Reference Ontology for Semantic Service Oriented Architectures Version 1.0

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Abstract:
This Reference Ontology for Semantic Service Oriented Architectures is an abstract framework for understanding significant entities and relationships between them within a Semantically-enabled Service-Oriented environment. It may be leveraged for the development of related standards or specifications supporting that environment, as well as guiding efforts to realize concrete solutions.

This Reference Ontology builds on the OASIS Reference Model for Service Oriented Architecture (SOA-RM) and combines it with the key concepts of semantics that are relevant for Semantically-enabling Service Oriented Architectures.

A reference model is not directly tied to any standards, technologies or other concrete implementation details. It does seek to provide a common understanding that can be used unambiguously across and between different implementations. The relationship between this Reference Ontology, the SOA Reference Model, and particular architectures, technologies and other aspects of SOA is illustrated in Figure 1.

Just as the SOA-RM, this reference ontology focuses on the field of software architecture. The concepts and relationships described may apply to other "service" environments; however, this specification makes no attempt to completely account for use outside of the software domain.

Status:

This document was last revised or approved by the Semantic Execution Environment Technical Committee on the above date. The level of approval is also listed above. Check the "Latest Version" or "Latest Approved Version" location noted above for possible later revisions of this document.

Technical Committee members should send comments on this specification to the Technical Committee's email list. Others should send comments to the Technical Committee by using the "Send A Comment" button on the Technical Committee's web page at http://www.oasis-open.org/committees/semantic-ex/.

For information on whether any patents have been disclosed that may be essential to implementing this specification, and any offers of patent licensing terms, please refer to the Intellectual Property Rights section of the Technical Committee web page (http://www.oasis-open.org/committees/semantic-ex/ipr.php).

The non-normative errata page for this specification is located at http://www.oasis-open.org/committees/semantic-ex/.

Notices

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1 Introduction

Although Service Oriented Architectures (SOAs) have gathered a lot of attention within business organizations, for a long time there was no clear understanding of what an SOA precisely is. As a result reference models have been published to define SOA; we note particularly the OASIS SOA Reference Model **Error! Reference source not found.**. However, with the emergence of **Semantic Web** technologies, in particular **Semantic Web Services (SWSs)**, new breeds of SOAs are being developed, namely **Semantic Service Oriented Architectures (SSOAs)**. SSOAs use semantic technologies to advance solutions to problems by which SOAs are limited. They provide a means for further automation for service consumers' tasks, particularly service discovery, selection, composition and execution, as well as easing general interoperability issues between services.

In order to use the semantic descriptions present in a SSOA to automate such SOA features, a set of platform services that provide this automation functionality are required within the SSOA. These services are collectively termed a **Semantic Execution Environment (SEE)** for Semantic Web Services, with a SEE being at the core of a SSOA. There are a number of different implementations of SEEs currently under development in the research community, which have some common features. Thus the purpose of this document is to define an extended reference model for SSOAs, as supported by SEEs. This model will be defined formally using an ontology. The aim of this ontology is to provide a point of reference formally specified so that it can support the definition and development of SSOAs.

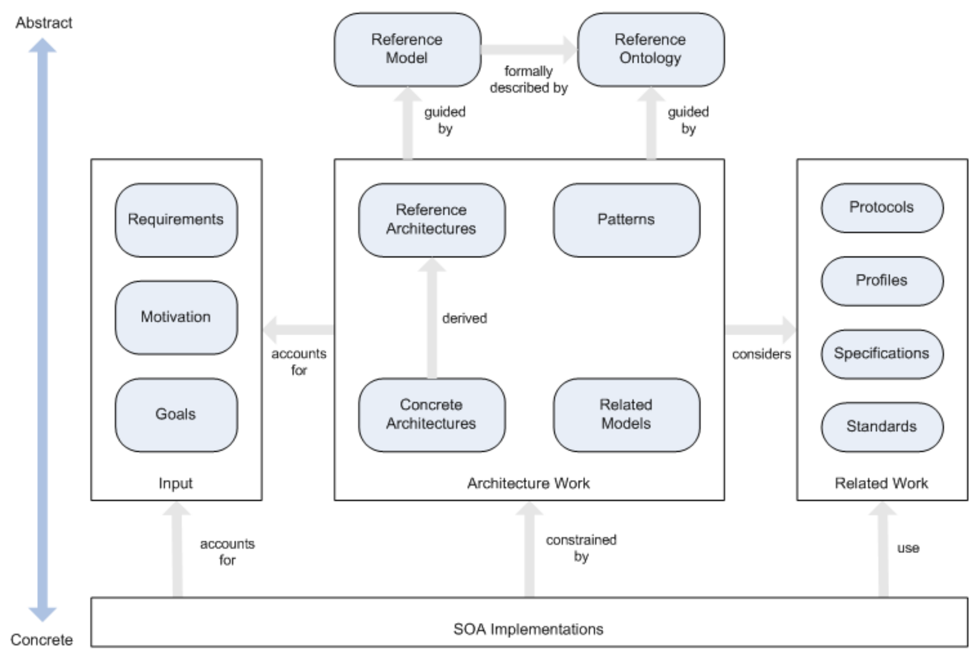

Figure 1-1 – Relationship of the Reference Ontology to Other SOA Specifications and Standards

Figure 1-1 depicts how the Reference Ontology relates to other pieces of work within the SOA community. The figure is derived from Figure 1 in the SOA Reference Model document **Error! Reference source not found.** and introduces the Reference Ontology alongside the Reference Model element. The Reference Ontology presented in this document is a further step towards formalization of the Reference Model but also accommodates the extensions associated with Semantic Web Services resulting in Semantic SOAs. Since the start of this work, the SOA-RM committee have also started work on a Reference Architecture, which also aims at further formalisation of the reference model, but we consider ontologisation central to the semantics-based approach and diverge. Indeed when we say Reference Architecture we shall refer to a reference architecture for SEEs, not to the SOA Reference Architecture. Furthermore when we say Concrete Architectures we refer to implementations of semantics-enabled SOAs such as WSMX **Error! Reference source not found.**, IRS III 0and METEOR-S 0.

The Related Models in Figure 1 include, for us, the Web Service Modeling Ontology (WSMO) 0, Semantic Annotations for WSDL and XML Schema (SAWSDL) 0the Web Ontology Language for Services (OWL-S)[1] 0and the Semantic Web Services Ontology (SWSO) 0. Patterns fulfill the same role in Semantic- as in pre-Semantic- SOA, which is to say that they define more specific categories of service-oriented designs. The Protocols and Profiles (those considered as part of the related work) are the same as for classical SOAs. However, with respect to Specifications and Standards, we further take into account emerging Semantic Web Languages such as the OWL, RDF and RIF standards from W3C, and the WSML and SWSL de facto standards. These “standards” play a very important role since they are the pillars of Semantic Technologies. The Input features (Requirements, Motivation and Goals) are the same as for SOAs, with the addition that we have more emphasis on automation, as stated earlier.

1.1 Motivation and Scope

With the term “Semantic” we mean the formal (and thus unambiguous) description of some particular object (more in section 2), which is subject to automated ontology-based reasoning. Within the context of the Reference Ontology, these objects are mainly the data handled by the services and the services themselves. Semantic descriptions within SOAs allow reasoning tools to automate tasks. More specifically, semantics help in the following ways:

- Formally and unambiguously define the data models and processes underlying the system;
- Allow automated discovery and composition of services;
- Automatically resolve data and process mismatches, easing integration and improving interoperability;
- Ease the process of service ranking, negotiation and contracting.

The scope of this document is therefore to provide an ontology that formally describes the different elements comprising a SSOA in order to achieve the above objectives.

1.2 Audience

The target audience for this document extends that of the SOA RM; however we provide an exhaustive list in order to keep the document self-contained:

- Architects and developers designing, identifying or developing a system based on the Service Oriented Architectures;
- Standards architects and analysts developing specifications that rely on Service Oriented Architecture concepts;
- Decision makers seeking a "consistent and common" understanding of Service Oriented Architectures;
- Users who need a better understanding of the concepts and benefits of Service Oriented Architectures;
- Academics and researchers that are researching within the Semantic Web and Semantic Web Service communities;

[1] It may be noted that no unified Semantic Execution Environments exist for OWL-S; a list of the major, but separate, OWL-S tools is available as http://www.daml.org/services/owl-s/tools.html, which includes the OWL-S VM

- I.T. consultants that provide businesses with support on Semantic technologies and SOAs in general.

1.3 Guide to this Document

It is assumed that readers who are not familiar with SOA concepts and terminologies read first the SOA Reference Model **Error! Reference source not found.**document since this document builds on top of its concepts. Furthermore, readers who are new to the concept of Semantic Technologies are encouraged to read this document in its entirety.

Section 1 introduces the Semantic SOA Reference Ontology and how it relates to other work (in particular the SOA RM). It defines the audience and also provides a description of the notational conventions used in this document. Both of these elements are important in order for the reader to understand the content of the rest of the document.

Section 2 provides an overview of Semantics and how they interrelate with SOAs. It starts by describing the deficiencies of the classical SOA and the problems in building them. It then continues with examples and situations of how Semantic Technologies can help to overcome these deficiencies. Section 2 strengthens the motivations and objectives already described in this section.

Section 0 describes the SOA Reference Model **Error! Reference source not found.** and builds on top of this by introducing new key concepts required for SSOAs. It first describes what we understand by a service followed by the dynamics of a service – how the service is perceived by the real world. Other related concepts are also described (including, for example, the behavior of the Web service). Section 3 shows the differences between the classical SOA RM and the SSOA RM and provides the necessary building blocks for specifying the Reference Ontology.

Section 4 defines the Reference Ontology for SSOAs. The ontology is first described using Concept Maps and UML Diagrams (notation described in Section 1.4 below). It is then formally described using WSML 0in Appendix 0 as explained in Section 1.4.2.

The glossary provides definitions of terms that are relied upon within the document. Terms that are defined in the glossary are marked in **bold** at their first occurrence in the document.

Note that while the concepts and relationships described in this document may apply to other “service” environments, the definitions and descriptions contained herein focus on the field of software architectures and make no attempt to completely account for their use outside of the software domain. Examples included in this document, which are taken from a variety of domains, are used strictly for illustrative purposes.

1.4 Notational Conventions

Throughout this document we use both Concept Map and UML Class Diagram notations to illustrate models, this is due to the derivation from – and preservation of links to – the SOA RM specification, which uses the former, together with the need to provide an accessible representation of the ontology-based model. For clarity these two notations are distinguished in the caption of the figures throughout the document; figures whose caption end with [Concept Map] conform to the Concept Map notation, while figures whose caption end with [UML] conform to the representation of ontologies in the UML Class Diagram notation, as described below. This document does not use the notation from RFC2119 0, for example MUST, MUST NOT, REQUIRED, SHALL, SHALL NOT, SHOULD, SHOULD NOT, RECOMMENDED, MAY, and OPTIONAL as cardinality constraints are present within the UML diagrams.

1.4.1 Concept Maps

The Concept Map notation used in this document is the same as for that in the SOA RM; however we give a brief description here to keep the document self-contained.

There is no normative convention for interpreting Concept Maps and other than described in this section, no detailed information can be derived from the Concept Maps.

Figure 1-2 - A basic Concept Map [Concept Map]

As used in this document, a line between two concepts represents a relationship whereby the relationship is not labeled but rather is described in the text immediately preceding or following the figure. The arrow on a line indicates an asymmetrical relationship, where the concept to which the arrow points can be interpreted as depending in some way on the concept from which the line originates. The text accompanying each figure describes the nature of each relationship.

1.4.2 Ontologies

Within this document we use UML Class Diagrams to illustrate the Reference Ontology; the underlying formal definitions are made in WSML. This is for two reasons: first, we must use a language with well-founded semantics, capable of machine reasoning – the general motivation of work in the Semantic Web that has produced several ontology languages. For this purpose we could equally use OWL or (to a more limited degree) RDFS for the definitions. Secondly, for the purposes of the SEE Reference Architecture, we need a language that allows us to attach elements of this model to SWS elements, including goals and mediators, and WSML is the only language that allows this.

This document sticks to the ontology definition facilities of WSML and does not define (meta-) service objects, and hence the Reference Ontology itself could be defined using OWL. The Reference Architecture will attach Reference Ontology concepts to *goal* descriptions to allow the characterization of the components of a Semantic Execution Environment (the core services of a SSOA). The Execution Scenarios will attach Reference Ontology concepts, and Reference Architecture goals, to *service* descriptions to illustrate how the SEE components can work together to achieve common tasks. Finally, concrete architectures may be defined by linking concrete services to the goals from the Reference Architecture. For this reason, and due to the deficiency of the OWL-S and other service models, the Reference Architecture must be defined in WSML and it is therefore easiest to define the Reference Ontology in which it is based on the same language.

In the remainder of this section we sketch the relationship between UML Class Diagrams, as used within the text, to WSML descriptions. In the following section we reproduce these definitions.

Concepts

The fundamental feature of Class Diagrams – and indeed Object-oriented design (OOD), which is the real target of UML – are classes, which are shown as square boxes with their identifier listed inside. We use UML classes to represent WSML concepts. Where the namespace into which concepts are defined is clear, we allow ourselves to omit this information in the Class Diagram. Where different namespaces are used, we use the notation for packages to make the namespace clear.

Figure 1-3 hence corresponds with Listing 1.

```
concept A

concept _”http://www.example.com/ontologies/ns1#B”
```

Listing 1: Example Concepts in WSML

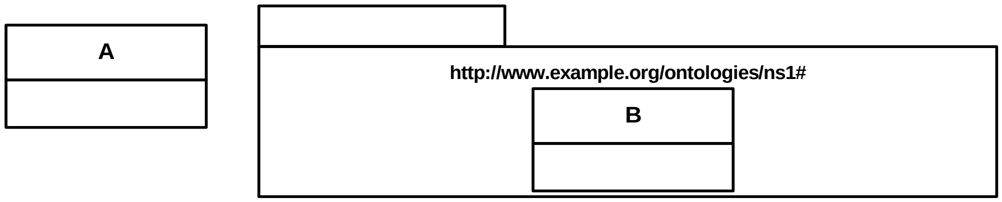

Figure 1-3: Representation of WSML Example Concepts in UML Class Diagram [UML]

While UML Class Diagrams allow the definition of operations and attributes within classes, we choose not to use these and always show classes with an undivided box. Regarding the representation of attributes of WSML concepts, see below.

Subsumption

The fundamental relationship between concepts in WSML, as with many ontology languages, is *subsumption*. This is represented by inheritance in UML Class Diagrams. Since we declare no operations there are thus no unwanted side-effects due to UML/OOD semantics; in particular there are no complications in the use of multiple parents for a given concept.

Figure 1-4 hence corresponds with Listing 1.

```
concept A

concept B subConceptOf A

concept C

concept D subConceptOf {A, C}
```

Listing 2: Example of Subsumption between Concepts in WSML

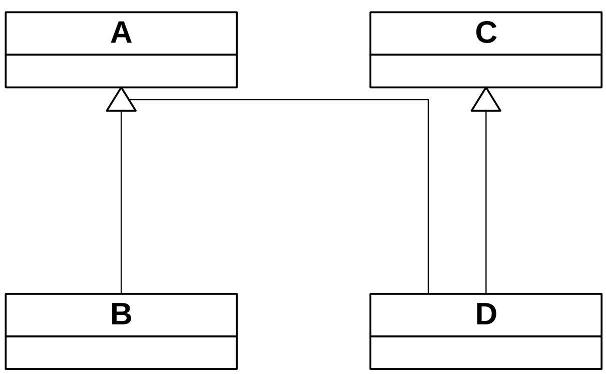

Figure 1-4: Representation of Subsumption Example in UML Class Diagram [UML]

Attributes

The other explicit relationship between concepts in WSML is via *attributes*. These are represented by (directed) *associations* in UML Class Diagrams, which is to say associations with a one-way navigability, so that the innavigable side of the association (or, more correctly, the end of unspecified navigability) is the concept whose definition includes the attribute, and the other side the attribute range. The name of the association will be the name of the attribute; where the attribute name is the default 'hasE', where 'E' is the name of the concept that is the attribute range, we shall often omit this. Cardinality constraints –

i.e., restrictions on the number of values the attribute may take for any given instance – are represented, where possible, by a constraint on the association. Figure 1-5 hence corresponds with Listing 3.

```
concept E

concept F
  hasE ofType (0 1) E

concept G
  hasEorF ofType EorF

concept EorF

axiom anEisEorF definedBy
  ?e memberOf E implies
  ?e memberOf EorF.

axiom anFisEorF definedBy
  ?f memberOf F implies
  ?f memberOf EorF.
```

Listing 3: Example of Attributes between WSML Concepts

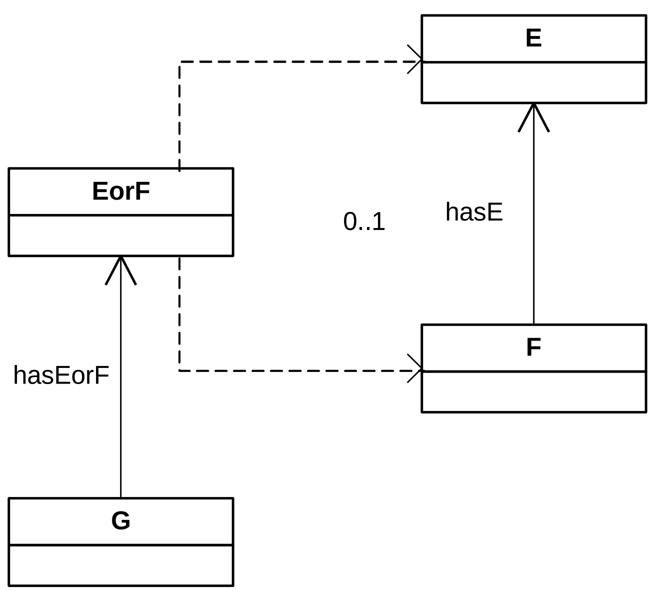

Figure 1-5: Representation of Attributes Example in UML Class Diagram [UML]

We also make use of disjunctive attribute ranges by way of an intentionally-defined union class, as shown by hasEorH of concept G.

1.5 Terminology

The key words “MUST”, “MUST NOT”, “REQUIRED”, “SHALL”, “SHALL NOT”, “SHOULD”, “SHOULD NOT”, “RECOMMENDED”, “MAY”, and “OPTIONAL” in this document are to be interpreted as described in **[RFC2119]**.

1.6 Normative References

[RFC2119] S. Bradner, *Key words for use in RFCs to Indicate Requirement Levels*, http://www.ietf.org/rfc/rfc2119.txt, IETF RFC 2119, March 1997.

1.7 Non-Normative References

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[8] J. Farrell, H. Lausen: Semantic Annotations for WSDL and XML Schema. W3C Recommendation, 28 August 2007, available at: http://www.w3.org/TR/sawsdl/

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[11] D. Fensel, M. Kerrigan, M. Zaremba (eds.): Implementing Semantic Web Services - The SESA Framework, (Springer), 2008

2 Semantics and SOA

As noted in the Reference Model for Service Oriented Architecture (SOA-RM) committee specification, the notion of Service Oriented Architecture has received a lot of attention in the software design and development community. According to the SOA-RM, a “Service Oriented Architecture (SOA) is a paradigm for organizing and utilizing distributed capabilities that may be under the control of different ownership domains.” Service Oriented Architecture provides an architectural mechanism for building applications from unassociated units of functionality, called services. The perceived value of SOA is that it provides a powerful framework for matching needs and capabilities and for combining capabilities to address those needs, by enhancing the ability of adapting applications more quickly to changes in market conditions and improving the reusability, modularity, composability and interoperability of functionality.

A service, in the context of SOA, refers to a software mechanism that provides access to a capability that may have a real world effect or results in the exchange of information. Such services can be implemented leveraging many different standards and technologies, including Web services using WSDL descriptions and SOAP messaging.

Building Service Oriented Architectures using existing services still involves substantial human effort in the process of finding and using appropriate services. The need for human intervention can be attributed partly to the fact that standards that are typically used for describing services (e.g., WSDL), only focus on the syntactic aspect of the service interface, and provide little support for finding and using services that provide the appropriate desired functionality. In this “classical SOA” scenario, developers building an application using SOA, typically look for services that are available, either within their company’s repository of services or in remote locations. Each time a need to invoke a service is identified, a set of candidate services must be found browsing in repositories (e.g. UDDI or ebXML repositories). While keywords and text search features can be leveraged to identify candidate service, the syntactically focused descriptions typically require evaluation by a human before a service can be used. In many instances further human interaction between the developer on the consumer side and the service provider is required to clarify the functionality and the meaning of the information that is being exchanged. Then tests can be performed on the candidate services. Finally, a service may be selected and added to the application.

Not only is this process labor intensive, but the solution is fairly static, limiting the ability to adapt to changes quickly, which is a key promise of the SOA approach. Changes, whether it is new services that provide improved functionality or unavailability of currently used services, typically require human interaction in the classical SOA. The goal of a Semantically-enabled SOA is to add features that can help overcome these limitations and provide mechanisms to automate tasks that currently require human intervention.

2.1 Semantics

A key limitation of a “classical SOA”, as mentioned above, is that the standards used for describing Web services provide very little detail about the service, beyond a simple description of the external interface they provide. With these descriptions it is impossible to provide further meaning about a service, such that reasonable inferences can be drawn regarding the functionality offered by the service, or the behavior of its outwardly facing interfaces.

Semantics is the study of meaning. A formal semantic description offers the opportunity of providing a mechanism for describing things more clearly and extensively. A formal semantic description is unambiguous within the context of the formalism and opens the opportunity for automated reasoning. Semantics come in many forms. Very basic advances towards semantics include annotations or tags that can be associated with an entity in order to give a description of what that thing is. Annotations or tags can be seen in action on sites like flickr.com®, where they are used for denoting what content appears in a particular picture or what a picture is about. This mechanism, of course, is very rudimentary and certainly not unambiguous in nature as annotations or tags are freeform in nature. To bring more meaning to the annotations, taxonomies can be introduced. Such structures give a mechanism for providing a controlled vocabulary of terms (i.e., a controlled set of annotations) and the relationship between them.

For example we can state that the term *banana* is a sub class of the term *fruit*. This additional semantic information enables us to reason about the semantic descriptions we have and make decisions based on the semantic descriptions, for example the query *"show me all photos containing a piece of fruit"* is posed, then those pictures that are annotated with the term banana would be found, as *banana* is a subclass of *fruit*. To add more semantics we can go even further and allow logical expressions to be added to taxonomies to turn them into ontologies, such that more complicated relationships between entities can be expressed. The addition of axiomatic information in this way also allows for much more sophisticated reasoning to take place and for new information to be inferred from existing information, for example the axiom *"all fruit is edible"* placed in a reasoner with the previous example would allow the fact *"bananas are edible"* to be inferred and thus queries like *"show me all photos containing things that are edible"* would find pictures of bananas.

2.2 Applying Semantics to SOA

As indicated earlier, the syntactically focused descriptions of services in the "classical SOA" scenario limits the ability to automate tasks that are important for a quickly and reliably adapting to changes. The idea here is to apply semantics to SOA and enhance service descriptions with additional semantic information that can be used in conjunction with semantic processing mechanisms (i.e., mediation).

By extending ontologies to describe services in a SOA, a machine can reason about the functionality they provide, the mechanism to invoke them, and the data they expect as input and return as output. In other words each service that currently has a syntactic description (i.e., a WSDL document) will also have a semantic description in some formalism. Thus services within a Semantic SOA are not a reinvention of services, but an enhancement of them. In order to effectively describe services semantically we need to have an understanding of what elements need to be modeled within our semantic description. Within this document you will find the Reference Ontology for Service Oriented Architectures, which provides such a description of what elements need to be modeled in order to effectively provide semantic description for services and build a SOA that is semantically-enabled, referred to as a Semantic SOA (SSOA).

Once services are described semantically, many of the tasks previously requiring human intervention in building and maintaining and application using SOA can be automated. For example, services can be *discovered* based upon the functionality they advertise in their semantic description, can be *selected* based upon the advertised (or observed) quality of the service, heterogeneity issues with respect to the data they exchange or the process to invoke them can be *mediated*. This allows for a SSOA, to dynamically bind to services at run time, removing the hard-wired behaviours that are typically for classical SOAs. When new services appear on the market that fulfill functionality needed by the application, they can be considered alongside existing services that are being used already by the application and may be selected over these existing services based on the requirements of the application. Also if a given service that is usually used by the application is no longer available, it can be automatically replaced by another service that fulfills the same function.

3 Overview of SOA-RM

The notion of Service Oriented Architecture has been greatly used in the last couple of years by the software design and development communities. Yet, the various and very often conflicting definitions and terminology for SOA and its elements could hamper the adoption process and threaten the success and the impact of this technology. In order to provide a standard reference point in the design and implementation of SOAs the OASIS SOA-RM Technical Committee[2] proposes an abstract framework for understanding the main entities and the relationships between them within a services oriented environment **Error! Reference source not found.**.

The resulting specification is a SOA Reference Model (SOA-RM), which is not directly dependent of any standards, technologies and implementation details. Its goal is to define the essence of Service Oriented Architecture, a normative vocabulary and a common understanding of SOA. The Reference Ontology takes this reference model as a starting point in defining the main aspects of a Semantically-enabled Service Oriented Architecture and it specifies how the normative elements of the SOA-RM can be augmented with semantics. As a consequence, this section gives a brief overview of the SOA-RM, along the several aspects it covers: the notion of *service*, the *dynamics of service* and the service-related concepts such as *service description*, *service execution context* and *service contracts and policies*, as shown in Figure 3-1.

3.1 What is a service?

SOA-RM defines a service as "…*a mechanism to enable access to one or more capabilities, where the access is provided using a prescribed interface and is exercised consistent with constraints and policies as specified by the service description.*" It identifies four main aspects regarding the service that have to be considered in any SOA:

- A service *enables access to one or more capabilities*;
- A service *enables access through a prescribed interface*;
- A service is *opaque to the service consumer* except from the information and behavioural models in the interface and the information requires to assess if a service meets the requesters needs;
- *Consequences of invoking a service* should either be response information to the invocation or a change to the shared state of the defined interface.

It is important to note that SOA-RM makes a clear distinction between the capability of a service (i.e. some functionality created to address a need) and the point of access where the capability can be consumed in the context of SOA.

3.2 Dynamics of Services

SOA-RM also provides guidelines regarding the interactions of the requester with a service. As such, among the service related concepts mentioned above, it identifies three fundamental concepts related with dynamics of the service: *Visibility, Interaction* and *Real World Effect* (see Figure 3-1).

[2] For more details, see http://www.oasis-open.org/committees/soa-rm.

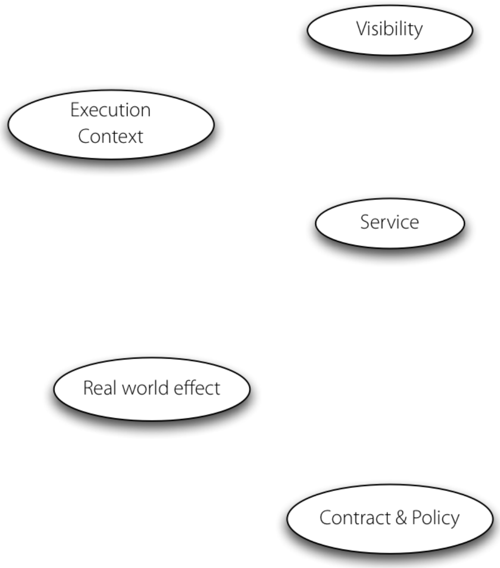


Figure 3-1. Fundamental Concepts of Service Dynamics (directly from ***Error! Reference source not found.****) [Concept Map]*

Visibility in terms of SOA-RM is characterized in terms of *Awareness*, *Willingness* and *Reachability* (see Figure 3-2) where:

- *Awareness* is the state whereby the service requester is aware of the service provider or the other way around. It is normally achieved by having either the requester or the provider discovering the information the other party published in for example a public directory.
- *Willingness* concerns the intent to communicate. Even if the discovery process has been successful, without willingness to communicate from both requester and provider the interaction will fail.
- *Reachability* is the state that characterizes service participants that are able to interact, for example by exchanging information.

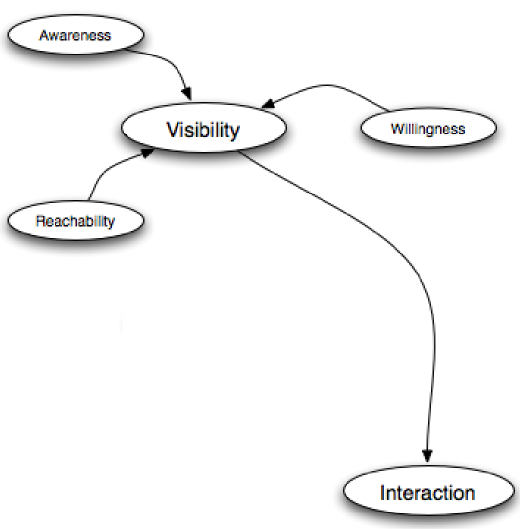


Figure 3-2. Service Visibility (adapted from ***Error! Reference source not found.****) [Concept Map]*

The *interaction* with a service is reflected by the actions performed on the service, for example exchanging messages with the services. According to SOA-RM the key concepts affecting the interaction with a service are the following (see Figure 3-3):

- *Information Model* of a service characterizes the information that may be exchanged with the services and only descriptions of information that can be potentially exchanged with the service and their data structures are included in the information model. The information model can be also portioned in:
  - *Structure (Syntax)* refers to the representation, structure, and a form of information;
  - *Semantics* refers to the actual interpretation and intent of the data. Semantics becomes important especially when interaction occurs across ownership boundaries since the interpretation of data must be consistent between the participants in a service interaction.
- *Behavior Model* deals with *“knowledge of the actions invoked against the service and the process or temporal aspects of interacting with the service”.* It consists of two distinct aspects:
  - *The action model* characterizes the actions that can be invoked against the service. Since a great part of the behavior implied by an action is private, the public view of the service includes the implied effects of actions;
  - *The process model* defines temporal relationships of actions and events associated when interacting with a service. SOA-RM does not fully define the process model since it could include aspects that are not strictly part of SOA, e.g. orchestration of services.

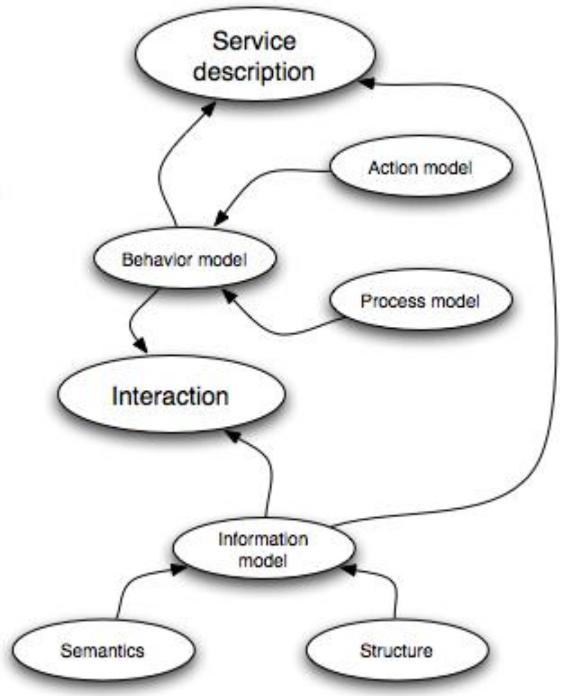


Figure 3-3. Service Interaction (adapted from ***Error! Reference source not found.****) [Concept Map]*

The r*eal world effect* is the ultimate purpose associated with the interaction with a particular service. It can be the response to a request for information or the change in the state of some shared entities between the participants in the interaction.

3.3 Service Related Concepts

SOA-RM identifies a set of concepts crucial in enabling the interaction between a service consumer and a service. These concepts are the *service description*, the *service policies and contracts* and the *execution context.*

The *service description* encompasses the information needed in order to use the service (see Figure 3-4). The purpose of the service description is to facilitate the interaction of the visibility especially if the participants are part of different ownership domains. By using the service description the service consumer should be able obtain the following items of information:

- Whether the service is reachable or not;
- Whether the service provides the function required by the requester;
- The set of policies the services operates under;
- That the service complies with the service consumer's policies;
- The means to interact with the service, including the format and content of the information to be exchanged, as well as the expected sequence of the information exchange.

As a consequence, there are several important aspects that have to be captured by the service description: the service reachability, the service functionality, the service-related policies, and the service interface.

- *Service reachability* is assured by including in the service description enough information to enable the service providers and services consumers to interact with each other. Such information could include service metadata (e.g. location, supported or required protocols), dynamic information about service (e.g. if the service is currently available), etc.
- *Service functionality* should be unambiguously captured by the service description and it should contain information about the function of a service and the real world effects that result from it being invoked. This piece of information should be expressed in a general-enough way to be understandable by service consumers while at the same time the vocabulary used should be expressive enough to capture the domain-specific details of the service functionality. Such information could include a textual description (for human consumption) or identifiers or keywords referencing machine-processable definitions.
- *Service-related policies* should be reflected by the service description in order to enable the prospective service consumer to determine if the service will act in a manner consistent with consumer's own constraints.
- The *service interface* describes the means to interact with the service. It could include specific protocols, commands and information exchange by which actions are initiated. It prescribes what information needs to be provided to the service in order to access its capabilities and interpret responses. This information is also referred as the information model of the service.

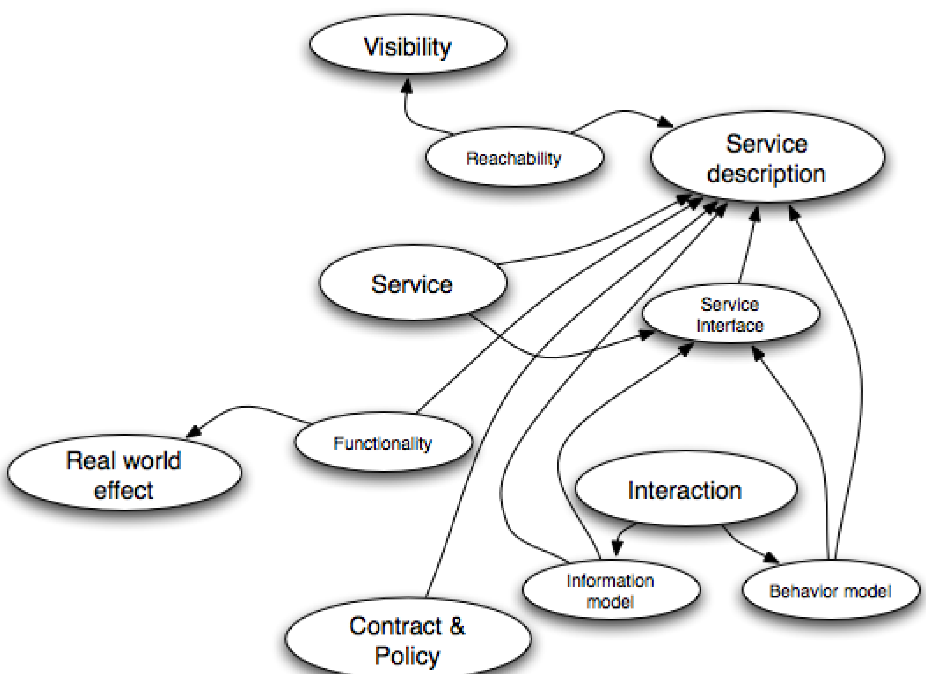


Figure 3-4. Service Description (directly from ***Error! Reference source not found.****) [Concept Map]*

The *service policy* represents the constraints or the conditions on the use, deployment or description of a service while a *contract* is a measurable assertion that governs the requirements and expectations of one or more parties. Policies potentially apply to various aspects of SOA such as security, manageability, privacy, etc. but they could also be applied to business-oriented aspects, e.g. hours of business. In their turn contracts can as well cover a wide range of aspects of services: quality of services agreements, interface and choreography agreements, commercial agreements, etc.

The *execution context* represents the set of infrastructure elements, process entities, policy assertion and agreements associated with a particular service interaction, forming a path between service consumers and service providers. The execution context is not limited to one side of the interaction but rather concerns the overall interaction, which includes the service provider, service consumer and the infrastructure in between.

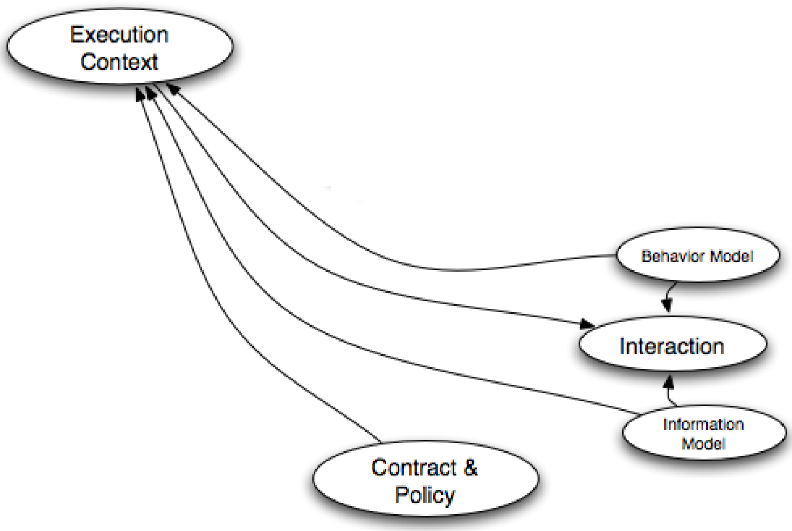


Figure 3-5. Execution Context (adapted from ***Error! Reference source not found.****) [Concept Map]*

4 Reference Ontology for Semantic Service Oriented Architectures

The reference ontology for Semantic SOA formalises and extends those sections of the SOA Reference Model described above, as illustrated in Figure 1-1.

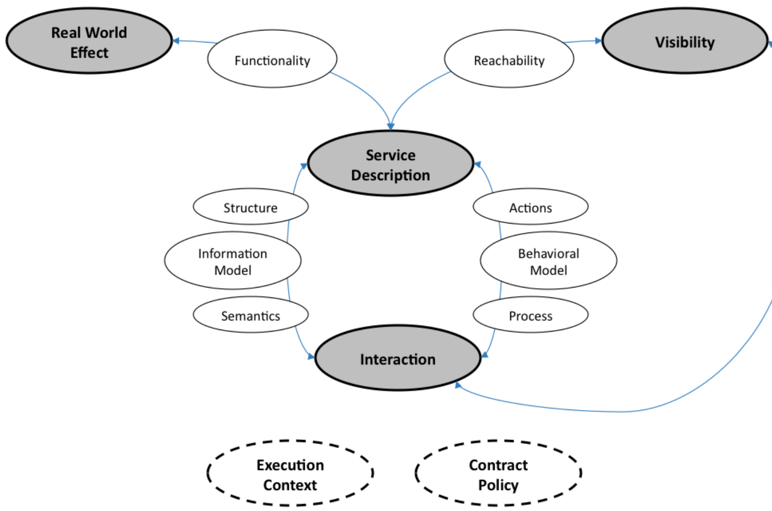


Figure 4-1 – Concepts from SOA-RM as preserved in Reference Ontology [Concept Map]

Oval shapes are used to represent the *top-level* elements from the SOA Reference Model and rectangles the others. Those which are shaded are the ones on which we concentrate in the Semantic SOA Reference Ontology. Although *Execution Context* and *Contracting & Policy* are all important issues for SOA, they are less mature from the point of view of ontology-based semantics, and less ready for standardisation.

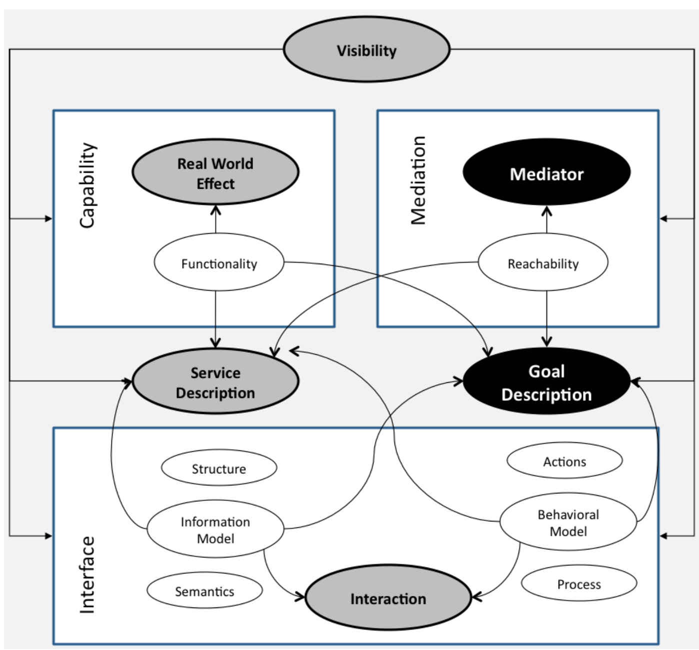


Figure 4-2 - Extension of SOA RM in the Reference Ontology [Concept Map]

In Figure 4-2 we show how we have extended and arranged the Reference Model to enable a thorough semantic description. New elements are shown with an asterix. The most notable difference is that we replace the *Visibilty* concept with the concept of *Mediator*. *Visibility* is taken as more fundamental to the semantics-driven approach and shown underlying all concepts. Secondly, as well as a *Service Description* we introduce the first class notion of *Goal Description*, which is a top-level element like *Mediator* in our extended model. *Goal Description* is a formal description of the requirements for a service from the point of view of a consumer. In this way we can make a first class representation of the more restricted sense of *Visibility*, from the SOA RM, and *Reachability* via *Mediator*. The more general concept of *Mediation* is a grouping concept, and represented by a shaded area. In a similar way, we group the description of functionality into a concept *Capability*, and the *Behavioural Model* and *Information Model*, describing *Interaction*, into a concept *Interface*.

The Reference Ontology is introduced in small pieces over the next sections and the complete Reference Ontology can be seen in Figure 4-10.

4.1 Visibility

The two fundamental principles of the semantics-based approach are that: all descriptions of service-oriented concepts should be made in an ontology-based formalism; that all ontology-based descriptions should be capable of being connected via mediation. For this reason we see visibility, which is the ability to access a description and thereby the service it represents, as the underlying concept of the entire approach. In the following, we introduce the concepts and requirements for a formalism to be based on ontologies.

4.1.1 Ontologies

Ontologies, as introduced in Section 1.4.2, provide the basis for all elements in the Reference Ontology and contain Concepts, Relations, Instances, and Axioms. Service Descriptions, Goal Descriptions, and Mediators can import Ontologies in order to utilize the terminology that they provide.

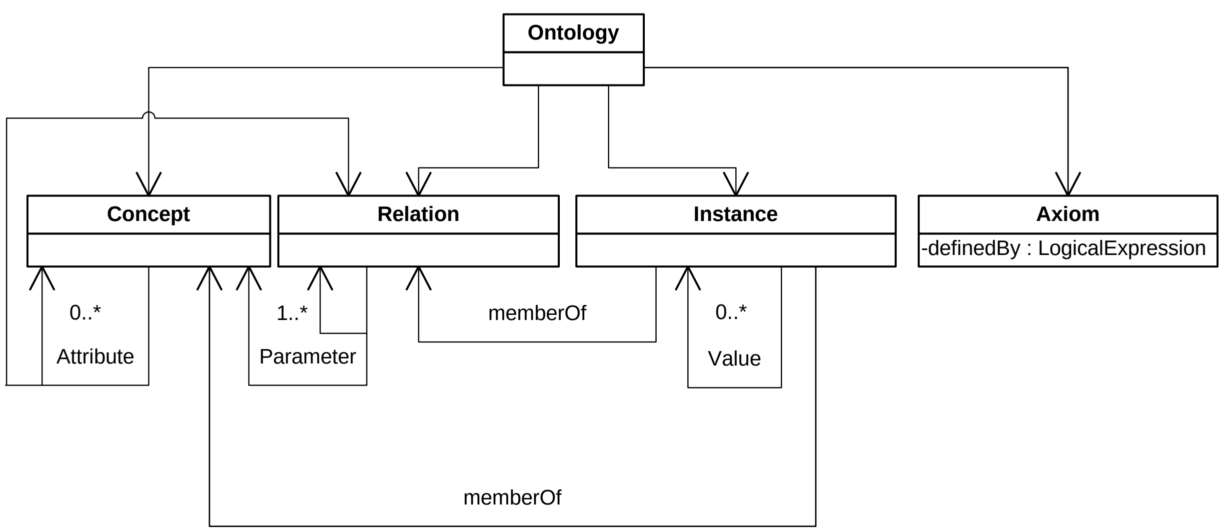


Figure 4-3 – Fundamental Modeling Elements Contained within Ontologies [UML]

4.1.2 Concepts

Concepts provide a means for describing pieces of terminology and can be related to each other via the subclass-superclass relationship (see Subsumption in Section 1.4.2). Concepts define attributes that range over concepts and relations. Instances of the defined concepts then carry attribute values belonging to those concepts and relations ranged over, allowing relationships instances to be captured.

4.1.3 Relations

Relations allow further relationships, over those captured as conceptual attributes, between instances to be established. Unlike attributes there is no source to the relationship but there is an arbitrary number (arity) of parameters typed as concepts and other relations so that instances capture multi-party relationships between instances.

4.1.4 Instances

Instances are identifiable or anonymous members of concepts and relations and also provide values to the attributes or parameters of concepts and parameters of relations respectively. Instances may be explicitly declared as members of concepts and relations or they may be implicitly included as members therefore via effects of axioms.

4.1.5 Axioms and Logical Expressions

Through the use of logical expressions, axioms define constraints that must hold over all contents of their containing ontology in order for this to be consistent. These can be used to support an explicit style of modelling, where instances and their concept memberships are declared explicitly and axioms merely constrain their allowed membership and attribute values (cf. relational database constraints), or intentionally, where concepts may be implicitly populated via axioms.

4.2 Service Description

SOA RM requires: *"The service description represents the information needed in order to use a service," and states that "The service concept above emphasizes a distinction between a capability that represents some functionality created to address a need and the point of access where that capability is brought to bear in the context of SOA."* In SSOA we regard this as the critical division in the description of a service: the capability and the interface.

In the Semantic SOA Reference Ontology, these core service descriptions represent a core element in defining Semantic Web Services, which we aim to support automated reasoning over by the use of semantic technologies. Therefore semantic descriptions are associated to all resources, thus services as well. The semantic descriptions are grounded to concrete service realizations, such that once the semantic description is known the implementation of the service can be found as well.

It is important to point out that the Semantic SOA Reference Ontology allows for both functional, including behavioural, and non-functional descriptions of the service. While the functional descriptions are formal definitions expressed in terms of ontologies, the non-functional properties are extension of the Dublin Core, and might contain human-readable descriptions as well.

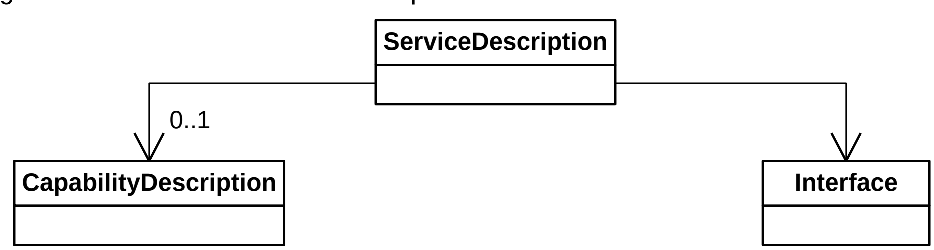


Figure 4-4 - The Top-Level Structure of a Service Description [UML]

4.3 Goal Description

SOA RM defines *awareness* as the state "whereby one party has knowledge of the existence of the other party". Semantic technologies aim to automate as much as possible the process of bringing the service requesters and the services providers in the "awareness state" and to create a dynamic infrastructure able to support all the necessary communication aspects.
Along these lines, the Semantic SOA Reference Ontology has adopted the ontological role separation principle by which the service consumers exist in a specific context, different than the one of the services

to be consumed. As a consequence, the requester needs can be independently formalized as *Goals* in accordance with their internal requirements, isolated from the peculiarities of the provider infrastructure, data or behavior models.

Nevertheless, in order to facilitate the matchmaking process between requester goals and provider services, the Reference Ontology defines a GoalDescription as being formed from the same elements as a ServiceDescription: namely a *CapabilityDescription* and a set of *Interfaces*. The CapabilityDescription of a GoalDescription represents the requested capability, i.e. the capability the requester desires to find and consume. The Interface of a GoalDescription describes the interfaces the requester intends to use during the communication with the matching service.

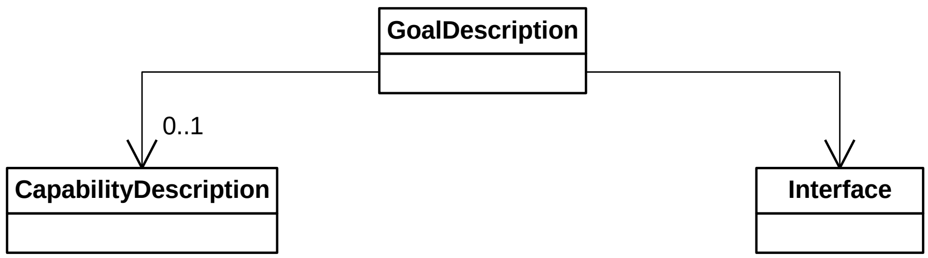


Figure 4-5 - The Top-Level Structure of a Goal Description [UML]

4.4 Capability Description

SOA-RM requires: *"A service description SHOULD unambiguously express the function(s) of the service and the real world effects that result from it being invoked."*

As we have seen in sections 4.2 and 4.3, a CapabilityDescription is a description of the functionality provided by a service or the functionality desired by a service requester and as such can be linked to one or more Service or Goal Descriptions. CapabilityDescriptions are generally used for automating the process of discovering services, by comparing the offered functionality of each provider with the desired functionality of the requester. A Capability is described in terms of conditions on the state of the world that must exist for execution of the service to be possible and conditions on the state of the world that are guaranteed to hold after execution of the service. We make a distinction between the state of the information and the state of the real world, thus these conditions can be broken down into two groups namely those related to the state of the information space (preconditions and postconditions) and those related to the to the state of the real-world (assumptions and effects). By providing these 4 elements, the Reference Ontology allows the state change that occurs in both the information space and in the real world to be effectively described.

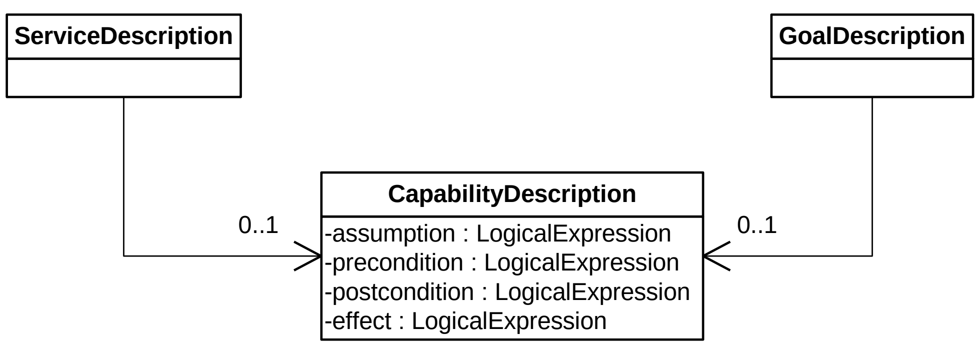


Figure 4-6 – Service and Goal Capabilities [UML]

4.4.1 Functionality

In terms of the SOA-RM the preconditions and postconditions of a service make up the description of its functionality. Preconditions describe the state of the information space prior to execution and postconditions describe the state of the information space after execution. Therefore preconditions can be used to specify what information needs to be available in order for a service to be invoked and postconditions describe what information will be generated by the service into the information space.

4.4.2 Real World Effect

Many services that can be invoked will have as the SOA-RM describes a *Real World Effect*, that is that the process of invoking a service will not only change the state of the data sources related to the service requester and service provider but also an actual change will occur to the state of the world, for example when buying a book from a book selling service the physical book will change location from the warehouse to the home of the purchaser. In the Reference Ontology we consider this real world effect by describing the state of the world prior to execution in terms of Assumptions and the state of the world after execution by Effects.

4.5 Interface

SOA-RM specifies that "*the service interface is the means for interacting with a service*". Furthermore, SOA-RM recommends that the interface consists of two parts, Information Model and Behavioral Model. The Information Model is represented both in a semantic and a structural manner.

In the Semantic SOA Reference Ontology the semantic part of information model is based on an ontological description, but this needs to be considered both by the capability and the interface, so this is attached directly to the service (or goal) description, as described in Section 4.5.1. The structural part of the information model needs to be considered only by the communicated information and therefore is represented, via groundings to a schema representation of the appropriate semantic concepts, in the action model, as described in 4.5.2.1.

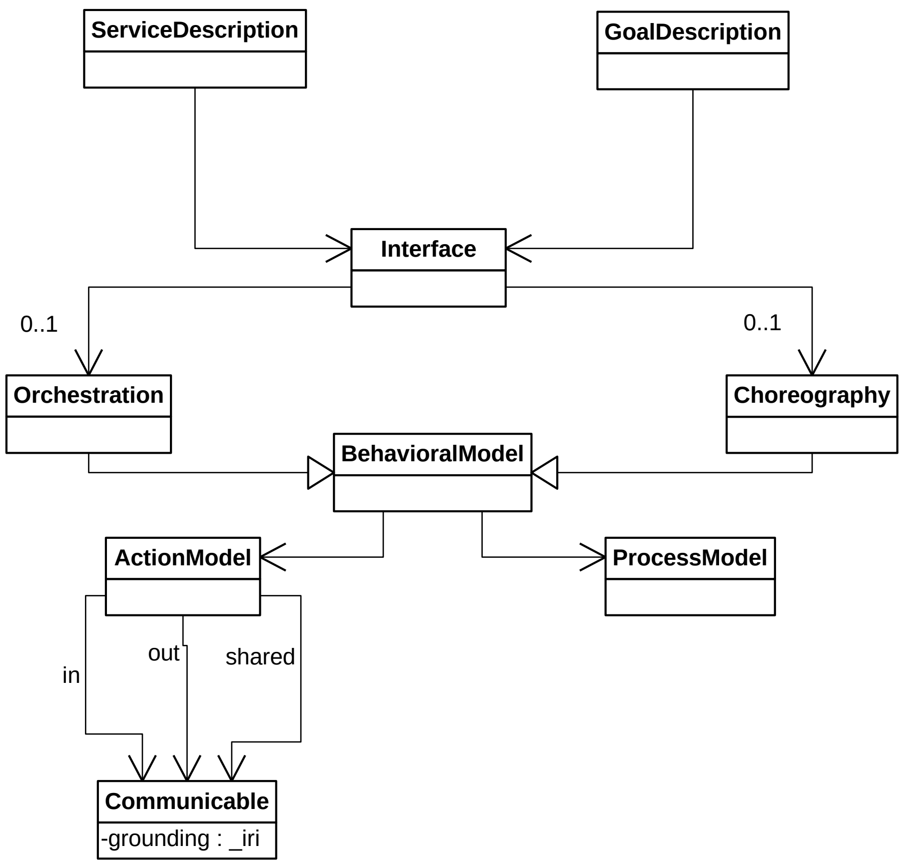


Figure 4-7 - The Structure of an Interface [UML]

For the Semantic SOA Reference Ontology, the notion of behavioural model is specialised into two different concepts, representing different perspectives:

- Service requester perspective - the information that is needed for service execution by the service requester, specified as *Choreography*;

- Communication with other services – information on how the service can coordinate the cooperation between other services in order to fulfill its functionality, specified as the *Orchestration*.

4.5.1 Information Model

"*The information model of a service is a characterization of the information that may be exchanged with the service*". As previously described, for Semantic SOA this information is provided by the domain ontology of the service; this ontology specifies all the information needed for the service execution and for its communication with other services or with the requestors.

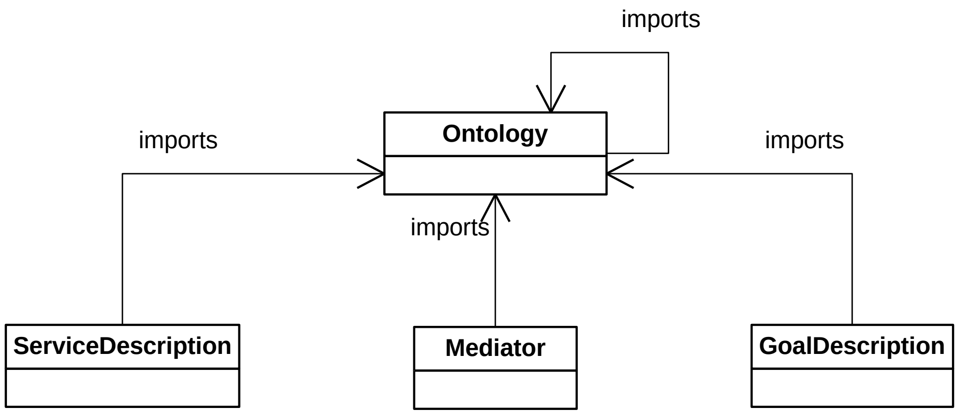


Figure 4-8 Ontologies as Semantic Information Model [UML]

4.5.1.1 Semantics

The parties involved in a communication need to have a common understanding of the semantic of the exchanged messages. When the parties use ontologies for describing their information model, this common understanding implies either a previous agreement regarding what ontologies are used, or the existence of a mediator for solving any heterogeneity problems. This will ensure a high degree of automation for the communication.

4.5.1.2 Structure

As described above, some of the concepts (and relations) from the Semantic Information Model will actually be communicated by the service. The structural definition of these components will be represented by the groundings in the Action Model, described in Section 4.5.2.1.

4.5.2 Behavioral Model

The SOA RM defines the Behavioral Model as "*knowledge of the actions invoked against the service and the process or temporal aspects of interacting with the service*". For Semantic SOA this knowledge is encapsulated by the definition of what information needs to be exchanged during the communication, the concepts and relations of an ontology being marked to support a particular role (or mode). Furthermore, the order in which the messages are exchanged needs to be unambiguously specified.

4.5.2.1 Action Model

For specifying what information needs to be exchanged during the communication the concepts and relations of an ontology are marked to support a particular role (or mode). There are five modes defined in the state signature:

- *static* - meaning that the extension of the concept cannot be changed;
- *in* - meaning that the extension of the concept or relation can only be changed by the environment and read by the service;

- *out* - meaning that the extension of the concept or relation can only be changed by the service and read by the environment;
- *shared* - meaning that the extension of the concept or relation can be changed and read by the service and the environment;
- *controlled* - meaning that the extension of the concept is changed and read only by the service.

4.5.2.2 Process Model

For using the modes defined in the state signature a grounding mechanism needs to be provided for allowing the environment (i.e. the communication partner) to read or to write information in the services ontology. For each mode except static and controlled, a different grounding mechanism needs to be provided as follows:

- *in* - a **grounding** mechanism for the in items, that implements *write* access for the environment, must be provided;
- *out* - a **grounding** mechanism for the out items, that implements *read* access for the environment, must be provided;
- *shared* - a **grounding** mechanism for the shared items, that implements *read/write* access for the environment and the service, must be provided.

For the static and controlled items a grounding mechanism is not needed, as these items can either be changed only by the service or remain unchanged for the duration of the communication.

The Semantic SOA Reference Ontology is not prescriptive about what form the behavioural description should take, except that it should take account of these modes. These rules could, for instance, be specified using the Abstract State Machine methodology, each rule evaluating some conditions on the current state of the service, and prescribing what activities should be performed if the conditions are fulfilled.

4.6 Mediation

SOA RM defines Visibility as "*the relationship between service consumers and providers that is satisfied when they are able to interact with each other*". Visibility itself subsists in the publication of Service and Goal Descriptions, but a prerequisite of Visibility is represented by Reachability, and when two entities are aware of each other and willing to interact in order to fulfill a need, heterogeneity can be a barrier that prevents this prerequisite to be fulfilled. Given two heterogeneous entities, mediation enables Reachability by resolving mismatches between them.

A mediator is described in terms of the entities it is able to connect and states how it will resolve mismatches. Ontology to Ontology mediators (OO-Mediators) connect ontologies and resolve terminological and representational mismatches, Service Description to Service Description mediators (SS-Mediators) connect service descriptions resolving mismatches between the representation of their functionality and/or in the means by which they are accessed (i.e., between their capabilities and/or interfaces), Goal Description to Goal Description mediators (GG-Mediators) connect Goal descriptions resolving mismatches in the requirements of the service requestor, again either in capability or interface terms, and Service Description to Goal Description (SG-Mediators) connect Service descriptions and goal descriptions, mediating between the consumer's and provider's viewpoint of the functionality and/or its access. By using a Mediation Service, a Mediator explicitly describes the link to a concrete solution to perform mediation. This mechanism allows Mediators to be used to describe pieces of functionality offered by complex services that are able to perform concrete mediation scenarios. A mediation service can either be a Goal or a Service Description. The former links to a Goal that is to be used in the discovery process to find a Service offering the functionality described by the Mediator, while the latter directly links to a Service that is able to offer the functionality described by the Mediator.

By publishing the description of the Mediator and all its needed Ontologies, Goal and Service Descriptions, the requirements for Visibility are met, thus allowing a Goal to interact with the Service.

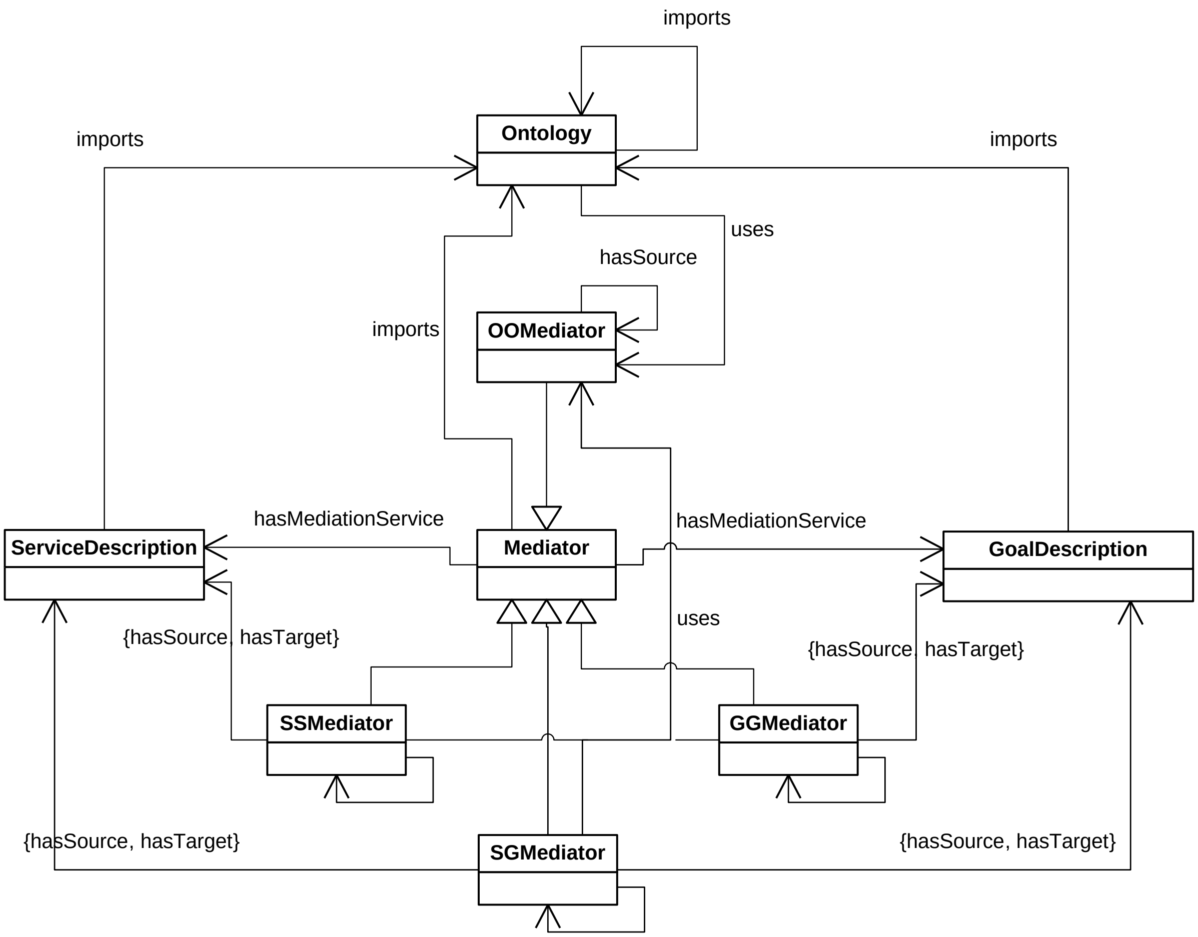
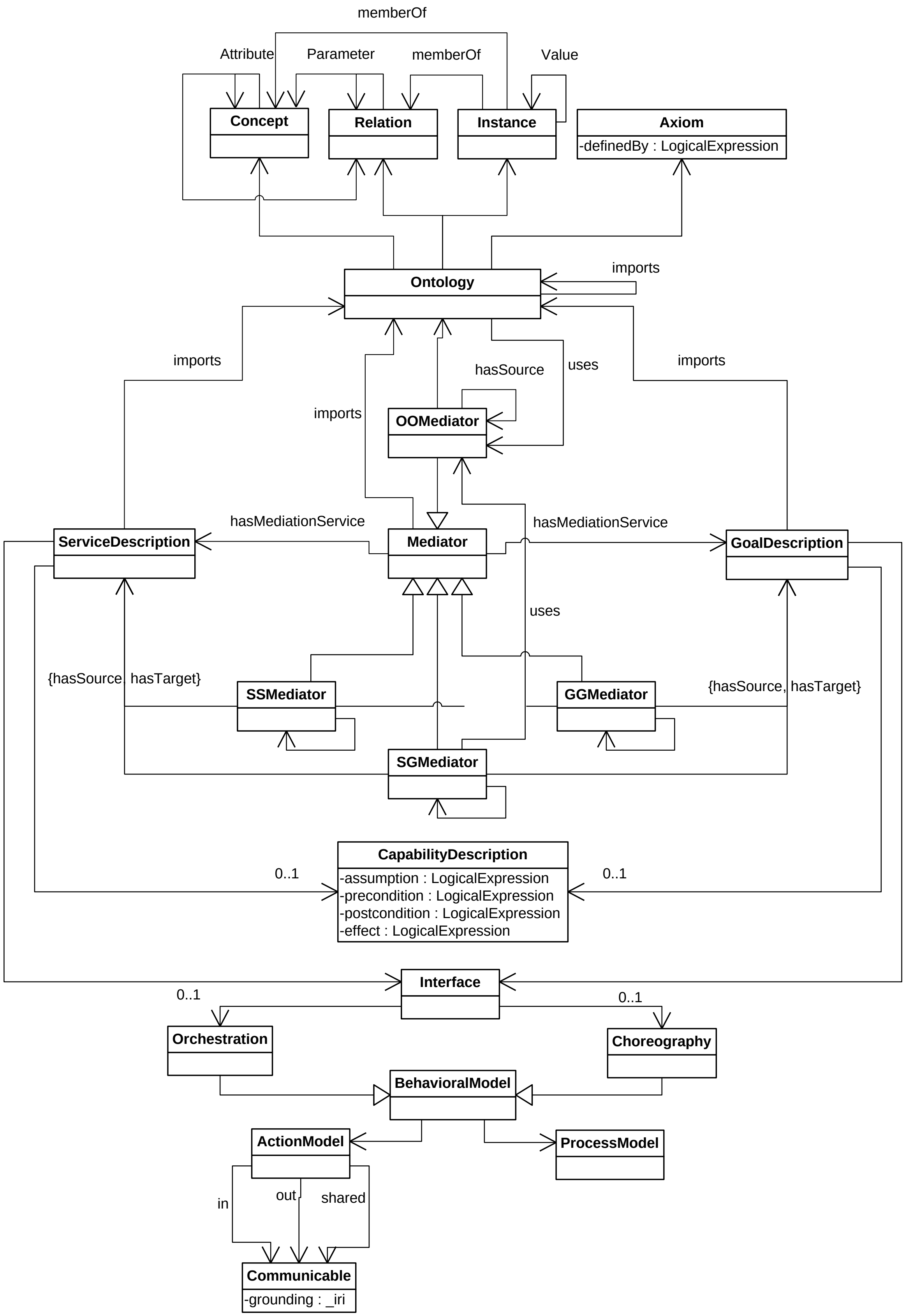


Figure 4-9 – Mediators and their Connection of other RO Concepts [UML]

4.7 Complete Reference Ontology

In Figure 4-10 shows complete UML diagram for the Reference Ontology, which combines all the information from Figure 4-3 to Figure 4-9. The formalization of this ontology in WSML is presented in Appendix B.



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704 *Figure 4-10 - The Complete Reference Ontology [UML]*

5 Conformance

This Reference Ontology for Semantic Service Oriented Architectures is an abstract framework for understanding significant entities and relationships between them within a Semantically-enabled Service-Oriented environment. It may be leveraged for the development of related standards or specifications supporting that environment, as well as guiding efforts to realize concrete solutions. As such, it has no explicit conformance statements.

A. Glossary

This section extends the terminology described in Glossary (Appendix A) of the “Reference Model for Service Oriented Architecture, Public Review Draft 1.0” and introduces any new terms needed by the Semantic SOA Reference. The two glossaries are intended to be used together, therefore terms from the other glossary will not be repeated here.

Goal Description-to-Goal Description Mediator (GG-Mediator)

Connects Goal descriptions resolving mismatches in the requirements of the service requestor in terms of the requested functionality and/or in the means by which they wish to access the service

Internet Reasoning Service 3 (IRS III)

A framework and infrastructure that supports the creation of Semantic Web Services according to the WSMO ontology.

Managing End-To-End OpeRations for Semantic Web Services and Processes (METEOR-S)

Project that aims to extend Web service –related standards with Semantic Web technologies to achieve greater dynamism and scalability for Service-oriented Architectures.

Object-oriented Design (OOD)

Object-oriented design is part of OO methodology and it forces programmers to think in terms of objects, rather than procedures, when they plan their code.

Ontology-to-Ontology Mediator (OO-Mediator)

Connects ontology and resolves terminology as well as representation or protocol mismatches.

Resource Description Framework (RDF)

Resource Description Framework (RDF) is a family of World Wide Web Consortium (W3C) specifications originally designed as a metadata model but which has come to be used as a general method of modeling information, through a variety of syntax formats.

Rule Interchange Format (RIF)

The Rule Interchange Format (RIF) is a W3C recommendation-track effort to develop a format for interchange of rules in rule-based systems on the semantic web. The goal is to create an interchange format for different rule languages and inference engines.

Semantic Annotations for WSDL (SAWSDL)

The Semantic Annotations for WSDL and XML Schema (SAWSDL) W3C Recommendation defines mechanisms using which semantic annotations can be added to WSDL components.

Semantic Execution Environment (SEE)

Execution environment capable to consume semantic messages, discover semantically described Web services, and invoke and compose them for the end-user benefit.

Semantic Web

The **Semantic Web** is an evolving extension of the World Wide Web in which the semantics of information and services on the web is defined, making it possible for the web to understand and satisfy the requests of people and machines to use the web content. [cite: Wikipedia]

Semantic Service Oriented Architecture (SSOA)

A **Semantic Service Oriented Architecture** (**SSOA**) is a computer architecture that allows for scalable and controlled Enterprise Application Integration solutions. SSOA describes a sophisticated approach to enterprise scale IT infrastructure. It leverages rich, machine-interpretable descriptions of data, services, and processes to enable software agents to autonomously interact to perform critical mission functions. [cite: Wikipedia]

Semantic Web Services (SWS)

Semantic Web Services are self-contained, self-describing, semantically marked-up software resources that can be published, discovered, composed and executed across the Web in a task driven semi-automatic way. Semantic Web Services can be defined as the dynamic part of the semantic web.

Semantic Web Service Ontology (SWSO)

An ontology for Semantic Web Services, which is expressed in two forms: FLOWS, the First-order Logic Ontology for Web services; and ROWS, the Rules Ontology for Web services, produced by a systematic translation of FLOWS axioms into the SWSL-Rules language.

Service-oriented Architecture (SOA)

Service Oriented Architecture (SOA) is a paradigm for organizing and utilizing distributed 128 capabilities that may be under the control of different ownership domains.

Unified Modeling Language (UML)

The Unified Modeling Language (UML) is a standardized visual specification language for object modeling. UML is a general-purpose modeling language that includes a graphical notation used to create an abstract model of a system, referred to as a UML model.

Web Ontology Language for Services (OWL-S)

OWL-S is an ontology built on top of Web Ontology Language (OWL) by the DARPA DAML program. It replaces the former DAML-S ontology.

Web Service Description Language (WSDL)

The Web Services Description Language is an XML-based language that provides a model for describing Web services.

Service Description-to-Goal Description Mediator (WG-Mediator)

Connects service descriptions and goal descriptions, mediating between the consumer’s and provider’s viewpoint of the functionality and/or its access

Service Description-to-Service Description Mediator (WW-Mediator)

Connects service descriptions resolving mismatches between the representation of their functionality and/or in the means by which they are accessed.

Web Service Modeling eXecution environment (WSMX)

An execution environment for business application integration where enhanced Web services are integrated for various business applications. It is the reference implementation of WSMO (Web Service Modeling Ontology).

Web Service Modeling Language (WSML)

A language that formalizes the Web Service Modeling Ontology (WSMO).

Web Service Modeling Ontology (WSMO)

WSMO or Web Service Modeling Ontology is an ontology currently developed to support the deployment and interoperability of Semantic Web Services.

B. WSML Formalization of Reference Ontology

```
wsmlVariant _"http://www.wsmo.org/wsml/wsml-syntax/wsml-flight"
namespace { _"http://docs.oasis-open.org/semanticsoa/referenceontology/v1.0#",
            dc _"http://purl.org/dc/elements/1.1/" }

ontology ReferenceOntology

concept Ontology
   imports ofType Ontology
   hasConcept ofType Concept
   hasRelation ofType Relation
   hasInstance ofType Instance
   hasAxiom ofType Axiom
   uses ofType OOMediator

concept Concept
   has Attribute ofType ConceptOrRelation

concept ConceptOrRelation
   nfp
     dc#relation hasValue { aConcept,
                            aRelation}
   endnfp

axiom aConcept definedBy
   ?x memberOf Concept
   implies
   ?x memberOf ConceptOrRelation.

axiom aRelation definedBy
   ?x memberOf Relation
   implies
   ?x memberOf ConceptOrRelation.

concept Instance
   memberOf hasValue ConceptOrRelation
   hasValue hasValue Instance

concept Axiom
   hasLogicalExpression ofType _"http://www.wsmo.org/wsml/wsml-
syntax#logicalExpression"

concept ServiceDescription
   imports ofType Ontology
   offersCapability ofType (0 1) Capability
   hasInterface ofType Interface

concept GoalDescription
   imports ofType Ontology
   requiresCapability ofType (0 1) Capability
   hasInterface ofType Interface

concept Capability
   hasPrecondition ofType _"http://www.wsmo.org/wsml/wsml-
syntax#logicalExpression"
   hasAssumption ofType _"http://www.wsmo.org/wsml/wsml-
syntax#logicalExpression"
   hasPostcondition ofType _"http://www.wsmo.org/wsml/wsml-
syntax#logicalExpression"
```

```
  hasEffect ofType _"http://www.wsmo.org/wsml/wsml-syntax#logicalExpression"

concept Interface
  hasChoreography ofType (0 1) Choreography
  hasOrchestration ofType (0 1) Orchestration

concept Choreography subConceptOf BehaviourModel

concept Orchestration subConceptOf BehaviourModel


concept BehaviourModel
  hasActionModel ofType (1) ActionModel
  hasProcessModel ofType (0 1) ProcessModel

concept ActionModel
  hasInAction ofType (1) Communicable
  hasOutAction ofType (1) Communicable
  hasSharedAction ofType (1) Communicable

concept Communicable
  grounding ofType (0 1) _iri

concept MediationService
  nfp
    dc#relation hasValue { aServiceIsAPotentialMediationService,
                           aGoalIsAPotentialMediationService}
  endnfp

axiom aServiceIsAPotentialMediationService definedBy
  ?m memberOf ServiceDescription implies
  ?m memberOf MediationService.

axiom aGoalIsAPotentialMediationService definedBy
  ?m memberOf GoalDescription implies
  ?m memberOf MediationService.

concept Mediator
  imports ofType Ontology
  hasMediationService ofType (0 1) MediationService


concept SGMediator subConceptOf Mediator
  hasSource ofType (1) SGMediatorSource
  hasTarget ofType (1) SGMediatorTarget
  RO#usesMediator ofType (1) OOMediator

concept SGMediatorSource
  nfp
    dc#relation hasValue { aServiceIsAPotentialSGMediatorSource,
                           aGoalIsAPotentialSGMediatorSource,
                           anSGMediatorIsAPotentialSGMediatorSource}
  endnfp

axiom aServiceIsAPotentialSGMediatorSource definedBy
  ?x memberOf ServiceDescription
  implies
  ?x memberOf SGMediatorSource.

axiom aGoalIsAPotentialSGMediatorSource definedBy
  ?x memberOf GoalDescription
  implies
  ?x memberOf SGMediatorSource.
```

```
axiom anSGMediatorIsAPotentialSGMediatorSource definedBy
   ?x memberOf SGMediator
   implies
   ?x memberOf SGMediatorSource.

concept SGMediatorTarget
   nfp
     dc#relation hasValue { aServiceIsAPotentialSGMediatorTarget,
                            aGoalIsAPotentialSGMediatorTarget,
                            anSGMediatorIsAPotentialSGMediatorTarget}
   endnfp

axiom aServiceIsAPotentialSGMediatorTarget definedBy
   ?x memberOf ServiceDescription
   implies
   ?x memberOf SGMediatorTarget.

axiom aGoalIsAPotentialSGMediatorTarget definedBy
   ?x memberOf GoalDescription
   implies
   ?x memberOf SGMediatorTarget.

axiom anSGMediatorIsAPotentialSGMediatorTarget definedBy
   ?x memberOf SGMediator
   implies
   ?x memberOf SGMediatorTarget.

concept OOMediator subConceptOf Mediator
   hasSource ofType OOMediatorSource

concept OOMediatorSource
   nfp
     dc#relation hasValue { anOntologyIsAPotentialOOMediatorSource,
                            anOOMediatorIsAPotentialOOMediatorSource}
   endnfp

axiom anOntologyIsAPotentialOOMediatorSource definedBy
   ?x memberOf Ontology
   implies
   ?x memberOf OOMediatorSource.

axiom anOOMediatorIsAPotentialOOMediatorSource definedBy
   ?x memberOf OOMediator
   implies
   ?x memberOf OOMediatorSource.
```

Listing 4: Semantic SOA Reference Ontology Expressed in WSML

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