involving geoprocessing services, performance is a key issue. Therefore, three research aspects are promising to improve performance of large scale data handling within geoprocessing services:

- Bringing the service to the data (moving code paradigm)
- Enabling Grid Computing technologies
- Enabling stateful communication with the service.

The moving code paradigm to bring the actual service to the data, instead of the classic approach (data is tightly coupled or the data is brought to the service), is not new, but was never further explored. This is due to the fact that the administrative overhead to establish such a framework is massive and the data servers are usually not optimized for computational power. The biggest challenge to apply the moving code paradigm is to establish a mechanism that is able to execute arbitrary processes on every machine. Beyond the Grid Computing approach, the actual geodata has to be available on every grid node. This leads to further problems to keep the data up-to-date and in the same state at every machine with a minimum of data transfer. New mechanisms have to be invented, that enable a synchronization of the (mostly binary raster) data sets, which are necessary for the specific process. We propose to examine the *rsync* protocol (Tridgell 1999) or similar technologies for this purpose.

Beside this moving code paradigm, only few experiments have yet been carried out concerning integrating geoprocessing services into a Grid Computing infrastructure (OGC 2009), although computational power and networking bandwidth have increased constantly for complex web-based geoprocessing in the past.

The Grid Computing approach (Foster and Kesselman 1998) or related methods and technologies from Distributed Computing domain are typically used to improve service availability or to speed up service performance. To improve availability, incoming processing tasks are typically submitted for execution to available computing nodes on the Grid infrastructure. To speed up performance, they are divided into smaller sub-tasks if applicable (following a classic Divide-and-Conquer approach). If tasks are indivisible, the Grid infrastructure can be used to find the laziest node for processing. Afterwards, the results from the sub-tasks have to be reintegrated into an overall result. Geoprocesses are often considered to be very complex and therefore the effort to divide and conquer them is in most cases very high (see for example Hazel et al. 2008). However, in some cases the Divide-and-Conquer approach is not applicable. Therefore, we propose that Grid Computing technologies should be further examined, with a special focus on a structure to determine when and how to divide what kind of geoprocesses in order to enable parallel execution.

Geoservices as well as mainstream Web Services (e.g. Google, Amazon and eBay) are meant to be stateless and thereby implement a stateless design principle for Web Service interaction. *Stateless* means that all parameters that are needed to perform the process have to be present before executing it. No further user interaction is possible during runtime. In the case of geoprocessing services, the usual internal workflow does not only encompass the processing, but also the import in internal data formats and the export of data. These additional runtime expenses, especially when considering orchestrated workflows, should be measured. To reduce them, stateful communication is a means. We support the proposal by Keens (2006) to explore the Web Service Resource Framework (WSRF) to enable stateful processing.

5. CONCLUSION

Enabling geoinformation on the web is currently identified as an important goal for research and applications. In this context geoprocessing services provide a means to realize this vision. This paper analyzes commonalities regarding research about geoprocessing services and derives a research agenda accordingly.

The developed agenda identifies three main issues. Service orchestration is promising to enable value added chains and to establish new SDI business models based on outsourcing processing tasks to specialized providers in a secure manner. The Cloud Computing paradigm seems to be a promising aspect especially for outsourcing processing tasks. Therefore it has to be further studied in the context of SDIs. However, beyond technical obstacles such as security, licensing and trust relationship management, missing semantic interoperability seems to be the limiting factor to enable automated service orchestration. In this context, the creation of semantic service descriptions is considered as being essential. From an application-oriented perspective, performance is identified as another obstacle when using geoprocessing services. Grid Computing technologies can be used to overcome these limitations but further research is essential.

In the future, those three research aspects could be again subdivided into more fine-grain aspects. At the current stage the research agenda is based on an analysis of the current issues related to geoprocessing services. This includes a comprehensive overview of current activities in research and industry, as presented in Section 2.

Finally, the research agenda will be beneficial as input for related projects of commercial or research bodies in the future. The research agenda might be refined in the future by projects, which involve different bodies and aim at prototyping and testing specification in a large scale and cross-institutional manner (e.g. Persistent Testbed (PTB); Hobona et al. 2009; website: http://plone.itc.nl/gitestbed).

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