WSMO-Lite: Lightweight Semantic Descriptions for Services on the Web*

Tomas Vitvar
Digital Enterprise Research Institute
National University of Ireland
Galway, Ireland
tomas.vitvar@deri.org

Jacek Kopecký
Digital Enterprise Research Institute
University of Innsbruck
Innsbruck, Austria
jacek.kopecky@deri.at

Maciej Zaremba
Digital Enterprise Research Institute
National University of Ireland
Galway, Ireland
maciej.zaremba@deri.org

Dieter Fensel
Digital Enterprise Research Institute
University of Innsbruck
Innsbruck, Austria
dieter.fensel@deri.at

Abstract

The current Web service technology brought a new potential to the Web of services. However, the success of Web services still depends on resolving three fundamental challenges, namely search, integration and mediation. In this paper we define an extended Web service stack enabling total or partial automation of web service provisioning process. With the goal of a maximal Web standards compliance, we describe various types of service semantics, use RDF Schema (RDFS) to define a pragmatic meaning for those descriptions, and use Semantic Annotations for WSDL and XML Schema (SAWSDL) to define a place for a semantic description in a Web service. We elaborate on the existing SAWSDL specifications and define precise rules for semantic annotations of Web services.

1 Introduction

In order to enable automation of services on the Web, various initiatives (e.g. WSMO [14] or OWL-S [16]) aim at defining semantic service models and architectures with goal to provide automated services' tasks while describing services semantically. In this direction, the initiative of the Semantic Annotations for WSDL and XML Schema (SAWSDL)[11][1] is the first step towards standardization of Semantic Web Services at W3C. SAWSDL defines attribute extensions allowing for the semantic annotations of WSDL elements while neither prescribing ontology language nor the form of semantic service descriptions. One of the first use of SAWSDL was to define grounding mechanisms for WSMO or OWL-S (e.g. [12], [10]). Although such works are important from the point view of respecting standards, it basically does not provide any new value to semantic service descriptions. Existing specifications already have the grounding mechanism which works. The more valuable gain of SAWSDL lies in opportunities to annotate existing WSDL descriptions in a bottom-up fashion while at the same time only use descriptions of services which are relevant to specific domain requirements.

With this respect and with input of WSMO, we define an *extended Web service specification stack*, adding semantic layers which offer richer descriptions for Web services. With the goal of a maximal Web standards compliance, we describe various types of service semantics, then we use RDF Schema (RDFS)[2] to define a pragmatic realization for those descriptions, and finally we use SAWSDL to define a place for the semantic descriptions of a Web service. In this paper we use the Web Service Modeling Language (WSML) [3] as a certain style to express the semantic descriptions and also the language for capturing logical expressions. It is important to note that our goal is not to define yet another Web syntax for logics but to show how existing logic languages can be used to describe service semantics while at the same time preserving maximal compliance with Web standards. WSML is a language that can be used for that purpose. We want to allow the domain experts to define various types of service descriptions com-

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[1] `http://www.w3c.org/ws/sawsdl`

[2] `http://www.w3.org/TR/rdf-schema/`

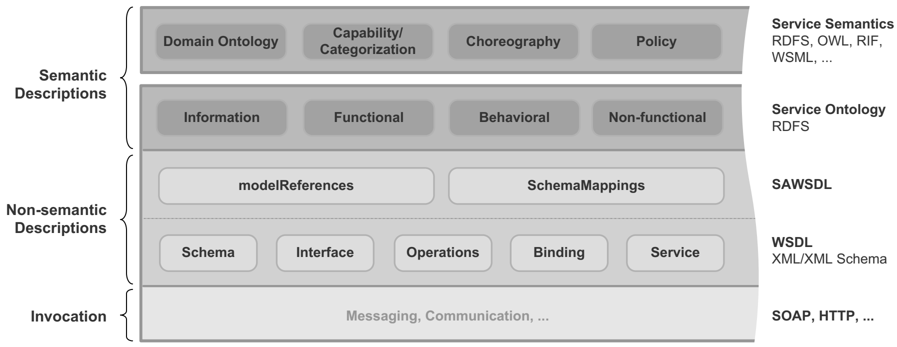

Figure 1. Extended Web Service Specification Stack

pliant with RDFS and to choose the types and expressivity for those descriptions according to specific domain requirements.

Figure 1 depicts the extended Web service specification stack, showing the standard specifications, Web languages and semantic extensions. In Section 2 we describe the underlying Web languages used for the non-semantic and semantic descriptions in the stack, as well as the underlying Web service standards. In Section 3 we define the various types of semantic descriptions and the service ontology for those descriptions. In Section 4 we specify how these semantic descriptions are linked with the non-semantic descriptions. In Section 5 we talk about related work and in Section 6 we conclude the paper and describe our future plans.

2 Underlying Specifications

2.1 Semantic Web Languages

The W3C has produced several language recommendations for representation and exchange of knowledge on the Semantic Web. At the core, the Resource Description Framework (RDF)[3] represents information in graph-based models with so called *triples*, i.e. statements in the form ⟨subject, predicate, object⟩. The subjects and objects link the triples into a graph. RDF provides various syntaxes including RDF/XML[4] and Notation 3 (N3)[5]. RDF Schema (RDFS) defines constructs on top of RDF that allow the specification of lightweight ontologies: RDFS allows to define classes, properties as well as class and property hierarchies. Forming additional layers of expressivity on the top of RDF(S), the Web Ontology Language (OWL) [7] provides further vocabulary along with a formalism based on Description Logics. Last but not least, an ongoing effort aims to extend the existing languages with rules. In particular, the W3C Rule Interchange Format Working Group (RIF WG)[6] aims to produce a core rule language for the Semantic Web together with extensions that allow rules to be translated between different rule languages.

There are also several languages outside the W3C. For instance, WSML is a family of ontology languages compatible in many ways with the W3C recommendations and their underlying principles. WSML defines several variants covering the two major directions of knowledge representation paradigms, namely Description Logics (WSML-DL variant) and Logic Programming (WSML-Flight and WSML-Rule variant). Some WSML variants (e.g. WSML-DL) have direct mapping to OWL. In addition, WSML-Rule is the basis of the Web Rule Language (WRL)[7] specification which serves as an input for the RIF WG. Thus, RIF can be expected to be compatible with WSML-Rule to a large extent. The detailed description of WSML and its compliance with standards can be found in [2].

2.2 Web Services

The Web Service Description Language (WSDL)[8] provides a standard description format for Web services, using XML as a common flexible data exchange format, and applying XML Schema for data typing. WSDL describes a Web service in three levels: 1) an XML-based reusable *abstract interface*, and the concrete details regarding 2) how and 3) where this interface can be accessed. The interface defines a set of operations, each representing a simple exchange of messages that follows a specific message exchange pattern (MEP). Messages in operations reference XML Schema element declarations to describe their contents. In order to communicate with a Web service de-

[3] http://www.w3.org/RDF/
[4] http://www.w3.org/TR/rdf-syntax-grammar/
[5] http://www.w3.org/DesignIssues/Notation3.html
[6] http://www.w3.org/2005/rules/
[7] http://www.w3.org/Submission/2005/08/
[8] http://w3.org/TR/wsdl20

scribed by an abstract interface, a client must know how the XML messages are serialized on the network and where exactly they should be sent. In WSDL, on-the-wire message serialization is described in a *binding*, which generally follows the structure of an interface and specifies the necessary serialization details. Finally, the *service* construct in WSDL represents a single physical Web service that implements a single interface. The Web service can be accessible at multiple *endpoints*, each potentially with a different binding.

While the WSDL specifies what the messages *look like* rather then what the messages or operations *mean*, the specification called Semantic Annotations for WSDL and XML Schema (SAWSDL) defines a simple extension layer over WSDL that allows the *semantics* to be specified on various WSDL components. SAWSDL defines extension attributes that can be applied to elements both in WSDL and in XML Schema in order to annotate WSDL interfaces, operations and their input and output messages.

3 Semantics for Web Services

The major goal of adding semantics to web services is to increase automation of certain tasks which need to be performed with services before or during the invocation. Based on various efforts in Semantic Web Services and Service-Oriented Computing communities (e.g., [1, 5, 13, 15, 16, 19]), there are generally accepted types of semantic descriptions of *information*, *functional*, *non-functional*, and *behavioral* aspects of services, as well as general tasks of *discovery*, *negotiation*, *selection*, *composition*, *mediation* and *invocation*. The tasks are performed by a *semantic client*, i.e. a service requester or a middleware system both performing various combinations of tasks according to the requirements of a particular application. In this paper we use the term semantic client (or client) with no further definition (see e.g. [19] for more information about an intelligent middleware system for the Semantic Web Services).
In this section we define the above mentioned types of service descriptions and use RDFS to model them as part of a *service ontology*. In particular, we define modeling elements based on RDFS for each type of the service description. We will show examples in Notation 3 and use the namespaces and their prefixes as shown in Listing 1.

```
@prefix rdfs: <http://www.w3.org/2000/01/rdf−schema#> .
@prefix rdf: <http://www.w3.org/1999/02/22−rdf−syntax−ns#> .
@prefix dc: <http://purl.org/dc/elements/1.1/> .
@prefix xs: <http://www.w3.org/2001/XMLSchema#> .

@prefix wl: <http://www.wsmo.org/wsmo−lite#> .
@prefix ex: <http://example.org/onto#> .
@prefix wsml: <http://www.wsmo.org/wsml−rdf−syntax#> .
```

Listing 1. Namespace declarations

3.1 Information Semantics

Information semantics is the formal definition of some domain knowledge used by the service in its *input* and *output* messages. We describe the information semantics as an ontology

$$\Omega = (C, R, E, I) \quad (1)$$

with a set of classes (unary predicates) C, a set of relations[9] (binary and higher-arity predicates) R, a set of explicit instances of C and R called E (extensional definition), and a set of axioms called I (intensional definition) that describe how new instances are inferred.

We use basic RDFS terms to express ontology, but other ontology languages (e.g. OWL, WSML) can also be used. In fact, for some of the semantics detailed further in this paper we require a language that can express logical conditions. Table 1 shows the representation of information semantics in RDF and RDFS. Note that symbols such as c, r_1 etc. on the left-hand side are translated into URIs `c` and `r1` etc. on the right-hand side using a bijective naming function $N : symbol \rightarrow uri$. For instance instead of `r1` we could write $N(r_1)$, but we chose the former for readability. Our information semantics definition allows predicates with arity higher than two. RDFS only defines classes (unary predicates) and properties (binary predicates). For the higher-arity predicates, it is a common style to represent an n-ary predicate as a class, with attributes (properties with pre-set domain) representing the n parameters.

In Listing 2 we show a simple domain ontology in RDFS that describes the semantics of information needed for a telecommunication service. The *NetworkConnection* (line 3) stands for the class of all network connections which can be put in a hierarchy by means of *rdfs:subClassOf* predicate (lines 15). Classes can have properties, such as *Bundle* has a property *hasConnection* that points to the network connection which is part of the bundle.

3.2 Functional Semantics

Functional semantics describes service functionality, i.e. what a service can offer to its clients when it is invoked. We distinguish two types of service functionality: (1) *capability* — the functionality defined using conditions which must hold before and after service invocation, and (2) *categorization* – the functionality defined using some classification schema[10] such as the United Nations Standard Products

[9] Note that the minimal definition would combine the sets of classes and relations as a set of predicates, but we choose to split them, due to familiarity and also reuse in further definitions.

[10] In [6], Hepp develops the ontologized versions of some classifications.

Information semantics construct	RDFS triples
$c \in C$	`c rdf:type rdfs:Class`
$c \in C \wedge c(e) \in E$	`e rdf:type c`
$r \in R$ r is a binary predicate	`r rdf:type rdf:Property`
$r \in R \wedge r(a,b) \in E$	`a r b`

$r \in R$
r is an n-ary predicate with parameters $r_1 \dots r_n$
	`r  rdf:type rdfs:Class`
	`r1 rdf:type rdf:Property`
	⋮
	`rn rdf:type rdf:Property`

$r \in R \wedge r(a_1, \dots, a_n) \in E$	`_:x rdf:type r`
	`_:x r1 a1`
	⋮
	`_:x rn an`

$(\forall a, \forall b : r(a,b) \Rightarrow c(a)) \in I$	`r rdfs:domain c`
$(\forall a, \forall b : r(a,b) \Rightarrow c(b)) \in I$	`r rdfs:range c`
$(\forall a : c_1(a) \Rightarrow c_2(a)) \in I$	`c1 rdfs:subClassOf c2`
$(\forall a, \forall b : r_1(a,b) \Rightarrow r_2(a,b)) \in I$	`r1 rdfs:subPropertyOf r2`
Other axioms are expressed in some rule language	

Table 1. Information semantics in RDFS

```
...
ex:Bundle rdf:type rdfs:Class .
ex:NetworkConnection rdf:type rdfs:Class .
ex:Service rdf:type rdfs:Class .
ex:hasService rdf:type rdf:Property ;
    rdfs:domain ex:Bundle ;
    rdfs:range ex:Service .
ex:hasConnection rdf:type rdf:Property ;
    rdfs:domain ex:Bundle ;
    rdfs:range ex:NetworkConnection .
ex:providesBandwidth rdf:type rdf:Property ;
    rdfs:domain ex:NetworkConnection ;
    rdfs:range xs:integer .
ex:DSLConnection rdf:type rdfs:Class ;
    rdfs:subClassOf ex:NetworkConnection .
...
```

Listing 2. Example ontology

and Services Code (UNSPSC)[11]. While a classification can be described as an ontology according to Equation 1, a capability is defined here as

$$F = (\Sigma, \phi^{pre}, \phi^{eff}), \tag{2}$$

where $\Sigma \subseteq (\{x\} \cup C \cup R \cup E)$ is is the signature of symbols, i.e. variable names $\{x\}$ or identifiers of elements from C, R, E of some information semantics Ω; ϕ^{pre} is a precondition which must hold in a state before the service can be invoked and ϕ^{eff} is the effect, a condition which must hold in a state after the successful invocation. Preconditions and effects are defined as statements in logic $\mathcal{L}(\Sigma)$.

[11] `http://www.unspsc.org/`

Below, in Definition 1, we specify a *restriction* relationship (partial ordering $\leq$) between capabilities that share the symbol signature Σ and the information semantics Ω. Practically, if a capability F_1 is a restriction of another capability F_2, any discovery algorithm that discovers F_1 as a suitable capability for some goal would also discover F_2 as such.

Definition 1 (capability restriction) A capability $F_1 = (\Sigma, \phi_1^{pre}, \phi_1^{eff})$ is a restriction of $F_2 = (\Sigma, \phi_2^{pre}, \phi_2^{eff})$ (written as $F_1 \leq F_2$) if the precondition ϕ_1^{pre} only holds in states (denoted as s) where also ϕ_2^{pre} holds, and if the same is true for the effects:

$$F_1 \leq F_2 \iff \forall s: \; (holds(\phi_1^{pre}, s) \Rightarrow holds(\phi_2^{pre}, s)) \wedge (holds(\phi_1^{eff}, s) \Rightarrow holds(\phi_2^{eff}, s)) \tag{3}$$

In Listing 3 the service ontology defines the class *Capability* with predicates *hasPrecondition* and *hasEffect*. The range of both these predicates is *Axiom*, meaning an arbitrary logical expression. The logical expression can be written in the syntax of any logical language, for instance WSML-Rule or RIF. Please note that we do not prescribe any constructs for functional semantics defined as a classification ontology, see Section 3.1 for discussion on expressing ontologies.

In Listing 4 we show how precondition and effect are described using WSML-Rule for the Video on Demand subscription service whose information semantics is shown in Listing 2. The precondition specifies that the customer must have a minimal required bandwidth and the effect identifies a valid bundle having both the connection and the service defined when the subscription is completed successfully.

```
...
wl:Capability rdf:type rdfs:Class .
wl:hasPrecondition rdf:type rdf:Property .
    rdfs:domain wl:Capability ;
    rdfs:range wl:Axiom .
wl:hasEffect rdf:type rdf:Property ;
    rdfs:domain wl:Capability ;
    rdfs:range wl:Axiom .
wl:Axiom rdf:type rdfs:Class .
...
```

Listing 3. Service Ontology: Functional Semantics Constructs

We use the *wsml:AxiomLiteral* datatype to capture rules in the WSML syntax, thus a client can correctly process the axioms according to the WSML-Rule specification.

```
...
ex:VideoOnDemanSubscription rdf:type wl:Capability ;
    wl:hasPrecondition "
        ?customer[hasConnection hasValue ?connection]
            memberOf Customer and
        ?service[requiresBandwidth hasValue ?x]
            memberOf Service and
        ?connection[providesBandwidth hasValue ?y]
            memberOf NetworkConnection and
        ?y > ?x
    "^^wsml:AxiomLiteral .
    wl:hasEffect "
        ?bundle[hasService hasValue ?service and
                hasConnection hasValue ?connection]
            memberOf Bundle
    "^^wsml:AxiomLiteral .
...
wsml:AxiomLiteral rdf:type rdfs:Class
    rdfs:subClassOf wl:Axiom
...
```

Listing 4. Capability Example

3.3 Behavioral Semantics

In general, behavioral semantics is the formal description which defines a service's *external* (public) and *internal* (private) behavior. The external behavior describes a protocol that can be used by the client to consume the service functionality. The internal behavior describes a workflow, i.e. how the functionality of the service is aggregated out of other services. However, internal behavior and its semantic description is outside the scope of this work; an interested reader can refer e.g. to the project SUPER[12].

For the purposes of our work, we call the public behavior of a service its *choreography*. The choreography is a description of a protocol from the service point of view, i.e. all the messages that are sent in to the service from the network and all the messages that are sent from the service out to the network[13]. We define the choreography X (read: chi) of the service using a state machine as

$$X = (\Sigma, L), \tag{4}$$

where $\Sigma \subseteq (\{x\} \cup C \cup R \cup E)$ is the signature of symbols, i.e. variable names $\{x\}$ or identifiers of elements from C, R, E of some information semantics Ω; and L is a set of rules. Further, we distinguish dynamic symbols denoted as Σ_I (input), and Σ_O (output) and static symbols denoted as Σ_S. While the static symbols cannot be changed by the service invocation, the dynamic symbols correspond to input and output data of the service which can be changed by the invocation. Each rule $r \in L$ defines a state transition $r : r^{cond} \rightarrow r^{eff}$ where $cond$ is defined as an expression in logic $\mathcal{L}(\Sigma_I \cup \Sigma_S)$ which must hold in a state before the transition is executed; eff is defined as an expression in logic $\mathcal{L}(\Sigma_I \cup \Sigma_O \cup \Sigma_S)$ describing how the state changes when the transition is executed. Σ_I and Σ_O correspond to the input and output data which is sent to the service and received back. Both input and output data is "linked" with input and output messages of an underlying Web service operation using the annotation mechanism described in Section 4. When the transition is executed, the input data is sent as a message to the underlying operation which then responds with a message containing the output data.

In Definition 2, we define a *consistency* between a choreography and a capability that share the symbol signature Σ and the information semantics Ω.

Definition 2 (capability and choreography consistency) Let $X = (\Sigma, L)$ be a choreography, $F = (\Sigma, \phi^{pre}, \phi^{eff})$ be a capability, and $\tau = (s_1, s_2, ..., s_n)$ be some sequence of states where for each $s_i \in \tau, i = 1, ..., n-1$ exists $r_i \in L$ such that r_i^{cond} holds in s_i and r_i^{eff} changes the state to the state s_{i+1}. Then, X and F are consistent (denoted as $X \sim F$) iff ϕ^{pre} holds in s_1 and ϕ^{eff} holds in s_n.

In Listing 5 the service ontology defines constructs for the choreography description where the *Choreography* class holds *hasInput*, *hasOutput* and *hasRule* properties. The *hasInput* and *hasOutput* refer to classes from information semantics and define input and output symbols for the behavioral description. The *hasRule* defines a transition rule with range defined as *rdfs:Class* leaving a particular form of transition rules on the application and a concrete language used.

Listing 6 shows the choreography description for the service in the example in Listing 4. In here, we use the WSML-

[12] `http://www.ip-super.org`

[13] Please note that our notion of choreography is different from the one used in the Web Service Choreography Description Language (WS-CDL) (`http://www.w3.org/TR/ws-cdl-10/`)

```
...
wl:Choreography rdf:type rdfs:Class .
wl:hasInput rdf:Type rdfs:Property ;
    rdfs:domain wl:Choreography ;
    rdfs:range rdfs:Class .
wl:hasOutput rdf:Type rdfs:Property ;
    rdfs:domain wl:Choreography ;
    rdfs:range rdfs:Class .
wl:hasRule rdf:Type rdfs:Property ;
    rdfs:domain wl:Choreography ;
    rdfs:range wl:Rule .
wl:Rule rdf:Type rdfs:Class .
...
```

Listing 5. Service Ontology: Choreography Constructs

Rule language to describe a rule (lines 6-9) allowing a requester to quote for a price of the network service (the quote response can be sent out from the service if the quote request has been previously received). In order to execute the state transition, the rule's condition (lines 6,7) defines what must be true in a state and the rule's effect (line 9) defines how the state changes while at the same time the data of *ServiceQuoteResponse* is expected to be sent out from a corresponding service's operation. Similarly as in Listing 4 we use the *wsml:RuleLiteral* datatype to capture rules expressed in the WSML syntax.

```
1  ...
2  ex:PriceQuoteChoreography rdf:type wl:Choreography ;
3      wl:hasInput ex:ServiceQuoteRequest ;
4      wl:hasOutput ex:ServiceQuoteResponse ;
5      wl:hasRule "
6          if (?quoteRequest)
7              ?quoteRequest memberOf ServiceQuoteRequest
8          then
9              _# memberOf ServiceQuoteResponse
10     "^^wsml:RuleLiteral .
11 ...
12 wsml:RuleLiteral rdf:type rdfs:Class ;
13   rdfs:subClassOf wl:Rule .
14 ...
```

Listing 6. Choreography Example

3.4 Non-Functional Semantics

Generally, non-functional properties are incidental details specific to the implementation or running environment. Policy languages (e.g. WS-Policy[14]) are often used to express various service constraints that fall within non-functional semantics of the service. In addition, there are works that focus on semantic representation of policies, e.g. [8, 9, 17, 18]. While some of these works are based on the WS-Policy framework (esp. [9]), others offer their own models.

[14] `http://w3.org/TR/ws-policy`

Our service ontology does not prescribe any constructs to model non-functional semantics of the service and thus can be used with any of the proposed approaches. We allow a user to model non-functional semantics using any ontology language with RDF syntax, similarly as for the information semantics in Section 3.1. For instance, Listing 7 shows a simple non-functional property describing the price of a Video on Demand bundle change.

```
ex:VideoOnDemandPrice rdf:type ex:PriceSpecification ;
    ex:pricePerChange "30"^^ex:euroAmount ;
    ex:installationPrice "49"^^ex:euroAmount .
```

Listing 7. Non-functional Property Example

4 Semantic Annotations for Web Services

In this section, we define how various types of semantic descriptions described in Section 3 can be applied to various WSDL components using SAWSDL attribute extensions. We define rules for consistency and completeness of the semantic descriptions and annotations of the WSDL components with these descriptions. For this purpose we use following notation for WSDL, SAWSDL and types of semantic descriptions:

- **WSDL:** *Schema* S and $\{x\}_S$ as a set of all element declarations and type definitions of schema S; *interface* I and $\{o\}_I$ as a set of all operations of interface I, each operation $o \in \{o\}_I$ may have one input message element $m \in \{x\}_S$ and one output message element $n \in \{x\}_S$; *service*, *binding*, *endpoint*;

- **SAWSDL:** *modelReference*, $ref(x, \alpha)$ where x is a non-semantic description (any of the WSDL components) pointing to a semantic description α; *loweringSchemaMapping*, $lower(y, f(\beta))$ where y is an element or type from schema S, and $f(\beta) = y$ is a transformation function transforming some semantic description β to y; *liftingSchemaMapping*, $lift(z, g(z))$ where z is an element or type from S and $g(z) = \gamma$ is a transformation function transforming z to some semantic description γ;

- **Semantic Descriptions:** Information Ω (defined in Eq. 1 with $C(\Omega)$ as set of all classes), Functional (Capability) F (defined in Eq. 2), Behavioral (Choreography) X (defined in Eq. 4).

Please note that the SAWSDL specification only defines the use of annotations on the schema and the interface, but other uses are intentionally not precluded. In addition, SAWSDL does not specify the type of semantics used for annotations, nor does it specify any rules where such semantics should be placed, leaving some flexibility for the application. SAWSDL uses URIs for all semantic references, expecting that the application either knows the referenced concept, or can find its definition. Table 2 shows the summary of how we apply the semantic descriptions to the WSDL components.

4.1 Information Semantics

Information semantics apply to the *schema* that WSDL uses to describe messages, i.e. *element declarations* and *type definitions*. Both can carry *modelReferences* that link them to classes in the information semantics model Ω. At invocation time, the client needs to exchange data with the service, so the data needs to be transformed between the semantic model and the service-specific XML structure. For this, SAWSDL provides *liftingSchemaMapping* and *loweringSchemaMapping* annotations that link to the appropriate transformations. This is illustrated in Listing 8.

```
...
<xs:element name="NetworkConnection" type="
      NetworkConnectionType"
   sawsdl:modelReference="http://example.org/onto#
         NetworkConnection"
   sawsdl:loweringSchemaMapping="http://example.org/NetCn.xslt"/>
...
```

Listing 8. Schema linked to information semantics

According to Rule 1, all element declarations that are used as input messages must have consistent *modelReference* and *loweringSchemaMapping* annotations, and all element declarations that are used in output messages must have consistent *modelReference* and *liftingSchemaMapping* annotations. These mappings must exist for the client to understand and generate the messages in XML from ontology instances and vice-versa.

Rule 1 (completeness) Let S be a schema, $\{o\}_I$ be the set of operations of an interface I and Ω be a definition of information semantics. For each $m \in \{x\}_S$ where m is an *input message element* of any operation in $\{o\}_I$, there exists a class $c_1 \in C(\Omega)$ such that $\mathit{ref}(m, c_1)$ and $\mathit{lower}(m, f(c_1))$ with $f(c_1) = m$ are defined. Analogically, for each $n \in \{x\}_S$ where n is an *output message element* of any operation in $\{o\}_I$, there exists a class $c_2 \in C(\Omega)$ such that $\mathit{ref}(n, c_2)$ and $\mathit{lift}(n, g(n))$ with $g(n) = c_2$ are defined.

```
...
<wsdl:interface name="NetworkSubscription"
      sawsdl:modelReference="http://example.org/onto#
            NetworkSubscriptionCapability" >
   ...
</wsdl:interface>
...
```

Listing 9. WSDL interface linked to its capability

4.2 Functional Semantics

Functional semantics apply to the Web service, represented concretely by the *service* construct, and abstractly by the reusable *interface* construct. A SAWSDL *modelReference* is used to point from a service or an interface to its appropriate functional description, as shown in Listing 9. A WSDL interface may be shared by multiple services, therefore the functional description of the interface should be general, since it effectively applies to all services that implement that interface. A concrete functional description attached to the service then refines the functional description of the interface. Additionally, aggregate interfaces or services (i.e., those that combine multiple potentially independent functionalities) may be annotated with multiple functional descriptions.

According to Rule 2 each functionality of a service must be a restriction of some functionality of the service's interface (see Definition 1). This is in particular useful to allow discovery to first find appropriate interfaces and then only deal with services that implement these interfaces. Rule 3 is analogical to Rule 2 with the difference that it applies to interface extension[15] when it is ensured that functionality cannot be lost through WSDL interface extension.

Rule 2 (consistency) Let F, G ($F \neq G$) be some functional descriptions, E be the service and I be the interface such that E implements I. Then, if $\mathit{ref}(E, F)$ and $\mathit{ref}(I, G)$ are defined, then it must hold that $F \leq G$.

Rule 3 (consistency) Let F, G ($F \neq G$) be some functional descriptions, I and J be some interfaces such that I extends J. Then, if $\mathit{ref}(I, F)$ and $\mathit{ref}(J, G)$ are defined, then it must hold that $G \leq F$.

Apart from describing the service (or the interface) as a whole, it is also possible to ascribe functional descriptions to the operations, again using *modelReference* pointers. Describing the functional semantics with operation capabilities

[15] Interface extension is a feature of WSDL 2.0.

WSDL component	Semantics type	Description
Schema	Information	Ontology pointers, mappings
Interface	Functional	General, reusable capability or category
Interface Operation	Functional	Concrete operation capability or category
Service	Functional	Concrete service capability or category
Interface	Behavioral	General, reusable choreography
Service	Behavioral	Concrete service choreography
Schema	Behavioral	Pointers to input and output concepts in choreography signature
Service and Endpoint	Non-functional	Non-functional properties and policies
Binding (and sub-components)	Non-functional	For instance, operation-specific non-functional properties

Table 2. Semantic annotations for WSDL components

is especially useful for Web services whose interface is simply a collection of standalone operations. For instance, a network subscription service may offer independent operations for subscription to a bundle, cancellation of a subscription, or price inquiry. A client will generally only want to use one or two of the operations, not all three. This shows that service discovery can, in such cases, become operation discovery. In this case, discovery and composition approaches may be used to select and order the invocations of the operations, and then the interface may not have a choreography description.

According to Rule 4, if an operation within an interface is not annotated with a capability, the interface must be annotated with a choreography that uses the operation. This rule ensures that no operation is left invisible to the semantic clients.

Rule 4 (completeness) Let $o \in \{o\}_I$ be the interface operation. If for any F, the $ref(o, F)$ is not defined where F is the functional description, then $ref(I, X)$ must be defined with $o \in X$ where X is the choreography description (cf. Section 4.3).

Please note that all the definitions above apply to both types of functional semantics defined in Section 3.2, i.e. capability defined on an abstract state space and categorization using some classification schema. It is even possible to combine both types of functional semantics for a service, interface and its operations. While the SAWSDL *modelReference* URI values do not indicate whether the annotations go to capabilities or categories (or any other type of semantics, for that matter), the semantic model will make it clear.

4.3 Behavioral Semantics

Similarly to functional semantics, behavioral semantics (choreography) apply to the Web service, i.e. either to a WSDL service or to an interface. In this context, the purpose of a choreography is to define the order in which the client should invoke the operations of the Web service. Listing 10 shows the interface from Listing 9 with the additional choreography annotation; a *modelReference* can contain any number of semantic concept URIs and it is up to the client to interpret them and to make use of them as appropriate. In fact, both services and interfaces can be annotated with multiple alternative choreographies.

```
...
<wsdl:interface name="NetworkSubscription"
        sawsdl:modelReference="http://example.org/onto#
                NetworkSubscriptionCapability
                                        http://example.org/onto#
                                                NetworkSubscriptionBehavior" >
   ...
</wsdl:interface>
...
```

Listing 10. WSDL interface linked to its capability and choreography

According to Rule 5 each choreography of an interface (or a service) must be consistent (see Definition 2) with some capability of that interface (or that service).

Rule 5 (consistency) Let Z be an interface or a service and $\{X_i\}$ be all choreographies such that $ref(Z, X_i)$ is defined. Then, for each X_i some capability F must exist for which $ref(Z, F)$ is defined and $X_i \sim F$.

A reference to the choreography is complemented by information semantics annotations in the XML Schema, because the input and output symbols from the choreography signature need to be linked with the actual XML messages that will carry the data. Information semantics annotations are described in Section 4.1. In addition, according to Rule 6, for each input or output symbol used by the choreography of an interface (or service), there must be an element declaration used appropriately as an input or output message by an operation of the interface (or the interface implemented by the service) that has a *modelReference* to the input or output symbol.

Rule 6 (completeness) Let X be the choreography with Σ_{in} and Σ_{out} denoting the sets of input and output symbols of X, and let Z be an interface or a service such that $\mathit{ref}(Z, X)$ is defined. Further, let I be Z if Z is an interface, or the interface that Z implements, if Z is a service; then $\{o\}_I$ is the set of operations of I. For every concept α which is identified by an identifier from Σ_{in}, exists m as an input message in $\{o\}_I$ with defined $\mathit{ref}(m, \alpha)$. Analogically, for every concept β which is identified by an identifier from Σ_{out}, exists n as an output message in $\{o\}_I$ with defined $\mathit{ref}(n, \beta)$.

4.4 Non-Functional Semantics

Non-functional semantics may be attached to the service as a whole, as shown in Listing 11, or to particular endpoints (for instance to indicate different security or price combinations offered by the different endpoints). Non-functional semantics are always specific to a concrete service, annotating interfaces with non-functional properties should be avoided. In case non-functional properties need to be specified on the operations (for example, different operations may have different invocation micropayment prices), a WSDL binding or any of its sub-components may be used to capture these properties. With SAWSDL, non-functional properties are attached using *modelReference* from any of the WSDL components into the non-functional semantics model. Some of the works on semantic models for non-functional properties are based on the WS-Policy framework. This framework contains an attachment specification, WS-PolicyAttachment[16], that defines mechanisms for associating policies with policy subjects. In WSDL, any component can be viewed as a policy subject. Using WS-PolicyAttachment for capturing the non-functional properties would be an alternative to using SAWSDL *modelReference*.

```
...
<wsdl:service name="ExampleCommLtd"
      interface="NetworkSubscription"
      sawsdl:modelReference="http://example.org/onto#
            VideoOnDemandPrice">
   <wsdl:endpoint name="public"
      binding="SOAPBinding"
      address="http://example.org/comm.ltd/subscription" />
</wsdl:service>
...
```

Listing 11. WSDL service linked to its non-functional property

5 Related Work

OWL-S (Semantic Markup for Web Services [16]) was the first major ontology for semantic description of Web services. It is a set of three interlinked ontologies: Service Profile captures the functional and non-functional semantics; Service Model details the behavioral semantics — it models the service choreography as a (composite) process with inputs and outputs and a rich variety of intermediate steps; and Service Grounding ties the process ontology with actual physical Web services. Information semantics is captured using the Web Ontology Language OWL. Web Service Modeling Ontology WSMO [15] is a top-down conceptual model for semantic description of Web services which is realized in Web Service Modeling Language (WSML, [3]). It has four top-level components: ontologies capture information semantics; goals describe what the user (or the system) wants to achieve; Web services model the properties of the available services; and mediators resolve any heterogeneities that might arise in a distributed system. The WSMO describes a Web service along with the similar service semantics as we define in Section 3, however, these semantics are specified in the Meta Object Facility (MOF)[17]. In addition, the WSMO adopts the top-down approach to modeling of Web services when service semantics is not meant to be used separately but as a whole. Web Service Semantics (WSDL-S, [1]) was created in the METEOR-S[18] project as a specification of how WSDL can be annotated with semantic information. WSDL-S itself does not provide a concrete model for semantic description of Web services, instead it makes the assumption that the concrete model will be expressible as annotations in WSDL and XML Schema documents. Parts of WSDL-S were taken as the basis for SAWSDL, which is discussed in the previous sections. Above those parts, WSDL-S also supported explicit constructs for categorizing WSDL interfaces, and for attaching preconditions and effects to interface operations. However, all this functionality can be achieved using the appropriate semantic models and the SAWSDL model reference. Finally, the WSDL RDF mapping[19] represents the information from WSDL documents in RDF, in a simple OWL-based WSDL ontology. Also the SAWSDL annotations have their RDF representation. It is due to the existence of these RDF mappings that our lightweight semantic service ontology does not, in fact, need a class *Service* —

[16] http://w3.org/TR/ws-policy-attach

[17] http://www.omg.org/technology/documents/formal/mof.htm

[18] http://lsdis.cs.uga.edu/projects/meteor-s/

[19] http://w3.org/TR/wsdl20-rdf/

the underlying model for Web services is taken from the WSDL ontology.

6 Conclusion and Future Work

In this paper we have proposed an open approach to definition of service semantics with goal of the maximal compliance with Web standards. We have defined an extended specifications for Web service stack, i.e. semantic layer on the top of standard Web service specifications allowing to use and integrate not yet standardized rule languages for the Semantic Web. Building on the SAWSDL specifications we have defined the concrete semantic annotations for Web Services using the service descriptions including the set of rules ensuring completeness and consistency of annotations. In addition, our work takes into account that when annotating Web services with semantics, the domain expert might only want to use some of the semantic descriptions serving particular domain requirements of Web services' tasks and their automation. Using our approach it is possible to choose parts of service semantics, use them consistently for annotations of Web services and promote this way the automation of selected tasks in the service provisioning process.

In our future work we want to elaborate on the annotation of functional and behavioral descriptions for Web service interface. In particular we want to show how the behavioral semantics can be derived from annotations of interface operations. This would allow us to limit the semantic annotations to information and functional while other semantic descriptions could be derived automatically. On the top we plan to elaborate on the completeness and consistency rules to enable automatic validation of annotations. Also, we plan to define other types of grounding to other Web service technology such as REST [4] and to use semantic annotations of services for enhancing mash-ups, i.e. integration of different resources available through some API on the Web.

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