Ontology-Based GI Web Service Discovery for Service Composition

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Geographic information science is currently characterized by a paradigm shift – from theories for monolithic systems to theories for open and distributed GIS and their use processes. With this comes a move from standardized data formats to specifications of geographic information (GI) service interfaces [1, 2]. In practice, the number of GI services available on the web is rapidly and continually increasing.

While at present, these services are generally isolated, stateless applications, their composability is often perceived as greatest value as this enables more complex processing tasks [3]. First attempts at composing GI web service have been made. However, these relied on manually and statically coupling existing services [4] while for future applications service composition is envisioned to be automated [5].

The component GI services from which such complex services are composed, fall into three categories: Services providing data, which are usually the starting point for any complex GI service, geoprocessing services, which perform some kind of computation or analysis on the provided data, and presentation services, which present the result of a complex service to the user. As both the functionality of data and representation services are relatively limited and service interfaces for them are standardised and in widespread use, the focus of this thesis is on the most diverse category of geoprocessing services.

The starting point for (manually or automatically) composing a complex service is always a specific problem. Discovering services that are appropriate for solving this problem from among a large number of available services is a central task within the GI web services domain [6]. Descriptions of service capabilities (i.e. of what the service does) and of the requirements resulting from the given problem are key elements during service discovery, which is essentially about finding a match between the two [TBD].

During service discovery for (semi-)automatic service composition a match has to be ensured for two parts between the semantic descriptions of the service and the user requirements: (1) for the semantics of the operation (or functionality) and (2) for the interfaces of adjacent services. The first point ensures that the service actually does what the user expects it to do, the second point ensures that the service correctly interprets the data it receives as input from the preceding service and/or that it provides its outputs as is expected by the succeeding service. The latter is further complicated by the fact that the syntax and structure of the exchanged data can differ between services, too. This problem can be solved by using mediators. Identifying and configuring the mediators required for a complex service should also take place during service composition.

The methods and tools currently employed are not adequate for automated service discovery, let alone the more complex task of automated service composition [TBD]. In the work presented here it will therefore be investigated how the discovery of GI web services can be enhanced in order to enable (semi-) automated service composition.

Problems During State-of-the-Art GI Service Discovery

To facilitate the discovery and access to geospatial information, Spatial Data Infrastructures (SDIs) are currently being set up within regions, countries and even across borders [7, 8]. In these SDIs, catalogue services are used for discovering appropriate data and services for a specific task. In order to facilitate searching these catalogues standardised metadata templates have been developed, most notably those defined in ISO-DIS 19115 [9] for data and 19119 [10] for services. In the latter specification, two metadata items are defined that contain information about the capabilities of a service: operationDescription and serviceType.
The item operationDescription describes the intent and the results of an operation. This item has to be filled using free text, which can lead to the following problems:

- If requesters and providers use different terms (or different languages) for referring to the same concepts, services that might be useful for solving the requester’s problem might not be found at all, i.e. there are false negatives. This is also called low recall.

- Conversely, if requesters and providers use the same term for different concepts, services that are discovered might not be useful for solving the requester’s problem, i.e. there are false positives. This is also called low precision. A query returning false positives is probably most critical in cases where the used concepts differ only slightly, e.g. when both represent water levels but one implies meters and the other centimeters as a unit of measure, because in such cases the discovered service will produce erroneous results which might go unnoticed.

These examples show that keywords used in free-text entries have to be considered a poor way to capture the semantics of a query or item [11].

The other metadata item that contains information about the capabilities of a service is called serviceType and contains instances of the service taxonomy specified in [10]. However, this taxonomy is yet too unspecific for providing a reliable basis for a decision on whether or not a given service is appropriate for a given task. This is especially the case for loosely coupled geoprocessing services that are not of a well-known type. The approach of specifying additional service types as “flexible implementations of some one or more interfaces” from an interface hierarchy [12] is not of great help either as for geoprocessing only three interfaces are currently defined in the Transform package.

Currently, a move towards service descriptions using the W3C standards WSDL (Web Service Description Language, [13]) and UDDI (Universal Description, Discovery and Integration, [14]) is being discussed in the OGC [TBD]. However, as these are largely based on free text descriptions and service taxonomies, too, the problems remain the same.

Proposed Solution and Hypothesis

The proposed solution to the semantic heterogeneity and interpretation problems presented in the previous section rests on two theoretical bases: the explication of meaning using ontologies and the theory of function types and subtyping for matching between descriptions of services.

First, an approach is needed that exceeds the capabilities of current free-text search facilities in catalogues by enabling to navigate differences in meaning [15]. [16] suggests to use explicit context models that can be used to re-interpret information in the context of a new application. Ontologies have become popular in information science as they can be used to explicate contextual information. We adopt a modified version of Gruber’s [17] often-quoted definition of the term “ontology” by [18], who defines it as “an explicit formal specification of a shared conceptualization” (a conceptualization being a way of thinking about some domain [19]). This makes the ontology a perfect candidate for communicating a shared and common understanding of some domain across people and computers [18]. Specifications of requirements and capabilities based on ontologies have been successfully used for discovering services in the domain of software agents using a set of techniques for matching between the specifications [20]. These matchmaking methods have also been applied to the domain of web services [21, 22].

Second, the principle of safe substitution of functions [23, 24] provides a theoretical basis for matching between semantic descriptions of service requirements and capabilities. A function f₁ can safely substitute another function f₂ (i.e. the behaviour remains the same) if f₁ is a subtype of f₂. f₁ is a subtype of f₂ if the domain (argument type) D₁ is a supertype of the domain D₂, and the codomain (result type) C₁ is a subtype of the codomain C₂. Thus, the domains of f₁ and f₂ are said to be contravariant (ordered in the opposite direction) and codomains are covariant (ordered in the same direction) with respect to the subtyping relationship between the functions [24].

It is the overall hypothesis of this work that the problems encountered during free text search can be reduced by providing descriptions of requirements and service capabilities based on ontologies describing the operations used in GI services and a mechanism based on function subtyping for matching between them. We will subsequently refer to this proposed method as ontology-based discovery of GI services.
This hypothesis leads to the following research questions:

1. What are the requirements for a formalism for describing services and requirements and for a matchmaking mechanism between these descriptions (from a user’s perspective)?
2. How can the theory of function subtypes be used in a workflow for GI service discovery?
3. How can existing formalisms and matchmaking mechanisms be used for an implementation of this workflow?

**Methods and Results**

The development of our approach to ontology-based service discovery is based on two use cases from the geospatial domain describing specific tasks that are to be solved by a service requester. Problems during state-of-the-art service discovery are identified by comparing actual with expected results for a number of discovery scenarios. These scenarios are later used as test cases for comparing the ontology-based with the current keyword-based approach.

The use cases are also analysed to derive requirements for a methodology for ontology-based discovery of GI services based on the theory of function subtypes. In this workflow, available operations are described by specifying inputs, outputs and behaviour. Requirements are formulated by specifying an ideal operation, i.e. in the same way as available operations. An operation is considered a match for the requirement if it is a (function) subtype of it.

In order to actually plug the discovered services together and make the resulting complex service executable, wrappers/mediators will have to be included in many cases, e.g. if the syntax of interfaces of adjacent services differs.

**Ideas for solution for mediation -- TBD**

So-called template operations, which are part of the available domain ontologies, play an important role in this approach. Their specifications, which do not have to be complete, comprise the input and output types and behaviour of the operation. They provide templates for formulating descriptions of requirements and capabilities, which have to be (function) subtypes of template operations. Thus, template operation constrain the descriptions created by service providers and requesters and ensure greater recall during service discovery. In order for this approach to work, the same domain ontology (shared vocabulary) has to be used by service providers and requesters. Therefore the basis for template operations and concepts for input/output should be widely agreed-upon standards such as the ISO 19100 series of standards or the specifications of the OGC. The use of template operation might also create additional requirements during implementation. For example, it becomes possible that the syntax of inputs and outputs does not match exactly with the ontology concepts prescribed by the template operation.

**Further requirements for mediation -- TBD**

The requirements derived from the use cases are also used for identifying an appropriate formalism and associated matchmaking mechanisms and tools for implementing the developed methodology. Possible approaches include subsumption reasoning on Description Logics descriptions (e.g. using RACER), and queries on F-logic and HiLog descriptions (e.g. using Flora-2). The strengths and weaknesses for each of these approaches for implementing the methodology are illustrated. The evaluation will also take into account whether or how well each approach can be used in conjunction with existing catalogues of GI services.

Based on the evaluation, the most suitable approach will be chosen for implementing the developed methodology. A reference ontology of operations used in GI web services will be developed based on the ISO-FDIS 19107 [25]. All ontologies will be formalised using the ontology language used by the chosen matchmaking approach. The implementation will be test using the test cases developed for the use cases and the results will be compared with those obtained using keyword-based service discovery.

The thesis will produce the following results:

- A requirements analysis for GI service discovery in the context of service composition,
a methodology for ontology-based GI service discovery based on template operations and function subtypes,

• a prototypical implementation of the methodology including a reference ontology of operations used in GI web services, and

• an architecture that integrates the developed methodology into the components that make up existing SDIs.

Contents
The remainder of this thesis is structured as follows.

In chapter 2, the relevant background for GI service discovery in the context of service composition is given. This includes a discussion of the difference between service composition and service chaining and the development of an abstract process model of service composition.

Two use cases are described in chapter 3. This chapter also analyses the shortcomings of current approaches for discovering GI web services due to semantic problems. From this analysis, requirements for an enhanced solution for GI service discovery are derived.

In chapter 4, the building blocks for the a methodology for ontology-based service discovery are introduced. These include matchmaking, the theory of subtyping and ontologies. Also, several formalisms for implementing the approach are described.

The methodology for for ontology-based service discovery is then described in detail in chapter 5. This chapter includes guidelines for building the required ontologies.

Chapter 6 presents the prototypical implementation of the approach. For illustration, a step-by-step walkthrough will be given for one of the examples. This chapter also describes the development of an ontology of spatial operations based on the ISO-FDIS 19107.

In chapter 7, the test cases developed in chapter 3 are used to illustrate and discuss the benefits of the new approach and point to remaining issues. The results are also compared to other approaches to ontology-based service discovery.

Finally, the findings are concluded and future research is pointed out in section 8.

References


