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Architectural Viewpoints and Trends for the Implementation of the Environmental Information Space

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Abstract: Interoperability between environmental information systems across organisational, disciplinary and technological borders is one of the key challenges for both developers and stakeholders in the environmental domain. Stakeholders range from public authorities, private companies, consortia of environmental projects, thematic communities up to the citizen. The Single Information Space in Europe for the Environment (SISE) is a vision of the European Commission that promises to enable an easy-to-use but controlled and efficient collaboration between users and providers of environmental information and services. This paper approaches the SISE from an architectural point of view. It positions the SISE implementation problem within a research framework covering both the business and the technological aspects of large-scale environmental information systems. It presents existing and emerging reference models for open geospatial service-oriented architectures (SOA) based upon international standards as the currently established paradigm for distributed environmental applications. Furthermore, it describes selected architectural trends such as Web service paradigms, access control in geospatial SOAs and Semantic Web Services. It is expected that these trends, among others, will influence the discussion about suitable service and information infrastructures for the SISE in the next years. The paper concludes with an outline about the European support action GIGAS that is about to find harmonisation strategies for the different architectural frameworks in strategic European and world-wide initiatives such as INSPIRE, GMES and GEOSS.

Keywords: Environmental information space; Service-oriented Architecture; Reference Model; ORCHESTRA; SANY; GIGAS.

1. MOTIVATION

The Single Information Space in Europe for the Environment (SISE) is a vision of the European Commission that, once having been implemented, shall provide the infrastructure for the efficient, easy-to-use but controlled collaboration between users and providers of environmental information and services. The stakeholders range from public authorities, private companies, consortia of environmental projects up to the citizen. Organisational, disciplinary and technological borders shall be overcome in a rather seamless manner. The plethora of environmental data collected in environmental monitoring programs at several organisational levels shall be made available for further processing, information fusion, visualisation, reporting and decision support, not only for the environmental domain but also for associated thematic domains such as health, security, commerce and transport. Interoperability is a major concern in setting up the SISE [Coene and Gasser, 2007].

Such an ambitious vision needs a basic Information Technology (IT) architectural framework that enables a cost-effective but innovative implementation:

- It shall integrate existing environmental information systems on local, regional, national and international level.
- It shall be secure, dependable and flexible to cope with and integrate emerging technological trends.
- It shall be aligned with large-scale European initiatives such as the Infrastructure for Spatial Information in the European Community (INSPIRE) [EC, 2007], the Global Monitoring for Environment and Security (GMES) and the Shared Environmental Information System (SEIS)" [EC, 2008], but also with world-wide initiatives such as the Global Earth Observation System of Systems (GEOSS).

There is no single way of specifying an SISE architecture, instead, an architecture of such a complexity is typically specified from several viewpoints. The use of viewpoints is derived from the principle of abstraction as the heart of architectural specifications. According to the ISO Reference Model for Open Distributed Systems (RM-ODP) [ISO 1998], a viewpoint is a "form of abstraction achieved using a selected set of architectural concepts and structuring rules, in order to focus on particular concerns within a system."

Firstly, this paper sketches the research framework (section 2) for the SISE implementation. Secondly, reference models that are relevant for the specification of the SISE architecture are presented (section 3). Finally, the paper discusses architectural trends (section 4) and concludes with a summary and outlook (section 5).

2. SISE RESEARCH FRAMEWORK

When designing information systems, there is a dualism between the organizational design to create an effective organizational infrastructure that is derived from the business strategy, and the information system design to create an effective information system infrastructure derived from the IT strategy. Hevner et al [2004] state that on the one hand, "IT are seen as enablers of business strategy and organizational infrastructure", on the other hand "available and emerging IT capabilities are a significant factor in determining the strategies that guide an organization".

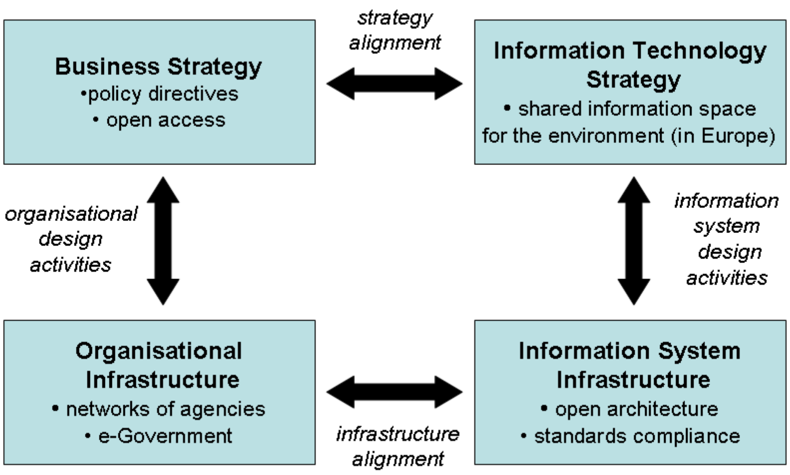

Figure 1. Business and IT Strategies [Henderson and Venkatraman, 1993], adapted to SISE

Based upon the original "strategic alignment model" of [Henderson and Venkatraman, 1993], Figure 1 illustrates the impact of European policies and initiatives upon the strategies and infrastructures of the SISE design activities:

- The Business Strategy for environmental risk management is mainly driven by European and national environmental legislation resulting in policy directives such as INSPIRE, SEIS or the Directive on Public Access to Environmental Information [EC

2003). These strengthen the need to exchange environmental information between the stakeholders and to enable the access to environmental information to the public.

- Translated to the IT domain, the Information Technology Strategy for the SISE is mainly determined by the SISE ambition. The SISE is defined both as a vision and a need towards which all IT research activity in this domain has to be directed.

These strategies determine the design activities on the organisational and the technical side:

- The "design" of the Organisational Infrastructure shall support European environmental legislation. Environmental agencies and ministries, research institutes and private organisations are organised as nodes in networks (e.g. networks of excellence for selected thematic domains in e-Government relationships) with defined levels of cooperation on managerial and technical level.

- An essential requirement for the Information System Infrastructure is an "open architecture" for a service platform which provides seamless access to information, services and applications across organizational, technical, cultural and political borders. "Open" hereby means that service specifications make use of existing standards where appropriate and possible, are published and made freely available to interested vendors and users with a view of widespread adoption.

3. ARCHITECTURAL VIEWPOINTS

The design of information system infrastructures is heavily related to the architectural evolution of environmental information systems (EIS) which have to be integrated. In the last 10-15 years, the EIS design has undergone fundamental changes following the need to correlate environmental information and services across various thematic domains, open it up to a wider spectrum of users (from employees in environmental agencies, over politicians in ministries up to the citizen) and make more sophisticated functions directly available within an EIS, such as environmental simulations or geo-processing capabilities [Usländer, 2008a].

Service-oriented architecture (SOA) is the design paradigm that is currently aimed at large-scale EIS. The major SOA design principles [Erl, 2008], the loose-coupling of functional entities (services) on the basis of an agreed service platform, their autonomy, reusability and composability, fosters its use in geospatial information systems. It enables to share geospatial resources, i.e. data and services with an explicit or implicit geospatial reference, to compose them to higher-level entities and to use them in geospatial applications possibly distributed across organizational and administrative boundaries. This is essential for EIS as natural phenomena are not limited to boundaries drawn by humans.

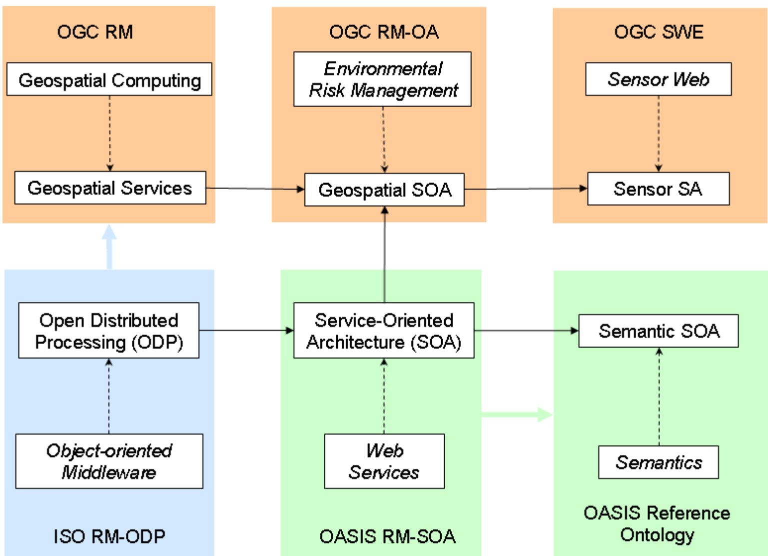

Figure 2. Evolution of Reference Models (RM)

However, as in many other businesses, the transition to service-oriented solutions is still ongoing. SOA requires significant changes in business process design as well as in modelling and solution development as, more than any other objective, SOA is intended to create a stronger alignment between IT and the businesses it supports [High, Krishnan and Sanchez, 2008]. Thus, large-scale EIS result in a system-of-systems architecture that spans multiple organizational, national and technological barriers. A recent example is the world-wide initiative to create GEOSS that aims to integrate existing earth observation systems into a global system that can be applied to various areas of environmental science and management.

For many years, the European Commission has supported research activities to analyse user and system requirements, to derive architectural principles, and to specify and implement generic components of an IT architecture for a future SISE implementation. Various approaches have been launched in order to stimulate a market based on agreed architectures resulting in a series of reference models (Figure 2). They set the conceptual foundation of distributed systems and especially SOAs, with the latest extensions towards geospatial and sensor-related SOAs worked out by the Open Geospatial Consortium (OGC), and, in parallel, extensions towards semantically-enabled SOAs worked out by the Organization for the Advancement of Structured Information Standards (OASIS), see Fensel et al [2008].

As a starting point, inspired by "distributed processing systems based on interacting objects", ISO has defined a Reference Model for Open Distributed Processing (RM-ODP) [ISO/IEC 1998]. The RM-ODP constitutes a way of thinking about architectural issues in terms of fundamental patterns or organizing principles, and it provides a set of guiding concepts and terminology for building distributed systems in an incremental manner. The major idea of RM-ODP is to structure the documentation of a distributed architecture according to five viewpoints (see the left-hand side of Table 1). The RM-ODP standards have been widely adopted.

The European research project ORCHESTRA [Klopfer and Kannellopoulos, 2008] has applied the RM-ODP approach to the specification of an Open Architecture and Spatial Data Infrastructure for Risk management. The resulting Reference Model for the ORCHESTRA Architecture (RM-OA), accepted as OGC best-practices document, has interpreted the RM-ODP viewpoints as described in table 1 [Usländer, 2007].

Table 1. Interpretation of the RM-ODP Viewpoints for the Design of a Geospatial SOA

RM-ODP Viewpoint	Definition according to ISO/IEC 10746	Interpretation for a geospatial SOA
Enterprise	Concerned with the purpose, scope and policies governing the activities of the specified system within the organization of which it is a part.	Reflects the analysis phase and results in a documentation of the functional, informational and qualitative requirements.
Information	Concerned with the kinds of information handled by the system and constraints on the use and interpretation of that information.	Specifies the modelling approach of all categories of information including their thematic, spatial, temporal characteristics as well as their meta-data.
Computational	Concerned with the functional decomposition of the system into a set of objects that interact at interfaces – enabling system distribution.	(referred to as Service Viewpoint) Specifies the modelling approach for Interface and Service Types including their syntax (signature) and semantics (functional effects).
Technology	Concerned with the choice of technology to support system distribution.	Specifies the technological choices of the service platform, its characteristics and its operational issues.
Engineering	Concerned with the infrastructure required to support system distribution.	Specifies the mapping of the service specifications and information models to the chosen platform and (geospatial) service networks including operational policies.

The RM-OA is built upon two main pillars: a conceptual model and a process model. The conceptual model provides a uniform meta-model including a set of rules how to specify information models, interfaces and services. The process model applies an incremental, iterative approach for the analysis and design phases. Usually, a multi-step breakdown process across several abstraction layers is necessary to analyse the functional, informational and non-functional user requirements and map them to the capabilities of a service platform. In practice, the individual process steps are often interlinked.

The RM-OA distinguishes between an abstract and a concrete service platform. The abstract service platform is specified independently of a given middleware technology. Its assumptions about the capabilities of the underlying concrete service platform are formulated in terms of the abstract SOA concepts of the OASIS Reference Model for Service Oriented Architecture [OASIS, 2006]. The most prominent example of a concrete service platform is the W3C Web Services technology based on the Web Service Description Language (WSDL) and bound to the SOAP protocol.

The European research project SANY (Sensors Anywhere) has extended the RM-OA to a Sensor Service Architecture (SensorSA) [Usländer (ed.), 2009] by the inclusion of sensors, sensor networks and related services based upon the information models and service specifications of the OGC Sensor Web Enablement (SWE) initiative [Simonis, 2008].

4. ARCHITECTURAL TRENDS

As pointed out in the research framework in section 2, there is a dualism in the definition of the IT strategy for the SISE and the technological capabilities for the design of the underlying infrastructure. Some of the emerging and ongoing trends are described below.

4.1 Web Service Paradigms

Looking at the technical foundation for service platforms, there is an ongoing discussion about the basic Web service paradigm to be used. OGC services are typically still used with an http/key-value pair binding although the OGC Technical Committee has decided in 2006 to provide additional WSDL/SOAP bindings for the OGC service interfaces. Furthermore, the mass-market in the Geospatial Web tends towards another paradigm, the RESTful web services [Richardson and Ruby, 2007]. RESTful web services aim at accessing and manipulating uniquely identified resources based on a uniform interface with commonly agreed, well-defined semantics such as the http-protocol of the World Wide Web.

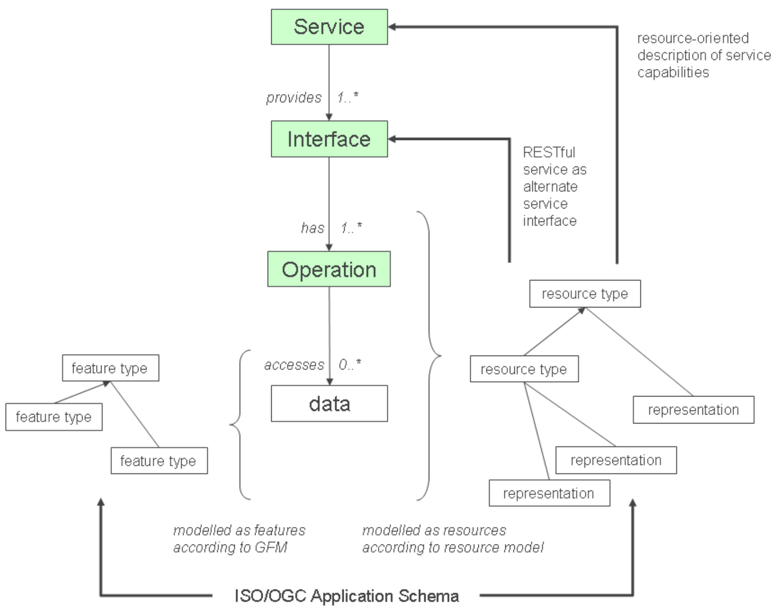

Figure 3. Services, features and resources and possible relationships

The OGC Architecture Working Group is discussing relationships and mapping possibilities between different service paradigms. The author of this paper claims that the conceptual relationships between OGC features, services and resources cannot be described without having a purpose of the resource modelling in mind. Figure 3 illustrates possible relationships derived from the basic assumption of the RM-OA that a service provides one or more interfaces, and each interface consists of one or more operations. Operations access underlying data in a read and write mode. The left-hand side of Figure 3 shows the traditional approach of OGC services accessing underlying data whose structure is modelled as an ISO/OGC application schema. The right-hand side shows a complementary resource-modelling approach. Here, operations are modelled together with their underlying data in form of resources and their representations. There are two possible purposes and applications for this modelling approach:

- The capabilities of a service may be specified in a resource-oriented way. Typically, the resulting resource model mirrors the basic elements of the underlying application schema of a service. As an example let's take the OGC Sensor Observation Service (SOS) whose capabilities may be as resources that reflect the basic SOS concepts such as offerings, features of interest, observation collections or observed properties.
- An extended approach is to provide a RESTful service as an alternate interface based on a resource model on top of a service instance (or by combining several service instances). Such a RESTful service would then provide a selected view (typically just a subset) upon the capabilities and operations of the underlying service.

Resource modelling may provide a modelling bridge between the Information and the Service Viewpoint in a system design. Resource-oriented modelling of services may facilitate the understanding of the functionality of the service to a system designer as the semantics of the operations upon the resources is simple, generic and well-defined. Furthermore, the provision of a resource-oriented view upon a service may facilitate the discovery of the service as the notion of resources may be closer to the "universe of discourse" of the user as it is the case for the signatures of specific services.

4.2 Access Control

Security is a cross-cutting concern in setting up an SOA-based infrastructure for the SISE. The most basic challenge is the protection of resource against unauthorized access as this is the foundation of most other security concepts and adjunct topics such as licensing, digital rights management and protection against malign system interaction. Access control mechanisms ensure that only authorized users (subjects) may access resources using well defined methods that comply with the security policy of the system. Access control solutions for geospatial SOAs are typically realised according to the abstract access control pattern introduced by the eXtensible Access Control Markup Language (XACML) of OASIS [2005], see Figure 4.

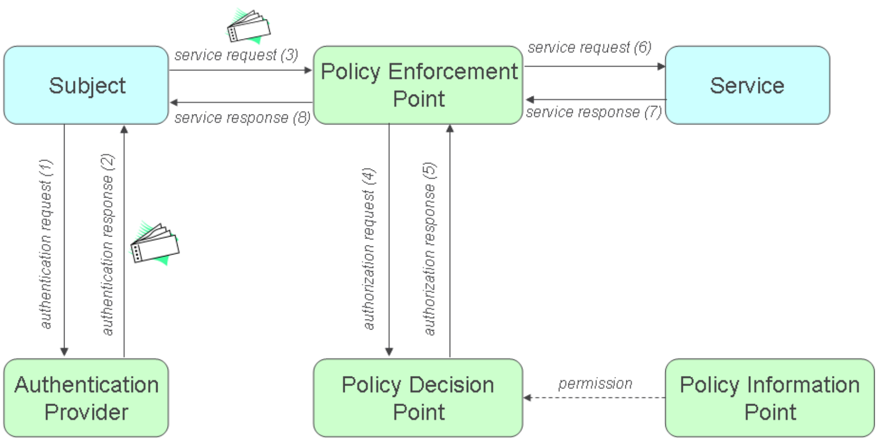

Figure 4. Abstract Access Control Pattern according to XACML [OASIS 2005]

It seizes on general ideas of policies as the basic mechanism to support the governance of SOAs and assumes that the permission "who may access which resource using which action" are recorded in access control policies. The data flow is as follows:

- Before the Subject may issue a service request to a Service, he has to authenticate his identity. He delivers credentials (e.g. password or a key) (1) to an Authentication Provider, and receives a ticket as proof of his successful authentication (2).
- The Policy Enforcement Point receives a service request associated with the ticket (3), but first has to enforce the access control policy (4), (5) before forwarding the service request to the Service (6) and getting back the service response (7), (8).
- The Policy Decision Point responds to an authorization request (4) with an authorization decision (5) based upon permissions of the Policy Information Point.

4.3 Semantic Web Services

Research work on semantic extensions of Web Services has resulted in competing submissions of sophisticated Semantic Web Services frameworks to the W3C as well as corresponding ontologies and semantic execution environments in OASIS [Fensel et al, 2008]. As a first step, the W3C recommends to use "Semantic Annotations for WSDL and XML Schema" (SAWSDL) [Farrell and Lausen, 2007] as a set of extension attributes for the WSDL and XML Schema definition language (Figure 5). The approach is to annotate elements of WSDL documents, in particular interfaces and operations as well as their input, output and fault message structures. This is realised by model references to concepts in semantic models, e.g. ontologies. SAWSDL enables service and data matching on semantic level. However, the interoperability gain has still to be validated in practical use cases.

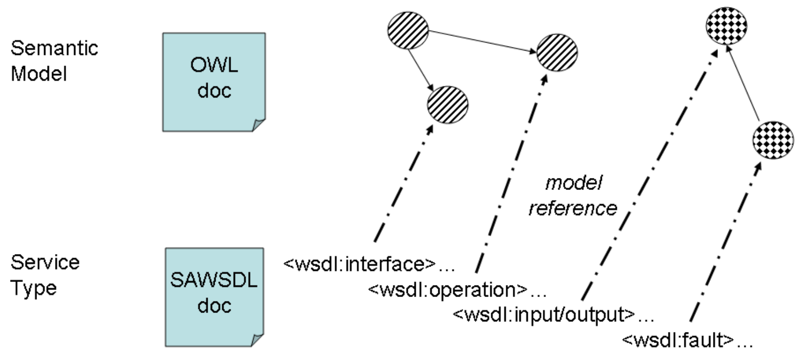

Figure 5. Model References of the Semantic Annotations for WSDL and XML Schema

5. CONCLUSION

In order to integrate the SISE vision into the business strategies of the stakeholders there is a need for a sound architectural basis that, on the one hand, enables interoperable environmental applications today, and, on the other hand, incorporates extension points to leverage emerging and future architectural trends. Key enablers for SISE are open standards-based geospatial information and service platforms. A harmonised IT strategy of the major stakeholders in the various private-public partnerships, initiatives and research programmes is essential to foster interoperability, the ambition of the European project GIGAS [2009]. GIGAS is a two-years coordinated support action that promotes the coherent and interoperable development of the GMES, INSPIRE and GEOSS initiatives through their concerted adoption of standards, protocols, and open architectures. GIGAS is analysing the architectural approaches and solutions for important use cases (e.g. resource discovery) of the above mentioned initiatives as well as major European research projects. GIGAS has adopted the ISO RM-ODP approach to streamline architectural discussions according to viewpoints that focus on selected concerns and different levels of abstraction.

The paper has shown that the technological capabilities are available and may be taken up to make the SISE vision a reality. However, a continuous alignment of business and IT strategies with well defined iteration milestones, as well as harmonised design activities for both information system and organisational infrastructures are indispensable to ensure the return on investments that is expected by the stakeholders.

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