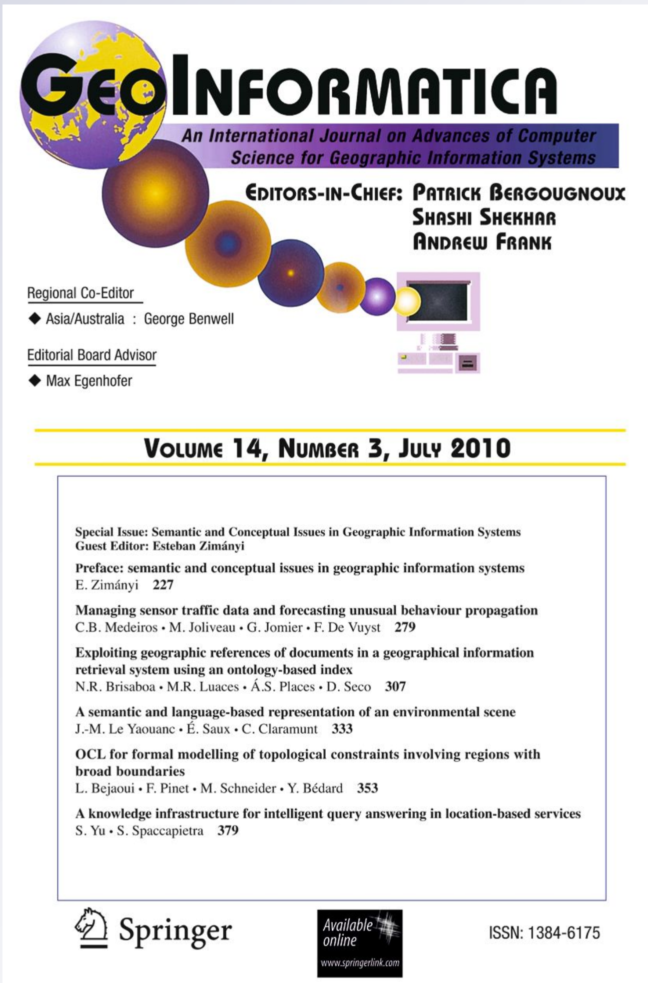
Integrating GI with non-GI services —showcasing interoperability in a heterogeneous service-oriented architecture

Martin Treiblmayr, Simon Scheider, Antonio Krüger & Marc von der Linden

GeoInformatica
An International Journal on Advances of Computer Science for Geographic Information Systems

ISSN 1384-6175

Geoinformatica
DOI 10.1007/
s10707-011-0132-9



Springer

Geoinformatica
DOI 10.1007/s10707-011-0132-9

Integrating GI with non-GI services—showcasing interoperability in a heterogeneous service-oriented architecture

Martin Treiblmayr · Simon Scheider · Antonio Krüger · Marc von der Linden

Received: 2 December 2008 / Revised: 5 May 2011
Accepted: 9 June 2011

Abstract The concept of a service-oriented architecture provides a technical foundation for delivering, using, and integrating software. It can serve as an approach to integrate GIS with other, non-GIS applications. This paper presents and discusses a service-oriented architecture that embraces a GIS and an enterprise resource planning system. The two information systems make mutually required functionalities available as services. This defines the showcase for making GI and non-GI services syntactically and semantically interoperable. The services-based integration leverages open-standard interfacing and, thus, removes syntactic heterogeneity. The integration is discussed in terms of an emergency management scenario. This scenario also helps to outline challenging semantic interoperability issues. When services provided by GIS and non-GIS applications interact, the problem arises how their different conceptualizations should be mapped. This paper analyzes essential ontological distinctions for mapping conceptual schemes in GI locator services and non-GI services. It proposes a hybrid decentralized approach of concept mapping, based on a common top-level ontology.

Keywords Service-oriented architecture (SOA) · Application integration · Enterprise resource planning (ERP) system · Interoperability · Semantic heterogeneity

M. Treiblmayr (✉)
SAP Research Walldorf, SAP AG, Dietmar-Hopp-Allee 16, 69190 Walldorf, Germany
e-mail: martin.treiblmayr@sap.com

S. Scheider
Institute for Geoinformatics, Westfälische Wilhelms-Universität Münster, Weseler Str. 253, 48151 Münster, Germany

A. Krüger
German Research Center for Artificial Intelligence, Stuhlsatzenhausweg 3, 66123 Saarbrücken, Germany

M. von der Linden
SAP AG, Dietmar-Hopp-Allee 16, 69190 Walldorf, Germany

Published online: 29 June 2011

1 Introduction

A service-oriented architecture (SOA) is an abstract concept of a software architecture that is concerned with the provision, search, and consumption of services over a network [1]. For this type of architecture it is negligible which hardware, software, programming language, or operating system is used; this is referred to as technology-agnostic. Therefore, service-oriented architectures are capable to overcome the difficulties in implementing distributed systems and application integration. Data and services in heterogeneous system landscapes can be integrated via standardized interfaces. The Organization for the Advancement of Structured Information Standards (OASIS) suggests a detailed reference model for a service-oriented architecture [2].

Geographic information systems (GISs) have been defined as digital computer applications to capture, store, manipulate, analyse, and display geographic information [3]. Thus, GIS users exploit geographic information for business, administration, scientific, or private reasons. The integration of GIS with other information systems potentially leads to enriched (geographic) information content: Combining the analytical capabilities of two systems helps to better transform data into useful information.

This paper gives an example how a GIS and an enterprise resource planning system are integrated in terms of a service-oriented architecture. Enterprise resource planning (ERP) systems are information systems which capture, schedule, and control business processes in different functional areas of an enterprise (e.g. human resource management, controlling, or logistics). Their origin, however, is in manufacturing; early systems used to be called material requirements planning systems [4].

Throughout this paper it is made clear that service-oriented architectures have the potential to open GIS to other non-GIS applications. This is one motivation for the concept of service-oriented architectures to be a subject of research in geographic information (GI) science. GIS is not always a stand-alone tool in decision support. The application of GIS in emergency and disaster management drives the scenario in this paper: GIS is used for vehicle dispatching and routing, environmental monitoring (in case of natural disasters), and for providing a steadily updated cartographic synopsis. GIS is not designed, however, to assign and manage appropriate units (human resources, equipment, vehicles). Functionalities from an enterprise resource planning system are necessary to do that. The requirements of the scenario thus indicate an integrated use of a GIS and an enterprise resource planning system. The approach taken here dissolves application integration difficulties in emergency management.

On the one hand, the paper screens references that elaborate the concept of service-oriented architectures. A service-oriented architecture refers to a system architecture model. The notion of s*oftware as a service* refers to a business model which is not discussed in this article (see [5, 6] for a discussion). On the other hand, the paper considers references from the field of geographic information science (e.g. on GIS applications in emergency management). Early papers [7, 8] that envision service-orientation for GIS propose architectures for distributing geographic information services. In some aspects these papers at least conceptually anticipate what is now referred to as service-oriented architecture. More recent papers [9, 10] push the discussion to service-oriented spatial data infrastructures; they take on the suggestion to shape spatial data infrastructures towards service-oriented architectures [11]. Thus, the concept of service-oriented architectures has found its way into the GI science community.

The paper discusses main challenges of service interoperability, especially *semantic heterogeneity* [12], from the practical viewpoint of GI service integration into legacy systems. This is still one of the major burdens to successful integration of services and data in general [13]. Data models of and services for geographic information, like the ones proposed by the Open Geospatial Consortium (OGC), have underlying ontological constraints about what constitutes a geographic object and its functionality [14]. Legacy applications like enterprise resource planning systems come with their own, domain specific conceptualization of resources. When services from both worlds interact, the problem arises how their different conceptualizations should be mapped [15], and in general, how they can be compared. This article proposes a hybrid decentralized approach [16] of concept mapping based on a common top-level ontology or on few primitives for semantic referencing [17]. While most authors in this field focus on technical approaches to ontology-based integration [16], this article also discusses essential *ontological distinctions* (in the sense [18]) for mapping conceptual schemes in GI *locator* services and non-GI services.

The paper is structured as follows. Section 2 provides some background about service-oriented architectures. Section 3 discusses the integration of geographic information services and enterprise resource planning services for covering typical business processes in emergency management. The same use case is resumed in Section 4: It illustrates semantic interoperability challenges and ontological engineering approaches to service-oriented architectures for integrating GIS and non-GIS applications. Section 5 concludes the paper.

2 Service-oriented architectures for facilitating GIS integration

The three-tier architecture of traditional information systems consists of a resource management layer (server), an application logic layer (middleware), and a presentation layer (client). This architectural principle has also been applied to GIS. However, GIS also interacts with other (enterprise) information systems in many (business) applications. And the three-tier architecture faces problems with the increasing number of systems to be integrated, also beyond boundaries of companies. While applications are distributed, the middleware remains centralized. It is hard to put standardized middleware protocols and infrastructures into practice throughout a supply chain of companies. The alternative of point-to-point integration between each and every information system leads to many heterogeneous middleware systems that have to be supported.

Alonso et al. [19] argue that these limitations led to the efforts around web services as well as to the shift to a service-oriented paradigm in application development. Liu and Deters [20] argue that the technology of web services is one technology to put the concept of service-oriented architectures into practice. Broadly, a web service is an application accessible to other applications over the Internet. Thus, a web service is a form of a distributed information system. Alonso et al. [19, p 132] define a web service as “a software application with a published, stable programming interface”. The OASIS [21, p 1] defines web services as “self-contained, modular business applications that have open, Internet-oriented, standards-based interfaces”. These definitions emphasize that a web service has to be open, i.e. requires a published interface that can be invoked over the Internet.

Web services expose the functionality of an information system and make it available through open-standard interfaces. They communicate using standards such as the hypertext transfer protocol (HTTP) and the simple object access protocol (SOAP). Interfaces are specified by the web service description language (WSDL) which is based on the extensible markup language (XML). Finally, a *platform* is required for *integrating* web services. This platform maps the messages that the services exchange based on SOAP. The use of open-standard technologies removes *syntactic* heterogeneity. Syntactic heterogeneity occurs when different information systems use incompatible encoding or formats for information [22].

The use of web services also promotes reusability as application components are offered as services. Application components could be reused by calling the corresponding services. In addition, service-oriented architectures allow interacting software components to be loosely coupled and to communicate dynamically at runtime as opposed to a static compile-time binding.

For years, academia and industry have argued that GIS has spatial data models that are distinct from those of other software environments (e.g. [22, 23]). This makes GIS compatibility difficult. The OGC has focused on interoperability of GIS since its existence. It has proposed among other services a standardized web map service and a web feature service. These services are approaches to provide geographic information through a service. Further, the web processing service defines a standardized interface that allows geospatial processes to be published and discovered [24]. Thus, a web processing service can offer any sort of GIS functionality to service consumers across a network. It should be added critically though, that these OGC services are not necessarily aligned with the mentioned standards SOAP or WSDL. This could also be seen as one of the reasons why many of the discussions about service-orientation in GIS, or particularly spatial data infrastructures, focus on the interoperability within the geospatial domain itself. This discussion is justified because further integration of geographic data, information, and services is desirable. However, the advantage of a service-oriented architecture goes beyond accessibility to data and information within the geospatial domain. Service-oriented architectures enable the exchange of services beyond the boundaries of GIS.

3 Integrating GI services with enterprise resource planning services for an emergency management use case

This section introduces a services-based integration of a GIS and an enterprise resource planning system for an emergency management use case. Typical emergency management processes are described in terms of functionalities as services of service-oriented architectures. The coupling of these GI and non-GI services is especially interesting from a semantic perspective that is adopted in Section 4.

3.1 An integrated architecture for covering emergency management processes

Emergency management requirements suggest an integration of GIS and enterprise resource planning systems. Location information about an incident is critical to emergency management organizations. The application of GIS in emergency situations has been discussed in literature [e.g. 25, 26]. To allocate personnel, vehicles, and equipment efficiently, emergency organizations deploy enterprise resource planning systems; these systems are not designed to solve inherently spatial problems, though. Thus, the interplay between enterprise resource planning systems and GIS is reasonable to assign units to an incident: Units as they are maintained in the enterprise resource planning system can get visualized on a map and spatially analyzed by the aid of a GIS.

As a result of a corporate research project that the authors were involved with, ESRI[1] and SAP[2] have built a joint solution for emergency management organizations (endorsed

[1] ESRI Inc., a GIS company, http://www.esri.com
[2] SAP AG, a provider of enterprise resource planning systems, http://www.sap.com

business solution "Geospatial Enablement for Public Security", abbreviated "GEPS"). Needed parts of the software are provided as services. Services exchange messages synchronously based on the hypertext transfer protocol (HTTP) and the simple access object protocol (SOAP). The web service description language (WSDL) is used to describe SAP interfaces.

The ESRI-SAP-solution integrates functionalities from a GIS and an enterprise resource planning system, based on a service-oriented architecture. This architecture can be referred to as a service-oriented architecture *by evolution* as *existing* software is modularized and delivered as a service. Figure 1 provides a structural view of this architecture. The illustration has been adapted from original architecture design work that the authors contributed to. Dashed lines in Fig. 1 indicate not yet implemented parts of the architecture.

SAP provides services from its enterprise resource planning solution for defense forces and public security (SAP ERP-DFPS); these services are referred to as enterprise services. Business add-ins (BADIs) are interfaces to other possible services to be implemented. ESRI's ArcGIS Server runs the necessary GIS services (map services, locator services, route services, geoprocess services, geodata services). SAP's NetWeaver Java Enterprise Edition (NW JEE) serves as the platform in the proposed service-oriented architecture.

One service often reflects a single business process. In a "standard" emergency situation, one of the first processes is to determine the location of the incident. An agent enters a reported postal address into his information system. A service is called in the background to geo-reference this address and to generate a map. The agent does not necessarily handle the graphical user interface of a GIS to do that. After the incident is located, appropriate units have to be allocated to the incident. This is a typical task that is carried out by the aid of an enterprise resource planning system.

The SAP ERP-DFPS solution enables units to be displayed in so called "force elements"—organizational entities that link personnel, material, infrastructure and accounting

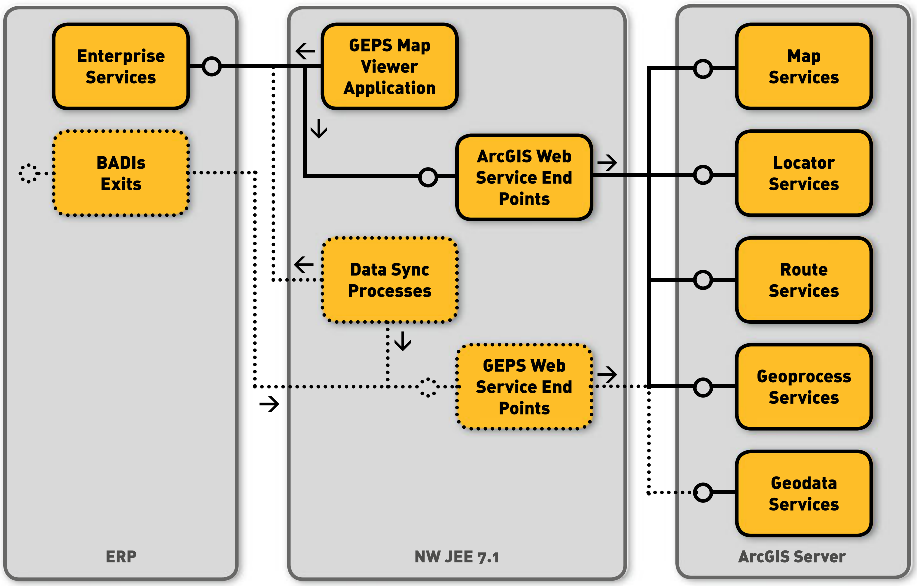


Fig. 1 Structural view of the service-oriented architecture integrating a GIS and an enterprise resource planning system (*dashed lines* indicate not yet implemented parts)

information. In addition, this solution allows to re-arrange operational teams. The corresponding functionalities (e.g. set a force element from "operational" to "mission" mode) are available as services. A service provides the units as they are recorded in the enterprise resource planning system to the GIS (WSDL is used for service description). This service is discussed again in Section 4 of the paper to illustrate semantic heterogeneity problems.

The service that provides the unit information is not specifically shaped for GIS requirements. It contains pairs of coordinates attached to the units. The GIS backend receives the message and with matching it against its own datasets it can display the units on the map of the incident. Unit information is accessed by selecting the units on the map. Classic GIS analysis (e.g. buffer zoning) can be carried out. As a result, units can be assigned taking into consideration geographic information. The enterprise resource planning system and the GIS both contribute to data analysis and, thus, enhance the information content.

3.2 Data storage

Particularly in emergency management many organizations have used enterprise resource planning systems and GIS—separately—for a long time. Organizational structures and asset data (e.g. on critical infrastructures) are stored in the corresponding databases of the GIS and the enterprise resource planning system.

This leads to large attribute datasets in GIS. GIS usually stores both geometric and attribute data in a single integrated database. These integrated relational databases often face performance problems [22]. Therefore it is desirable to stronger separate geometric and attribute data. A service-oriented architecture can help to minimize attribute datasets in GIS. Attribute data can reside close to the source of production, however, stay available to the GIS. This also avoids inconsistency in local copies. In the solution proposed, unit information can stay with the backend of the enterprise resource planning system. With decentralized datasets being realized, one of the proposed research items identified in [9] has been tackled.

4 Heading for semantic interoperability in service-oriented architectures with GIS and non-GIS applications

This section discusses the problem of semantic heterogeneity that appears in service-oriented architectures that integrate GIS with other applications. Engineering approaches and basic ontological distinctions for this problem are outlined, which can be used to compare and map service descriptions.

4.1 Semantic heterogeneity of GI and non-GI services

With the current trend to service-oriented computing it is overseen that a service-oriented architecture itself does not dissolve the problem of *semantic heterogeneity*. Bishr [12] defines semantic heterogeneity as the consequence of different conceptualizations of a real world fact described in a database. The authors of this article have argued that in order to successfully match user expectations in information requests, semantic interpretations of services by providers and requesters need to be effectively coordinated [27]. Only if this coordination is achieved, further manual or automatic processing of the information can lead to meaningful results. Providers and requesters of GI and enterprise resource planning services use data models and underlying conceptualizations that evolved in different application domains. Therefore the data models and the underlying conceptualizations can be expected to be different.

Consider a simple localization service on the part of GIS, that is, a service that delivers spatial footprints for units delivered by another system. The service-oriented architecture introduced in this paper includes a service that exports unit information (including geographic coordinates) from an enterprise resource planning system to a GIS. The term "unit" may imply a single entity that is unambiguously located at one position on the Earth, e.g. a certain fire station. However, the term "unit" may also refer to an organization that is scattered in space, and, thus, comprises several locations, e.g. a city's fire brigade. It may also be a moving object without a fixed location, like a certain ambulance vehicle. A semantic interoperability problem occurs when the GIS expects the unit to have one fixed location, however receives a message from the enterprise resource planning system including several pairs of coordinates, or a trajectory with a temporal component.

The term "unit" is used in an enterprise resource planning system. It clearly does not refer to a geographic feature. Once the boundaries of the enterprise resource planning system are crossed to the GIS, though, the term obtains spatial implications. It is a matter of semantics whether a unit should consist of one or several locations. But by making a certain syntactic a-priori choice on the GIS side, one risks losing either recall (some units cannot be served with locations) or precision (some units get inappropriate locations).

4.2 Engineering approaches to semantic heterogeneity of GI in service-oriented architectures

Approaches to semantic interoperability in service-oriented architectures have been discussed by Vetere and Lenzerini [28]: In addition to syntactic service descriptions, a *semantic layer* for semantic service interoperability is needed. This layer assures consistent interpretations and mappings of the *description messages* sent to and received from services. Vetere and Lenzerini [28] also distinguish approaches of having a centralized vs. a decentralized (peer-to-peer) integration logic, and employing any-to-one (single ontology hub) vs. any-to-any mappings of service descriptions.

The any-to-one approach would make a semantic framework necessary to ensure a common conceptualization of reality. It would constitute, for instance, whether a unit comprises one or several locations. This semantic framework would have to be tailored for services of the GIS and the enterprise resource planning system. Such a framework, however, makes it difficult to reuse services in environments that are not linked to this particular framework: The integration of the GIS and the enterprise resource planning system may be extended by a third information system. Furthermore, current service interoperability proposals mainly rest on the idea of annotating services with centralized domain ontologies, while it is improbable that GI and non-GI services share one underlying conceptualization. In the any-to-any approach, the service exchange and the corresponding semantic mapping of descriptions would work in a peer-to-peer fashion. Ambiguities of interpretation in this approach have to be avoided by making service descriptions as rigorous as possible without forcing commitment to a central conceptual framework.

Kuhn [29] has argued that *semantic engineering* consists in effectively constraining the use and interpretation of the language vocabulary used. This goal can be achieved by different means: By ontologies as top-down networks of constraints among terms; or bottom-up, by observation procedures into which abstract terms can be grounded. Another alternative would be the use of folksonomies, which constrain the use of a term by documenting its actual use in a community. Kuhn [17] has proposed semantic reference systems to overcome semantic heterogeneity in the GIS domain: Instead of trying to dissolve conceptual heterogeneity in a centralized framework of knowledge, one grounds the concepts actually needed in reproducible observation procedures, and makes them comparable this way.

The approaches mentioned are not mutually exclusive. They come in shades involving either more or fewer assumptions about a-priori agreements. For example, a centralized domain ontology has to encompass all the application concepts employed by GI and non-GI services, whereas a grounding approach only requires entertaining a universally shared subset of observation concepts [30]. These concepts can be used to make essential ontological distinctions across domains without formalizing these domains in their entirety. Similarly, top-level ontologies, like the descriptive ontology for linguistic and cognitive engineering (DOLCE) [31], provide a sound basis for distinguishing and comparing application concepts on a fundamental level, even if these concepts are not shared among applications. Hence, comprehensive domain ontologies, which are unlikely to be stable, must not be maintained. This is sometimes called a *hybrid approach* [16]: The concepts of each application are not shared, but are described based on primitive concepts from a common shared vocabulary.

For the purpose of integrating GI and non-GI services, a hybrid, decentralized approach is reasonable. This approach can be put into practice either by employing suitable top-level ontological distinctions, or by describing service concepts in terms of semantic reference systems. The idea is sketched in Subsection 4.3 using examples.

Services can be described and compared based on their input and output concepts or on their functionality. Lemmens et al. [10] enumerate five characteristics for semantic service descriptions:

- Description of each operation's input and output parameter.
- Description of spatial data that is coupled to each operation (for example, the road network computed in a route optimization operation).
- Classification of each operation's functionality.
- Description of the control flow in composite operations.

Lemmens et al. [10] draft a use case by means of the web ontology language for web services (OWL-S), however, they do not formalize the functional aspect. Lutz [15] formalizes two facets of a semantic service description: (i) the semantics of the operation (functionality) formalized by pre- and post-conditions in first order logic (FOL), and (ii) the semantics of the interfaces of adjacent services in OWL. The first ensures that a service does what the user expects it to do. The latter ensures that a service correctly interprets the data it receives as input from other, preceding services. Service matching can be computed using subsumption reasoners and function subtyping [15]. EU funded projects like SWING [14] employ the web service modeling ontology (WSMO) approach to service discovery, which is similar but more focused on discovering data instances than operation functionalities.

In any case, service descriptions need to be compared and mapped based on the underlying concepts. So, apart from the technical aspects of the mapping, one has to decide on some useful ontological distinctions to draw among the conceptual schemes used in services, such that over-simplistic or inappropriate mappings are prevented. This can be done by annotating the data schemes of services with appropriate top-level concepts discussed in the next section.

4.3 Basic ontological distinctions for integrating GI and non-GI services

Some essential ontological distinctions that can be used to describe and compare GI and non-GI services are outlined in the following. Examples are drawn from different kinds of units in emergency management. The focus is on interpreting these units in a GI locator service. The proposed distinctions are valid for many other GI applications, though, too.

Top level ontologies like DOLCE [31] fundamentally distinguish between *physical endurants* and *perdurants*. Physical endurants, e.g. physical objects, have a spatial extension (a region in a spatial reference system) and are (spatially) present in every time instant. An example would be an ambulance vehicle. Perdurants, i.e. events or processes, are temporally extended over intervals and not wholly present at one time instant. An example would be the ambulance's trip from the depot to the accident's location. Consequently, ambulances have spatial extensions only for a given time instant, while they give rise to spatio-temporal trajectories by participating in trips (DOLCE terminology is adopted here)[3]:

$$Trip(y) \rightarrow Perdurant(y);\ Ambulance(x) \rightarrow PhysicalObject(x);\ Participates(x, y, t)$$
$$ql_T(t, y); ql_S(s_i, x, t_i)$$

where s_i is the spatial region (a spatial quale, denoted by the predicate ql_S) of object x at time instant t_i, and t is the time interval of trip y, with $t_i \in t$. Fundamental distinctions are drawn here between logical entities and their spatio-temporal reference. Only the spatial reference is localized in the GIS, and the referencing logically depends on the kind of entity to be referenced.

For example, since a *trip* is an accomplishment, that is, a non-atomic event perdurant with definite boundaries, there is a definite starting location and an end location, and there are other locations in between. Therefore trips have associated trajectories, *temporal sequences* of distinguishable locations of their participating objects.

Physical objects are physical endurants that have a unity criterion with respect to their (spatial) parts [31]. This means they are *wholes* with respect to some unifying relation *R* among parts [18]: Parts of an ambulance vehicle (e.g. wheels) or sets of ambulances (fleets) are not ambulances themselves, and physical objects can change their parts, as long as these parts are functionally related by *R* [30, 32].

$$PhysicalObject(x) \rightarrow PhysicalEndurant(x) \wedge Whole_R(x)$$

Fleets are different entities from an ontological viewpoint. They are *pluralities* [18], or, more specifically, *non-empty collections* of physical objects. The difference is that a fleet is defined by its car elements, similar to sets, whereas cars can change wheels and still remain the same. Therefore, physical objects are on a more basic level. Collections can be defined extensionally from this level (the expression Σ_M(y) asserts that y is a mereological sum of entities from the domain of predicate *M*, compare [18]):

$$Fleet(y) \rightarrow \sum\nolimits_{Ambulance}(y) \wedge \exists x, t. P(x, y, t) \wedge Ambulance(x)$$

Since fleets are collections of objects, their spatial extension is defined by the set of spatial regions of its object parts x for a given time instant t. These parts are denoted by the "temporal part-of" predicate *P* [31]. Thus, each spatial object region of a fleet can be properly distinguished from one another.

Organizations, e.g. fire brigades, are *social objects*. Social objects are generically dependent on a community of agents (agentive physical objects) [31]. Their spatial extension will exist even though they are not equal to the set of people which they depend

[3] Alternatively, in a 4-dimensionalist approach, one can model spatial regions of objects as spatial projections of spatio-temporal worms.

on (i.e. they are not pluralities or groups of people): The spatial extension of an organization could be seen as the set of regions of those people forming the community at a certain time instant. An easy way to locate agents is to anchor agents in physical objects like buildings or cars. Therefore further distinctions among physical objects are reasonable.

The concept of semantic reference systems has been applied to the notion of physical objects as wholes [31] (as used in DOLCE). Physical objects can be conceived as either *bodies* or *media* grounded in affordances [30, 32]. In this case, the unifying relation *R* could be a perceivable affordance, and the physical object is conceived either as a medium or body affording some action. Affordances are action potentials directly perceivable in the human environment [33]. For example, a medium like a river affords swimming, and a road affords supported locomotion [32]. Furthermore, a *place,* a central category of GIS, can also be seen as a spatial container, a special medium affording, among others, to be "in" (compare [34, 35]). It is especially useful to ground different kinds of physical objects relevant in GIS as media or bodies in perceivable affordances because these distinctions are directly and universally observable, and are therefore not application dependent.

Fire brigades have *fire stations,* associated *places* that afford abidance for their community of agents during shift hours. A building, in turn, may not only be perceived as a place, but also a body. A fire rescue plan of a building, for instance, captures a building in both senses. It differentiates between rigid bodies (walls) and free media of locomotion (ways out). Places can have static spatial extents, but could also be moving, e.g. on a *fireboat*. An ambulance is such a moving place, because it is a container for patients and rescue personnel. The close association of spatial regions of places and the personnel inside allows drawing inferences for a locator service, which is expected to deliver locations of personnel resources.

A synopsis of all these distinctions is depicted in Fig. 2. Arrows indicate subsumption relations among concepts. Dotted arrows are relations proposed by the authors [30, 32], top-level concepts are adopted from DOLCE [31].

5 Conclusions

This paper illustrates the challenges and the possibilities of a service-oriented architecture in integrating a GIS with a non-GIS application. Emergency management requirements suggest an integration of GIS with enterprise resource planning systems (see Section 3): An enterprise resource planning system is used to efficiently allocate units (personnel, equipment, vehicles) to incidents. Location information is critical during this allocation. However, enterprise resource planning systems are not designed to solve inherently spatial problems. Thus, the integration of a GIS and an enterprise resource planning system is reasonable. Units as they are maintained in the enterprise resource planning system can get visualized on a map and spatially analyzed by the aid of a GIS.

A service-oriented architecture technically enables an integration between a GIS and an enterprise resource planning system. Services can expose the functionality of one information system to the counter-application and make it available through open-standard interfaces. As service-oriented architectures are scalable, the proposed solution could be extended by any other miscellaneous services, though. This, in turn, would facilitate the addition of a third services-based information system to the solution, for instance a customer relationship management system.

In the solution proposed, services exchange messages synchronously based on the hypertext transfer protocol (HTTP) and the simple access object protocol (SOAP). The web

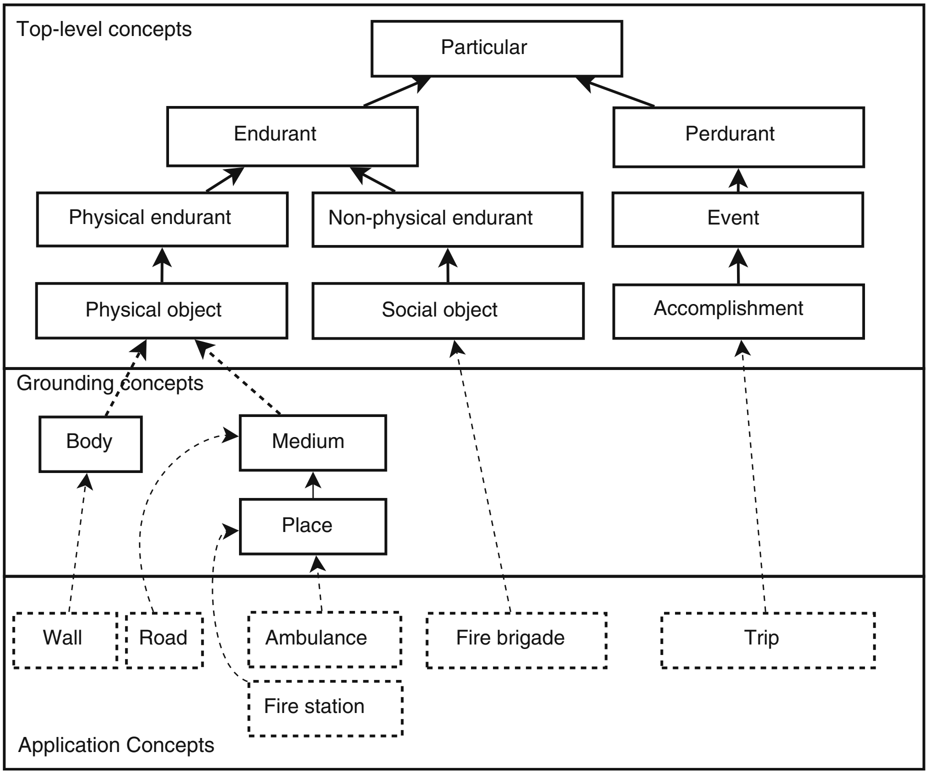


Fig. 2 Useful ontological distinctions (top-level and grounding concepts) for comparing service descriptions on the application level (application concepts)

service description language (WSDL) is used to describe interfaces of the enterprise resource planning system. This approach follows the recommendation in [9] to henceforth streamline service-oriented architectures in the geospatial domain with standards such as SOAP and WSDL. These standard technologies help to remove syntactic heterogeneity. This includes opening GIS to non-GIS applications in a service-oriented architecture, as the proposed solution demonstrates.

A service-oriented architecture itself does not dissolve semantic heterogeneity (see Section 4.1). Semantic service descriptions and decentralized mappings based on a hybrid approach can put semantic interoperability into practice. This involves few ontological distinctions or a top-level ontology shared by GI and non-GI services (Sections 4.2 and 4.3). So far, the discussion about ontology based integration of GI focuses on technical requirements, rather than on the basic ontological distinctions that would allow GI and non-GI services to interoperate. This paper proposes such distinctions and illustrates their usefulness with examples from a locator service for an enterprise resource planning system in emergency management. By using these distinctions for mappings among conceptual service schemes, services provided by non-GIS applications are enabled to handle spatial implications, too. Thus, systems can be provided unambiguously (i) with (geographic) information queried by services, and (ii) with operations offered as services (in the sense of web processing services). This has been demonstrated on the basis of generating spatial references for different kinds of units as they are maintained in an enterprise resource planning system for emergency management purposes.

Acknowledgements The work presented in this paper has been partly funded by the German Federal Ministry of Education and Research under grant no. 01ISO7009.

Discussions with Steve Benner, Johannes Elsinghorst, Werner Kuhn, Manfred Reinart, Sven Schade, Bastian Schäffer, Christoph Stasch, Cédric Ulmer, and Andreas Wendlberger have been helpful for writing this paper. Furthermore, the authors gratefully acknowledge Sidi Benmoh's and Enrique Yaptenco's assistance with the figures.

References

1. Dostal W, Jeckle M, Melzer I, Zengler B (2007) Service-orientierte Architekturen mit web-services: Konzepte, standards, Praxis. Spektrum Akad. Verlag, Berlin
2. Organization for the Advancement of Structured Information Standards (2006) Reference model for service oriented architecture 1.0. http://www.oasis-open.org/committees/download.php/19679/soa-rm-cs.pdf. Accessed 3 May 2011
3. Longley PA, Goodchild MF, Maguire DJ, Rhind DW (2005) Geographic information systems and science. Wiley, Chichester
4. Gronau N (2004) Enterprise resource planning und supply chain management—Architektur und Funktionen. Oldenbourg, München
5. Dubey A, Wagle D (2007) Delivering software as a service. The McKinsey Quarterly. http://www.mckinsey.de/downloads/publikation/mck_on_bt/2007/mobt_12_Delivering_Software_as_a_Service.pdf. Accessed 3 May 2011
6. Günther O, Müller R (1999) From GISystems to GIServices: spatial computing on the internet marketplace. In: Goodchild M, Egenhofer MJ, Fegeas R, Kottman C (eds) Interoperating geographic information systems. Kluwer Academic, Amsterdam, pp 427–442
7. Alameh NS (2001) Scalable and extensible infrastructures for distributing interoperable geographic information services on the internet. Dissertation, Massachusetts Institute of Technology
8. Tsou M-H, Buttenfield BP (2002) A dynamic architecture for distributing geographic information services. Trans GIS 6(4):355–381
9. Friis-Christensen A, Ostländer N, Lutz M, Bernard L (2007) Designing service architectures for distributed geoprocessing: challenges and future directions. Trans GIS 11(6):799–818
10. Lemmens R, de By R, Gould M, Wytzisk A, Granell C, van Oosterom P (2007) Enhancing geo-service chaining through deep service descriptions. Trans GIS 11(6):849–871
11. Bernard L, Craglia M (2005) SDI—from spatial data infrastructure to service driven infrastructure. Position paper. Workshop: cross-learning on spatial data infrastructures and information infrastructures. Enschede, Netherlands. http://www.ec-gis.org/sdi/ws/crosslearning/papers/PP%20Lars%20Bernard%20-%20Max%20Craglia.pdf. Accessed 3 May 2011
12. Bishr Y (1998) Overcoming the semantic and other barriers to GIS interoperability. Int J Geogr Inf Sci 12(4):299–314
13. Kuhn W (2005) Geospatial semantics: why, of what and how? In: Spaccapietra S, Zimányi E (eds) Journal on data semantics III. Lecture notes in computer science 3534. Springer, Heidelberg, pp 1–24
14. Gone M, Schade S (2008) Towards semantic composition of geospatial web services—using WSMO in comparison to BPEL. Int J Spatial Data Infrastructures Res 3:192–214
15. Lutz M (2007) Ontology-based descriptions for semantic discovery and composition of geoprocessing services. GeoInformatica 11(1):1–36
16. Wache H, Vögele T, Visser U, Stuckenschmidt H, Schuster G, Neumann H, Hübner S (2001) Ontology-based integration of information—a survey of existing approaches. In: Gómez-Pérez A, Gruninger M, Stuckenschmidt H, Uschold M (eds) Workshop: ontologies and information sharing (in conjunction with the international joint conferences on artificial intelligence). Morgan Kaufmann, San Francisco, pp 108–117
17. Kuhn W (2003) Semantic reference systems. Int J Geogr Inf Sci 17(5):405–409
18. Gangemi A, Guarino N, Masolo C, Oltramari A (2001) Understanding top-level ontological distinctions. In: Gómez-Pérez A, Gruninger M, Stuckenschmidt H, Uschold M (eds) Workshop: ontologies and information sharing (in conjunction with the international joint conferences on artificial intelligence). Morgan Kaufmann, San Francisco, pp 26–33

19. Alonso G, Casati F, Kuno H, Machiraju V (2004) Web services: concepts, architectures and applications. Springer, Heidelberg
20. Liu D, Deters R (2008) Management of service-oriented systems. Service-Oriented Comput Appl 2(2–3):51–64
21. Organization for the Advancement of Structured Information Standards (2001) UDDI executive white paper. http://www.uddi.org/pubs/UDDI_Executive_White_Paper.pdf. Accessed 3 May 2011
22. Worboys M, Duckham M (2004) GIS: a computing perspective. CRC, Boca Raton
23. Egenhofer M (1993) What's special about spatial—database requirements for vehicle navigation in geographic space. In: Buneman P, Jajodia S (eds) Proceedings of the international conference on management of data, SIGMOD 22(2), pp 398–402
24. Open Geospatial Consortium (2007) OpenGIS web processing service. Available at: http://portal.opengeospatial.org/files/?artifact_id=24151. Accessed 3 May 2011
25. Goodchild MF (2003) Geospatial data in emergencies. In: Cutter SL, Richardson DB, Wilbanks T (eds) Geographical dimensions of terrorism. Routledge, New York, pp 99–104
26. Radke J, Cova T, Sheridan MF, Troy A, Mu L, Johnson R (2000) Application challenges for geographic information science: implications for research, education, and policy for emergency preparedness and response. URISA J 12(2):15–30
27. Scheider S (2009) The case for grounding databases. In: Janowicz K, Raubal M, Levashkin S (eds) Proceedings of the international conference on geospatial semantics. Springer, Heidelberg, pp 44–62
28. Vetere G, Lenzerini M (2005) Models for semantic interoperability in service-oriented architectures. IBM Syst J 44(4):887–903
29. Kuhn W (2009) Semantic engineering. In: Navratil G (ed) Research trends in geographic information science. Springer, Heidelberg, pp 63–76
30. Scheider S, Probst F, Janowicz K (2010) Constructing bodies and their qualities from observations. In: Galton A, Mizoguchi R (eds) Proceedings of the international conference on formal ontology in information systems. Ios Press, Amsterdam, pp 69–87
31. Masolo C, Borgo S, Gangemi A, Guarino N, Oltramari A (2003) Wonderweb deliverable d18. http://wonderweb.semanticweb.org/deliverables/documents/D18.pdf. Accessed 4 May 2011
32. Scheider S, Janowicz K, Kuhn W (2009) Grounding geographic categories in the meaningful environment. In: Stewart Hornsby K, Claramunt C, Denis M, Ligozat G (eds) Proceedings of the conference on spatial information theory. Lecture notes in computer science 5756. Springer, Heidelberg, pp 69–87
33. Gibson JJ (1986) The ecological approach to visual perception. LEA, Hillsdale
34. Jordan T, Raubal M, Gartrell B, Egenhofer MJ (1998) An affordance-based model of place in GIS. In: Poiker TK, Chrisman N (eds) Proceedings of the international symposium on spatial data handling. International Geographical Union, Brussels, pp 98–109
35. Kuhn W (2007) An image-schematic account of spatial categories. In: Winter S, Duckham M, Kulik L, Kuipers B (eds) Proceedings of the international conference on spatial information theory. Lecture notes in computer science 4736. Springer, Heidelberg, pp 152–168

Martin Treiblmayr is research associate at SAP and PhD candidate at the University of Münster, Germany. He holds a dual diploma degree in Commerce and Geoinformation from Vienna University of Economics and Business/Vienna University of Technology, Austria.

Simon Scheider is research associate and PhD candidate at the University of Münster, Germany. He has worked in the area of spatial knowledge discovery and modelling at Fraunhofer IAIS. He is currently developing semantic reference systems for describing geospatial data. He holds a diploma degree in Applied Geography from the University of Trier, Germany.

Antonio Krüger is professor for Computer Science at Saarland University, Germany, and director of the Innovative Retail Laboratory at the German Research Center for Artificial Intelligence. Prior to joining the faculty of Saarland University, he was managing director of the Institute for Geoinformatics at the University of Münster. In addition, he is co-founder of Eyeled GmbH, a company developing mobile software solutions. He holds a PhD in Computer Science from Saarland University, Germany.

Marc von der Linden is solution manager at SAP; in this role he oversees SAP's global product portfolio in Public Safety and Security. Prior to joining SAP, he gained experience in strategy consulting and was officer with the German armed forces where he also received his PhD in Economics.