



D2v1.1. Web Service Modeling Ontology (WSMO)

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Abstract

This document presents an ontology called Web Service Modeling Ontology (WSMO) for describing various aspects related to Semantic Web Services. Having the Web Service Modeling Framework (WSMF) as a starting point, we refine and extend this framework, and develop an ontology and a description language.

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1. Introduction

This document presents an ontology called Web Service Modeling Ontology (WSMO) for describing various aspects related to Semantic Web Services. Having the Web Service Modeling Framework (WSMF) [[Fensel & Bussler, 2002](#)] as a starting point, we refine and extend this framework, and develop a formal ontology and language. WSMF [[Fensel & Bussler, 2002](#)] consists of four different main elements for describing semantic web services: ontologies that provide the terminology used by other elements, goals that define the problems that should be solved by web services, web services descriptions that define various aspects of a web service, and mediators which bypass interpretability problems.

This document is organized as follows: [Section 2](#) describes the language used for defining WSMO, then we define in the next Section the top level element of WSMO ([Section 3](#)), Ontologies in [Section 4](#), service descriptions in [Section 5](#), and mediators in [Section 6](#). In [Section 7](#) we define the syntax of the logical language that is used in WSMO. The semantics and computationally tractable subsets of this logical language are defined and discussed by the [WSML working group](#). [Section 8](#) describes the non functional properties used in the definition of different WSMO elements and [Section 9](#) presents our conclusions and further directions.

For a brief tutorial on WSMO we refer to the [WSMO Primer](#) [[Arroyo & Stollberg, 2004](#)], for a non-trivial use case demonstrating how to use WSMO in a real-world setting we refer to the [WSMO Use Case Modeling and Testing](#) [[Stollberg et al., 2004](#)] and for the formal representation languages we refer to [The WSML Family of Representation Languages](#) [[De Bruijn, 2004](#)].

Besides the [WSMO working group](#) there are two more working groups related to the WSMO initiative: The [WSML working group](#) focusing on language issues and developing a adequate Web Service Modeling Language with various sublanguages as well the [WSMX working group](#) that is concerned with designing and building a reference implementation of an execution environment for WSMO.

Note: The Vocabulary defined by WSMO is fully extensible. It is based on URIs with optional fragment identifiers (URI references, or URIs) [[Berners-Lee et al, 1998](#)]. URI references are used for naming all kinds of things in WSMO. The target namespace of this document is `wsmo: http://www.wsmo.org/2004/d2/`. Furthermore this document uses the following namespace abbreviations:

`dc: http://purl.org/dc/elements/1.1#`, `xsd: http://www.w3.org/2001/XMLSchema#` and `foaf: http://xmlns.com/foaf/0.1/`.

2. Language for defining WSMO

In order to define WSMO, which is meant to be a meta-model for semantic web services, we make use of [Meta Object Facility \(MOF\)](#) [[OMG, 2004](#)], a specification that defines an abstract language and a framework for specifying, constructing, and managing technology neutral metamodels. The meaning of the metamodeling constructs, marked as bold in the listings throughout this document, is given by the MOF specification ([\[OMG, 2004\]](#)). We make the following assumptions:

- every Attribute has its "multiplicity" set to multi-valued by default; when an Attribute requires its "multiplicity" to be set to "single-valued", this will be explicitly stated in the listings.
- for some WSMO elements there is the need to define attributes taking values from the union of several types, a feature that is not directly supported by MOF metamodeling constructs; this can be simulated in MOF by defining a new Class as super-Class of all the types required in the definition of the attribute (that represents the union of the single types), with the Constraint that each instance of this new Class is an instance of at least one of the types which are used in the union; to define this new Class in WSMO, we use curly parenthesis, enumerating the Classes representing the required types of the definition of the attribute in between.

3. WSMO top level elements

WSMO defines three top level elements:

Listing 1. WSMO definition

```
Class WSMO
  hasOntologies type ontology
  hasServices type service
  hasMediators type mediator
```

Ontologies

Provide the terminology used by other WSMO elements. They are described in [Section 4](#).

Services

Description of services that are requested, provided, and agreed by service

requesters and service providers. They are described in [Section 5](#).

Mediators

Deal with interoperability problems between different WSMO elements. They are described in [Section 6](#).

4. Ontologies

In WSMO Ontologies are the key to link conceptual real world semantics defined and agreed upon by communities of users. *An ontology is a formal explicit specification of a shared conceptualization* [Gruber, 1993]. From this rather conceptual definition we want to extract the essential components which define an ontology. Ontologies define a common agreed upon terminology by providing concepts and relationships among the set of concepts. In order to capture semantic properties of relations and concepts, an ontology generally also provides a set of axioms, which means expressions in some logical framework. An ontology is defined as follows:

Listing 2. Ontology definition

```
Class ontology
  hasNonFunctionalProperty type nonFunctionalProperty
  hasImportedOntology type ontology
  hasUsedMediator type ooMediator
  hasConcept type concept
  hasRelation type relation
  hasFunction type function
  hasInstance type instance
  hasAxiom type axiom
```

4.1 Non functional properties

The following non functional properties are available for characterizing ontologies: [Contributor](#), [Coverage](#), [Creator](#), [Date](#), [Description](#), [Format](#), [Identifier](#), [Language](#), [Owner](#), [Publisher](#), [Relation](#), [Rights](#), [Source](#), [Subject](#), [Title](#), [Type](#), [Version](#).

4.2 Imported Ontologies

Building an ontology for some particular problem domain can be a rather cumbersome and complex task. One standard way to deal with the complexity is modularization. `importedOntologies` allow a modular approach for ontology design; this simplified statement can be used as long as no conflicts need to be resolved, otherwise an `ooMediator` needs to be used.

4.3 Used mediators

When importing ontologies, most likely some steps for aligning, merging and transforming imported ontologies have to be performed. For this reason and in line with the basic design principles underlying the WSMF, ontology mediators (`ooMediator`) are used when an alignment of the imported ontology is necessary. Mediators are described in [Section 5](#) in more detail.

4.4 Concepts

Concepts constitute the basic elements of the agreed terminology for some problem domain. From a high level perspective, a concept – described by a concept definition – provides attributes with names and types. Furthermore, a concept can be a subconcept of several (possibly none) direct superconcepts as specified by the "isA"-relation.

Listing 3. Concept definition

```
Class concept
  hasNonFunctionalProperty type nonFunctionalProperty
  hasSuperConcept type concept
  hasAttribute type attribute
  hasDefinition type logicalExpression multiplicity = single-valued
```

Non functional properties

The non functional properties recommended are: [Contributor](#), [Coverage](#), [Creator](#), [Date](#), [Description](#), [Identifier](#), [Relation](#), [Source](#), [Subject](#), [Title](#), [Type](#), [Version](#).

Super-concepts

There can be a finite number of concepts that serve as a superConcepts for some concept. Being a sub-concept of some other concept in particular means that a concept inherits the signature of this superconcept and the corresponding constraints. Furthermore, all instances of a concept are also instances of each of its superconcepts.

Attributes

Each concept provides a (possibly empty) set of `attributes` that represent named slots for data values for instances that have to be filled at the instance level. An attribute specifies a slot of a concept by fixing the name of the slot as well as a logical constraint on the possible values filling that slot. Hence, this logical expression can be interpreted as a typing constraint.

Listing 4. Attribute definition

```
Class attribute
  hasNonFunctionalProperty type nonFunctionalProperty
  hasRange type concept multiplicity = single-valued
```

Non functional properties

The non functional properties recommended are: [Contributor](#), [Coverage](#), [Creator](#), [Date](#), [Description](#), [Identifier](#), [Relation](#), [Source](#), [Subject](#), [Title](#), [Type](#), [Version](#).

Range

A `concept` that serves as an integrity constraint on the values of the attribute.

Defined by

A logical expression (see [Section 7](#)) which can be used to define the semantics of the concept formally. More precisely, the logical expression defines (or restricts, resp.) the extension (i.e. the set of instances) of the concept. If C is the identifier denoting the concept then the logical expression takes one of the following forms

- `forall ?x (?x memberOf C implies l-expr(?x))`
- `forall ?x (?x memberOf C impliedBy l-expr(?x))`
- `forall ?x (?x memberOf C equivalent l-expr(?x))`

where `l-expr(?x)` is a logical expression with precisely one free variable `?x`.

In the first case, one gives a necessary condition for membership in the extension of the concept; in the second case, one gives a sufficient condition and in the third case, we have a sufficient and necessary condition for an object being an element of the extension of the concept.

4.5 Relations

Relations are used in order to model interdependencies between several concepts (respectively instances of these concepts).

Listing 5. Relation definition

```

Class relation
  hasNonFunctionalProperty type nonFunctionalProperty
  hasSuperRelations type relation
  hasParameters type parameter
  hasDefinition type logicalExpression multiplicity = single-valued

```

Non functional properties

The non functional properties recommended are: [Contributor](#), [Coverage](#), [Creator](#), [Date](#), [Description](#), [Identifier](#), [Relation](#), [Source](#), [Subject](#), [Title](#), [Type](#), [Version](#).

Superrelations

A finite set of relations of which the defined relation is declared as being a subrelation. Being a subrelation of some other relation in particular means that the relation inherits the signature of this superrelation and the corresponding constraints. Furthermore, the set of tuples belonging to the relation (the extension of the relation, resp.) is a subset of each of the extensions of the superrelations.

Parameters

The list of parameters.

Listing 6. Parameter definition

```

Class parameter
  hasNonFunctionalProperty type nonFunctionalProperty
  hasDomain type concept multiplicity = single-valued

```

Non functional properties

The non functional properties recommended are: [Contributor](#), [Coverage](#), [Creator](#), [Date](#), [Description](#), [Identifier](#), [Relation](#), [Source](#), [Subject](#), [Title](#), [Type](#), [Version](#).

Domain

A concept constraining the possible values that the parameter can take.

Defined by

A logicalExpression (see [Section 7](#)) defining the set of instances (n-ary tuples, if n is the arity of the relation) of the relation. If the parameters are

specified the relation is represented by a n-ary predicate symbol with named arguments (see [Section 7](#)) (where n is the number of parameters of the relation) where the identifier of the relation is used as the name of the predicate symbol. If R is the identifier denoting the relation and the parameters are specified then the logical expression takes one of the following forms:

- `forall ?v1,...,?vn (R[p1 hasValue ?v1,...,pn hasValue ?vn] implies l-expr(?v1,...,?vn))`
- `forall ?v1,...,?vn (R[p1 hasValue ?v1,...,pn hasValue ?vn] impliedBy l-expr(?v1,...,?vn))`
- `forall ?v1,...,?vn (R[p1 hasValue ?v1,...,pn hasValue ?vn] equivalent l-expr(?v1,...,?vn))`

If the parameters are not specified the relation is represented by a predicate symbol (see [Section 7](#)) where the identifier of the relation is used as the name of the predicate symbol. If R is the identifier denoting the relation and the parameters are not specified then the logical expression takes one of the following forms:

- `forall ?v1,...,?vn (R(?v1,...,?vn) implies l-expr(?v1,...,?vn))`
- `forall ?v1,...,?vn (R(?v1,...,?vn) impliedBy l-expr(?v1,...,?vn))`
- `forall ?v1,...,?vn (R(?v1,...,?vn) equivalent l-expr(?v1,...,?vn))`

`l-expr(?v1,...,?vn)` is a logical expression with precisely `?v1,...,?vn` as its free variables and `p1,...,pn` are the names of the parameters of the relation.

Using `implies`, one gives a necessary condition for instances `?v1,...,?vn` to be related; using `impliedBy`, one gives a sufficient condition and using `equivalent`, we have a sufficient and necessary condition for instances `?v1,...,?vn` being related.

4.6 Functions

A `function` is a special relation, with a unary range and a n-ary domain (`parameters` inherited from `relation`), where the range specifies the return value. In contrast to a function symbol, a function is not only a syntactical entity but has some semantics that allows to actually evaluate the function if one considers concrete input values for the parameters of the function. That means, that we actually can replace the (ground) function term in some expression by its concrete value. Function can be used for instance to represent and exploit built-in predicates of common datatypes. Their semantics can be captured externally by means of an oracle or it can be formalized by assigning a logical expression to the `definedBy` property inherited from `relation`.

Listing 7. Function definition

```
Class function sub-Class relation
  hasRange type concept multiplicity = single-valued
```

Range

A `concept` constraining the possible return values of the function.

The logical representation of a function is almost the same as for relations, whereby the result value of a function (resp. the value of a function term) has to be represented explicitly: the function is represented by an (n+1)-ary predicate symbol with named arguments (see Section 7) (where n is the number of arguments of the function) where the identifier of the function is used as the name of the predicate. In particular, the names of the parameters of the corresponding relation symbol are the names of the parameters of the function as well as one additional parameter `range` for denoting the value of the function term with the given parameter values. In Case the `parameters` are not specified the function is represented by an predicate symbol with ordered arguments and by convention the first argument specifies the value of the function term with given argument values.

If `F` is the identifier denoting the function and `p1,...,pn` is the set of parameters of the function then the logical expression for defining the semantics of the function (inherited from `relation`) can for example take the form

```
forall ?v1,...,?vn,?res ( F[p1 hasValue ?v1,...,pn hasValue ?vn, result
    hasValue ?res] equivalent l-expr(?v1,...,?vn,?res) )
```

where `l-expr(?v1,...,?vn,?res)` is a logical expression with precisely `?v1,...,?vn,?res` as its free variables and `p1,...,pn` are the names of the parameters of the function. Clearly, `result` may not be used as the name for a parameter of a function in order to prevent ambiguities.

4.7 Instances

`Instances` are either defined explicitly or by a link to an instance store, i.e., an external storage of instances and their values.

An explicit definition of instances of concepts is as follows:

Listing 8. Instance definition

```
Class instance
  hasNonFunctionalProperty type nonFunctionalProperty
  hasType type concept
  hasAttributeValues type attributeValue
```

Non functional properties

The `non functional properties` recommended are: [Contributor](#), [Coverage](#), [Creator](#), [Date](#), [Description](#), [Identifier](#), [Relation](#), [Source](#), [Subject](#), [Title](#), [Type](#), [Version](#).

Type

The `concept` to which the instance belongs to ([\[1\]](#)).

Attribute values

The `attributeValues` for the single attributes defined in the concept. For each attribute defined for the `concept` this instance is assigned to there can be a corresponding attribute value. These value have to be compatible with the corresponding type declaration in the concept definition.

Listing 9. Attribute value definition

```
Class attributeValue
  hasAttribute type attribute multiplicity = single-valued
  hasValue type {URIReference, Literal, AnonymousId}
```

Attribute

The `attribute` this value refers to.

Value

An URI reference, literal or anonymous id representing the actual value of an instance for a specific attribute.

Instances of relations (with arity n) can be seen as n-tuples of instances of the concepts which are specified as the parameters of the relation. Thus we use the following definition for instances of relations:

Listing 10. Relation instance definition

```
Class relationInstance
  hasNonFunctionalProperty type nonFunctionalProperty
  hasType type relation
  hasParameterValues type parameterValue
```

Non functional properties

The `non functional properties` recommended are: [Contributor](#), [Coverage](#), [Creator](#), [Date](#), [Description](#), [Identifier](#), [Relation](#), [Source](#), [Subject](#), [Title](#), [Type](#), [Version](#).

Type

The `relation` this instance belongs to ([\[2\]](#)).

Parameter values

A set of `parameterValues` specifying the single instances that are related according to this relation instance. The list of parameter values of the instance has to be compatible wrt. names and range constraints of that are specified in the corresponding relation.

Listing 11. Parameter value definition

```
Class parameterValue
  hasParameter type parameter multiplicity = single-valued
  hasValue type {URIReference, Literal, AnonymousId}
```

Parameter

The `parameter` this value refers to.

Value

An URI reference, literal or anonymous id representing the actual value of an instance for a specific attribute.

A detailed discussion and a concrete proposal on how to integrate large sets of instance data in an ontology model can be found in [DIP Deliverable D2.2 \[Kiryakov et. al., 2004\]](#). Basically, the approach there is to integrate large sets of instances which are already existing on some storage devices by means of sending queries to external storage devices or oracles.

4.8 Axioms

An `axiom` is considered to be a logical expression together with its non functional properties.

Listing 12. Axiom definition

```
Class axiom
  hasNonFunctionalProperty type nonFunctionalProperty
  hasDefinition type logicalExpression
```

Non functional properties

The non functional properties recommended are: [Contributor](#), [Coverage](#), [Creator](#), [Date](#), [Description](#), [Identifier](#), [Relation](#), [Source](#), [Subject](#), [Title](#), [Type](#), [Version](#).

Defined by

The actual statement captured by the axiom is defined by an formula in a logical language as described in [Section 7](#).

5. Service Descriptions

WSMO provides service descriptions for describing requested, provided, and agreed services. In the following, we will describe the common elements of these descriptions as a general `service description` definition. Then, in Sections 5.1 to 5.3 the differences compared to the general service definition are highlighted.

A service description is defined as follows:

Listing 13. Service description definition

```
Class service
  hasNonFunctionalProperty type nonFunctionalProperty
  hasImportedOntology type ontology
  hasUsedMediator type {ooMediator, sdMediator}
  hasCapability type capability multiplicity = single-valued
  hasInterface type interface
```

Non functional properties

The non functional properties recommended are: [Accuracy](#), [Contributor](#), [Coverage](#), [Creator](#), [Date](#), [Description](#), [Financial](#), [Format](#), [Identifier](#), [Language](#), [Network-related QoS](#), [Owner](#), [Performance](#), [Publisher](#), [Relation](#), [Reliability](#), [Rights](#), [Robustness](#), [Scalability](#), [Security](#), [Source](#), [Subject](#), [Title](#), [Transactional](#), [Trust](#), [Type](#), [Version](#).

Imported Ontologies

It is used to import ontologies as long as no conflicts are needed to be resolved.

Used mediators

A service can import ontologies using ontology mediators (`ooMediators`) when steps for aligning, merging and transforming imported ontologies are needed. A service can use `sdMediator` to deal with process and protocol mediation.

Capability

A `capability` defines the service by means of its functionality.

```

Class capability
  hasNonFunctionalProperty type nonFunctionalProperty
  hasImportedOntology type ontology
  hasUsedMediator type ooMediator
  hasPrecondition type axiom
  hasAssumption type axiom
  hasPostcondition type axiom
  hasEffect type axiom

```

Non functional properties

The non functional properties recommended are: [Accuracy](#), [Contributor](#), [Coverage](#), [Creator](#), [Date](#), [Description](#), [Financial](#), [Format](#), [Identifier](#), [Language](#), [Network-related QoS](#), [Owner](#), [Performance](#), [Publisher](#), [Relation](#), [Reliability](#), [Rights](#), [Robustness](#), [Scalability](#), [Security](#), [Source](#), [Subject](#), [Title](#), [Transactional](#), [Trust](#), [Type](#), [Version](#).

Imported Ontologies

It is used to import ontologies as long as no conflicts are needed to be resolved.

Used mediators

A capability can import ontologies using ontology mediators (`ooMediators`) when steps for aligning, merging and transforming imported ontologies are needed.

PreConditions

`PreConditions` specify the information space of the service before its execution.

Assumptions

`Assumptions` describe the state of the world before the execution of the service.

PostConditions

`PostConditions` describe the information space of the service after the execution of the service.

Effects

`Effects` describe the state of the world after the execution of the service.

Interfaces

An `interface` describes how the functionality of the service can be achieved (i.e. how the `capability` of a service can be fulfilled) by providing a twofold view on the operational competence of the service:

- `choreography` decomposes a capability in terms of interaction with the service (service user's view)
- `orchestration` decomposes a capability in terms of functionality required from other services (other service providers' view)

This distinction reflects the difference between communication and cooperation. The `choreography` defines how to communicate with the service in order to consume its functionality. The `orchestration` defines how the overall functionality is achieved by the cooperation of more elementary service providers [3].

An `interface` is defined by the following properties:

```

Class interface
  hasNonFunctionalProperty type nonFunctionalProperty
  hasImportedOntology type ontology
  hasUsedMediator type ooMediator
  hasChoreography type choreography
  hasOrchestration type orchestration

```

Non functional parameters

The non functional properties recommended are: [Accuracy](#), [Contributor](#), [Coverage](#), [Creator](#), [Date](#), [Description](#), [Financial](#), [Format](#), [Identifier](#), [Language](#), [Network-related QoS](#), [Owner](#), [Performance](#), [Publisher](#), [Relation](#), [Reliability](#), [Rights](#), [Robustness](#), [Scalability](#), [Security](#), [Source](#), [Subject](#), [Title](#), [Transactional](#), [Trust](#), [Type](#), [Version](#).

Imported Ontologies

It is used to import ontologies as long as no conflicts are needed to be resolved.

Used mediators

An interface can import ontologies using ontology mediators (`ooMediators`) when steps for aligning, merging and transforming imported ontologies are needed.

Choreography

`Choreography` provides the necessary information to communicate with the service. From a business-to-business perspective, the choreography can be split in two distinct choreographies:

- **meta-choreography** - consists of different types of choreographies, which are related to, and can influence the execution of a service. Negotiation, re-negotiation choreographies (protocols for message interactions which, on successful termination, will result in the agreement of a service between two parties, i.e. an agreed service) and monitoring choreographies (protocols for message interactions which monitors the execution of an agreed service; depending on the execution of the agreed service, the monitoring choreography may generate new re-negotiation choreographies, which in turn may generate new executions) are examples of such meta-choreographies.
- **execution choreography** - consists of a protocol for message interactions about an agreement, which has been agreed using (re-)negotiation choreographies. Web Services technologies can be used as grounding technologies for execution choreographies.

Orchestration

`Orchestration` describes how the service makes use of other services in order to achieve its capability.

5.1 Requested Services

A `requested service` is a partial or total service description, representing the functionality and/or the behavior of a service that is required by its owner - the service requester

Requested service descriptions replace the `goal descriptions` of [WSMO 1.0](#).

5.2 Provided Services

A `provided service` is a partial or total service description, representing the functionality and/or the behavior of a service that is provided by its owner - the service provider.

Provided service descriptions replace the `web service descriptions` of [WSMO 1.0](#).

5.3 Agreed Services

An `agreed service` is defined as an agreement between a service provider and a service requester on the service that is going to be provided. An `agreed service` is a service description, having totally defined its capability and interface and explicitly defined the owner of the provided service and the owner of the requested service.

Agreed services are a new element in WSMO 1.1 as compared to [WSMO 1.0](#).

6. Mediators

In this section, we introduce the notion of `mediators` and define the elements that are used in the description of a mediator.

We distinguish two different types of mediators:

- `ooMediators` - mediators that import ontologies and resolve possible representation mismatches between ontologies.
- `sdMediators` - mediators that link two services.

The `mediator` is defined as follows:

Listing 16. Mediators definition

```
Class mediator
  hasNonFunctionalProperty type nonFunctionalProperty
  hasImportedOntology type ontology
  hasSource type {ontology, service, mediator}
  hasTarget type {ontology, service, mediator}
  hasMediationService type service

Class ooMediator sub-Class mediator
  hasSource type {ontology, ooMediator}

Class sdMediator sub-Class mediator
  hasUsedMediator type ooMediator
  hasSource type {service, sdMediator}
  hasTarget type {service, sdMediator}
```

Non functional properties

The `non functional properties` recommended are: [Accuracy](#), [Contributor](#), [Coverage](#), [Creator](#), [Date](#), [Description](#), [Financial](#), [Format](#), [Identifier](#), [Language](#), [Network-related QoS](#), [Owner](#), [Performance](#), [Publisher](#), [Relation](#), [Reliability](#), [Rights](#), [Robustness](#), [Scalability](#), [Security](#), [Source](#), [Subject](#), [Title](#), [Transactional](#), [Trust](#), [Type](#), [Version](#).

Imported Ontologies

It is used to import ontologies as long as no conflicts are needed to be resolved.

Source

The source components define entities that are the sources of the mediator.

Target

The target component defines the entity that is the targets of the mediator.

Mediation Service

The `mediationService` points to a service that actually implements the mediation.

Used Mediators

`sdMediators` use a set of `ooMediators` in order to map between different vocabularies used in the description of service capabilities and align different heterogeneous ontologies.

7. Logical language for defining formal statements in WSMO

As the major component of `axiom`, logical expressions are used almost everywhere in the WSMO model to capture specific nuances of meaning of modeling elements or their constituent parts in a formal and unambiguous way. In the following, we give a definition of the syntax of the formal language that is used for specifying `logicalExpressions`. The semantics of this language will be defined formally by the [WSML working group](#) in a separate document.

[Section 7.1](#) introduces the identifiers recommended for the basic vocabulary of WSMO. [Sections 7.2](#) gives the definition of the basic vocabulary and the set of terms for building logical expression. Then we define in [Section 7.3](#) the most basic formulas (atomic formulae, resp.) which allows us to eventually define the set of logical expressions.

7.1 Identifiers

There are for different identifier within WSMO:

- **URI references**

WSMO is based on the idea of identifying things using web identifiers (called Uniform Resource Identifiers). Everything in WSMO is by default denoted by a URI, except when itself classifies it as Literal, Variable or Anonymous Id. Using URIs does not limit WSMO to make statements about things that are not accessible on the web, like with the uri: "urn:isbn:0-520-02356-0" that identifies a certain book. URIs can be expressed as follows: full URIs: e.g. <http://www.wsmo.org/2004/d2/> or qualified Names (QNames) that are resolved using namespace declarations. For more details on QNames, we refer to [\[Bray et al., 1999\]](#).

- **Literals**

Literals are used to identify values such as numbers by means of a lexical representation. Anything represented by a literal could also be represented by a URI, but it is often more convenient or intuitive to use literals. Literals are

either plain literals or typed literals. A Literal can be typed to a data type (e.g. to `xsd:integer`). Formally, such a data type is defined by [Hayes, 2004]:

- a non-empty set of character strings called the lexical space of `d`; e.g. `{"true", "1", "false", "0"}`
- a non-empty set called the value space of `d`; e.g. `{true, false}`;
- a mapping from the lexical space of `d` to the value space of `d`, called the lexical-to-value mapping of `d`; e.g. `{"true", "1"}->{true}`; `{"false", "0"}->{false}`.

Furthermore the data type may introduce facets on its value space, such as ordering and therefore define the axiomatization for the relations `<`, `>` and function symbols like `+` or `-`. These special relations and functions are called data type predicates and are defined more in detail in the WSML Family of Representation Languages [De Bruijn, 2004].

• Anonymous Ids

Anonymous Ids can be numbered (`_#1`, `_#2`, ...) or unnumbered (`_#`). They represent Identifier. The same numbered Anonymous Id represents the same Identifier within the same scope (`logicalExpression`), otherwise Anonymous Ids represent different Identifiers [Yang & Kifer, 2003]. Anonymous Ids can be used to denote objects that exists, but don't need a specific identifier (e.g. if someone wants to say that a Person John has an address `_#` which itself has a street name "hitchhikerstreet" and a street number "42", then the object of the address itself does not need a particular URI, but since it must exist as connecting object between John and "hitchhikersstreet", "42" we can denote it with an Anonymous Id). The concept of anonymous IDs is similar to blank nodes in RDF [Hayes, 2004], however there are some differences. Blank Nodes are essentially existential quantified variables, where the quantifier has the scope of one document. RDF defines different strategies for the union of two documents (merge and union), whereas the scope of one anonymous ID is a logical expression and the semantics of anonymous ids do not require different strategies for a union of two documents respectively two logical expressions. Furthermore Anonymous IDs are not existentially quantified variables, but constants. This allows two flavors of entailment: Strict and Relaxed, where the relaxed entailment is equivalent to the behavior of blank nodes and the strict entailment allows an easier treatment wrt. implementation.

• Variable names

Variable names are strings that start with a question mark '?', followed by any positive number of symbols in `{a-z, A-Z, 0-9, _, -}`, i.e. `?var` or `?lastValue_Of`.

7.2 Basic vocabulary and terms

Let *URI* be the set of all valid uniform resource identifiers. This set will be used for the naming (or identifying, resp.) various entities in a WSMO description.

Definition 1. The **vocabulary V** of our language **L(V)** consists of the following symbols:

- A (possibly infinite) set of **Uniform Resource Identifiers** URI .
- A (possibly infinite) set of **QNames** QN .
- A (possibly infinite) set of **anonymous Ids** $AnID$.
- A (possibly infinite) set of **literals** Lit .
- A (possibly infinite) set of **variables** Var .
- A (possibly infinite) set of **function symbols** (object constructors, resp.) $FSym$ which is a subset of URI .
- A (possibly infinite) set of **predicate symbols** $PSym$ which is a subset of URI .
- A (possibly infinite) set of **predicate symbols with named arguments** $PSymNamed$ which is a subset of URI .
- A finite set of **auxiliary symbols** $AuxSym$ including $(,)$, $ofType$, $ofTypeSet$, $memberOf$, $subConceptOf$, $hasValue$, $hasValues$, $false$, $true$.
- A finite set of **logical connectives and quantifiers** including the usual ones from First-Order Logics: or , and , not , $implies$, $impliedBy$, $equivalent$, $forall$, $exists$.
- All these sets are assumed to be *mutually distinct* (as long as no subset relationship has been explicitly stated).
- For each symbol S in $FSym$, $PSym$ or $PSymNamed$, we assume that there is a corresponding **arity** $arity(S)$ defined, which is a non-negative integer specifying the number of arguments that are expected by the corresponding symbol when building expressions in our language.
- For each symbol S in $PSymNamed$, we assume that there is a corresponding **set of parameter names** $parNames(S)$ defined, which gives the names of the single parameters of the symbol that have to be used when building expressions in our language using these symbols.

As usual, 0-ary function symbols are called *constants*. 0-ary predicate symbols correspond to propositional variables in classical propositional logic.

Definition 2. Given a vocabulary V , we can define the **set of terms** $Term(V)$ (over vocabulary V) as follows:

- Any identifier u in URI is a term in $Term(V)$.
- Any QName q in QN is a term in $Term(V)$.
- Any anonymous Id i in $AnID$ is a term in $Term(V)$.
- Any literal l in Lit is a term in $Term(V)$.
- Any variable v in Var is a term in $Term(V)$.
- If f is a function symbol from $FSym$ with $arity(f) = n$ and t_1, \dots, t_n are terms, then $f(t_1, \dots, t_n)$ is a term in $Term(V)$.
- Nothing else is a term.

As usual, the set of ground terms $GroundTerm(V)$ is the subset of terms in $Term(V)$ which do not contain any variables.

Terms can be used in general to describe computations (in some domain). One important additional interpretation of terms is that they denote objects in some universe and thus provide names for entities in some domain of discourse.

7.3 Logical expressions

We extend the previous definition (Definition 2) to the **set of (complex) logical expressions** (or formulae, resp.) $L(V)$ (over vocabulary V) as follows:

Definition 3. A **simple logical expression** in $L(V)$ (or atomic formula) is inductively defined by

- If p is a predicate symbol in $PSym$ with $arity(p) = n$ and t_1, \dots, t_n are terms, then $p(t_1, \dots, t_n)$ is a simple logical expression in $L(V)$.
- If r is a predicate symbol with named arguments in $PSymNamed$ with $arity(p) = n$, $parNames(r) = \{p_1, \dots, p_n\}$ and t_1, \dots, t_n are terms, then $R[p_1 \text{ hasValue } t_1, \dots, p_n \text{ hasValue } t_n]$ is a simple logical expression in $L(V)$.
- `true` and `false` are simple logical expression in $L(V)$.
- If P, ATT, T are terms in $Term(V)$, then $P[ATT \text{ ofType } T]$ is a simple logical expression in $L(V)$.
- If P, ATT, T_1, \dots, T_n (where $n \geq 1$) are terms in $Term(V)$, then $P[ATT \text{ ofTypeSet } (T_1, \dots, T_n)]$ is a simple logical expression in $L(V)$.
- If O, T are terms in $Term(V)$, then $O \text{ memberOf } T$ is a simple logical expression in $L(V)$.
- If C_1, C_2 are terms in $Term(V)$, then $C_1 \text{ subConceptOf } C_2$ is a simple logical expression in $L(V)$.
- If R_1, R_2 are predicate symbols in $PSym$ or $PSymNamed$ with the same signature, then $R_1 \text{ subRelationOf } R_2$ is a simple logical expression on $L(V)$.
- If O, V, ATT are terms in $Term(V)$, then $O[ATT \text{ hasValue } V]$ is a simple logical expression in $L(V)$.
- If O, V_1, \dots, V_n, ATT (where $n \geq 1$) are terms in $Term(V)$, then $O[ATT \text{ hasValues } \{V_1, \dots, V_n\}]$ is a simple logical expression in $L(V)$.
- If T_1 and T_2 are terms in $Term(V)$, then $T_1 = T_2$ is a simple logical expression in $L(V)$.
- Nothing else is a simple logical expression.

The intuitive semantics for simple logical expressions (wrt. an interpretation) is as follows:

- The semantics of predicates in $PSym$ is the common one for predicates in First-Order Logics, i.e. they denote basic statements about the elements of some universe which are represented by the arguments of the symbol.
- Predicates with named arguments have the same semantic purpose but instead of identifying the arguments of the predicate by means a fixed order, the single arguments are identified by a parameter name. The order of the arguments does not matter here for the semantics of the predicate but the corresponding parameter names. Obviously, this has consequences for unification algorithms.
- `true` and `false` denote atomic statements which are always true (or false, resp.)
- $C[ATT \text{ ofType } T]$ defines a constraint on the possible values that instances of class C may take for property ATT to values of type T . Thus, this is expression is a signature expression.
- The same purpose has the simple logical expression $C[ATT \text{ ofTypeSet } (T_1, \dots, T_n)]$. It defines a constraint on the possible values that instances of class C may take for property ATT to values of types T_1, \dots, T_n . That means all values of all the specified types are allowed as values for the property ATT .
- $O \text{ memberOf } T$ is true, iff element O is an instance of type T , that means the element denoted by O is a member of the extension of type T .
- $C_1 \text{ subConceptOf } C_2$ is true iff concept C_1 is a subconcept of concept C_2 , that means the extension of concept C_1 is a subset of the extension of concept C_2 .
- $O[ATT \text{ hasValue } V]$ is true if the element denoted by O takes value V under property ATT .

- Similar for the simple logical expression $O[ATT \text{ hasValues } \{v_1, \dots, v_n\}]$: The expression holds if the set of values that the element o takes for property ATT includes all the values v_1, \dots, v_n . That means the set of values of o for property ATT is a superset of the set $\{v_1, \dots, v_n\}$.
- $T_1 = T_2$ is true, if both terms T_1 and T_2 denote the same element of the universe.

Definition 4. Definition 3 is extended to **complex logical expressions** in $L(V)$ as follows

- Every simple logical expression in $L(V)$ is a logical expression in $L(V)$.
- If L is a logical expression in $L(V)$, then $\text{not } L$ is a logical expression in $L(V)$.
- If L_1 and L_2 are logical expressions in $L(V)$ and op is one of the logical connectives in $\{\text{or}, \text{and}, \text{implies}, \text{impliedBy}, \text{equivalent}\}$, then $L_1 \text{ op } L_2$ is a logical expression in $L(V)$.
- If L is a logical expression in $L(V)$, x is a variable from Var and Q is a quantor in $\{\text{forAll}, \text{exists}\}$, then $Qx(L)$ is a logical expression in $L(V)$.
- Nothing else is a logical expression (or formula, resp.) in $L(V)$.

The intuitive semantics for complex logical expressions (wrt. to in interpretation) is as follows:

- $\text{not } L$ is true iff the logical expression L does not hold
- $\text{or}, \text{and}, \text{implies}, \text{equivalent}, \text{impliedBy}$ denote the common disjunction, conjunction, implication, equivalence and backward implication of logical expressions
- $\text{forAll } x (L)$ is true iff L holds for all possible assignments of x with an element of the universe.
- $\text{exists } x (L)$ is true iff there is an assignment of x with an element of the universe such that L holds.

Notational conventions:

There is a precedence order defined for the logical connectives as follows, where $op_1 < op_2$ means that op_2 binds stronger than op_1 : $\text{implies}, \text{equivalent}, \text{impliedBy} < \text{or}, \text{and} < \text{not}$.

The precedence order can be exploited when writing logical expressions in order to prevent from extensive use of parenthesis. In case that there are ambiguities in evaluating an expression, parenthesis must be used to resolve the ambiguities.

The terms $O[ATT \text{ ofTypeSet } (T)]$ and $O[ATT \text{ hasValues } \{V\}]$ (that means for the case $n = 1$ in the respective clauses above) can be written simpler by omitting the parenthesis.

A logical expression of the form $\text{false impliedBy } L$ (commonly used in Logic Programming system for defining integrity constraints) can be written using the following syntactical shortcut: `constraint L`.

We allow the following syntactic composition of atomic formulas as a syntactic abbreviation for two separate atomic formulas: $C_1 \text{ subConceptOf } C_2$ and $C_1[ATT \text{ op } v]$ can be syntactically combined to $C_1[ATT \text{ op } v] \text{ subConceptOf } C_2$. Additionally, for the sake of backwards compatibility with F-Logic, we as well allow the following notation for the combination of the two atomic formulae: $C_1 \text{ subConceptOf } C_2 [ATT$

$\text{op } \vee]$. Both abbreviations stand for the set of the two single atomic formulae. The first abbreviation is considered to be the standard abbreviation for combining these two kinds of atomics formulae.

Furthermore, we allow path expressions as a syntactical shortcut for navigation related expressions: $p.q$ stands for the element which can be reached by navigating from p via property q . The property q has to be a non-set-valued property (`hasValue`). For navigation over set-valued properties (`hasValues`), we use a different expression $p..q$. Such path expressions can be used like a term wherever a term is expected in a logical expression.

Note: Note that this definition for our language $L(V)$ is extensible by extending the basic vocabulary V . In this way, the language for expressing logical expressions can be customized to the needs of some application domain.

Semantically, the various modeling elements of ontologies can be represented as follows: concepts can be represented as terms, relations as predicates with named arguments, functions as predicates with named arguments, instances as terms and axioms as logical expressions.

8. Non functional properties

Non functional properties are used in the definition of WSMO elements. Which non functional properties apply to which WSMO element is specified in the description of each WSMO element. We do not enforce restrictions on the range value type (and thus also omit the range restriction in the following listing) but in some cases we do provide additional recommendations in the textual description.

Non-functional properties are defined in the following way:

```

Class nonFunctionalProperty
  hasAccuracy type accuracy
  hasContributer type dc:contributor
  hasCoverage type dc:coverage
  hasCreator type dc:creator
  hasDate type dc:date
  hasDescription type dc:description
  hasFinancial type financial
  hasFormat type dc:format
  hasIdentifier type dc:identifier
  hasLanguage type dc:language
  hasNetworkRelatedQoS type networkRelatedQoS
  hasOwner type owner
  hasPerformance type performance
  hasPublisher type dc:publisher
  hasRelation type dc:relation
  hasReliability type reliability
  hasRights type dc:rights
  hasRobustness type robustness
  hasScalability type scalability
  hasSecurity type security
  hasSource type dc:source
  hasSubject type dc:subject
  hastitle type dc:title
  hasTransactional type transactional
  hasTrust type trust
  hasType type dc:type
  hasVersion type version

```

Accuracy

It represents the error rate generated by the service. It can be measured by the numbers of errors generated in a certain time interval.

Contributor

An entity responsible for making contributions to the content of the element. Examples of `dc:contributor` include a person, an organization, or a service. The Dublin Core specification recommends, that typically, the name of a `dc:contributor` should be used to indicate the entity.

WSMO Recommendation: In order to point unambiguously to a specific resource we recommend the use an instance of `foaf:Agent` as value type [[Brickley & Miller, 2004](#)].

Coverage

The extent or scope of the content of the element. Typically, `dc:coverage` will include spatial location (a place name or geographic coordinates), temporal period (a period label, date, or date range) or jurisdiction (such as a named administrative entity).

WSMO Recommendation: For more complex applications, consideration should be given to using an encoding scheme that supports appropriate specification of information, such as [DCMI Period](#), [DCMI Box](#) or [DCMI Point](#).

Creator

An entity primarily responsible for creating the content of the element. Examples of `dc:creator` include a person, an organization, or a service. The Dublin Core specification recommends, that typically, the name of a `dc:creator` should be used to indicate the entity.

WSMO Recommendation: In order to point unambiguously to a specific resource we recommend the use an instance of `foaf:Agent` as value type

[\[Brickley & Miller, 2004\]](#).

Date

A date of an event in the life cycle of the element. Typically, `dc:date` will be associated with the creation or availability of the element.

WSMO Recommendation: We recommend to use the an encoding defined in the ISO Standard 8601:2000 [\[ISO8601, 2004\]](#) for date and time notation. A short introduction on the standard can be found [here](#). This standard is also used by the the XML Schema Definition (YYYY-MM-DD) [\[Biron & Malhotra, 2001\]](#) and thus one is automatically compliant with XML Schema too.

Description

An account of the content of the element. Examples of `dc:description` include, but are not limited to: an abstract, table of contents, reference to a graphical representation of content or a free-text account of the content.

Financial

It represents the cost-related and charging-related properties of a service [\[O'Sullivan et al., 2002\]](#). This property is a complex property, which includes charging styles (e.g. per request or delivery, per unit of measure or granularity etc.), aspects of settlement like the settlement model (transactional vs. rental) and a settlement contract, payment obligations and payment instruments.

Format

A physical or digital manifestation of the element. Typically, `dc:format` may include the media-type or dimensions of the element. Format may be used to identify the software, hardware, or other equipment needed to display or operate the element. Examples of dimensions include size and duration.

WSMO Recommendation: We recommend to use types defined in the list of Internet [Media Types \[IANA, 2002\]](#) by the IANA (Internet Assigned Numbers Authority)

Identifier

An unambiguous reference to the element within a given context.

Recommended best practice is to identify the element by means of a string or number conforming to a formal identification system. In Dublin Core formal identification systems include but are not limited to the Uniform element Identifier (URI) (including the Uniform element Locator (URL)), the Digital Object Identifier (DOI) and the International Standard Book Number (ISBN).

WSMO Recommendation: We recommend to use URIs as Identifier, depending on the particular syntax the identity information of an element might already be given, however it might be repeated in `dc:identifier` in order to allow Dublin Core meta data aware applications the processing of that information.

Language

A language of the intellectual content of the element.

WSMO Recommendation: We recommend to use the language tags defined in the ISO Standard 639 [\[ISO639, 1988\]](#), e.g. "en-GB", in addition the logical language used to express the content should be mentioned, for example this can be [OWL](#).

Network-related QoS

They represent the QoS mechanisms operating in the transport network which are independent of the service. They can be measured by network delay, delay variation and/or message loss.

Owner

A person or organization to which a particular WSMO element belongs.

Performance

It represents how fast a service request can be completed. According to [\[Rajesh & Arulazi, 2003\]](#) performance can be measured in terms of throughput, latency, execution time, and transaction time. The response time of a service can also be a measure of the performance. High quality services should provide higher throughput, lower latency, lower execution time, faster transaction time and faster response time.

Publisher

An entity responsible for making the element available. Examples of `dc:publisher` include a person, an organization, or a service. The Dublin Core specification recommends, that typically, the name of a `dc:publisher` should be used to indicate the entity.

WSMO Recommendation: In order to point unambiguously to a specific resource we recommend the use an instance of `foaf:Agent` as value type [\[Brickley & Miller, 2004\]](#).

Relation

A reference to a related element. Recommended best practice is to identify the referenced element by means of a string or number conforming to a formal identification system.

WSMO Recommendation: We recommend to use URIs as Identifier where possible. In particular, this property can be used to define namespaces that can be used in all child elements of the element to which this non functional property is assigned to.

Reliability

It represents the ability of a service to perform its functions (to maintain its service quality). It can be measured by the number of failures of the service in a certain time interval.

Rights

Information about rights held in and over the element. Typically, `dc:rights` will contain a rights management statement for the element, or reference a service providing such information. Rights information often encompasses Intellectual Property Rights (IPR), Copyright, and various Property Rights. If the Rights element is absent, no assumptions may be made about any rights held in or over the element.

Robustness

It represents the ability of the service to function correctly in the presence of incomplete or invalid inputs. It can be measured by the number of incomplete or invalid inputs for which the service still function correctly.

Scalability

It represents the ability of the service to process more requests in a certain time interval. It can be measured by the number of solved requests in a certain time interval.

Security

It represents the ability of a service to provide authentication (entities - users or other services - who can access service and data should be authenticated), authorization (entities should be authorized so that they only can access the protected services), confidentiality (data should be treated properly so that only authorized entities can access or modify the data), traceability/auditability (it should be possible to trace the history of a service when a request was serviced), data encryption (data should be encrypted), and non-repudiation (an entity cannot deny requesting a service or data after the fact).

Source

A reference to an element from which the present element is derived. The

present element may be derived from the `dc:source` element in whole or in part. Recommended best practice is to identify the referenced element by means of a string or number conforming to a formal identification system.
WSMO Recommendation: We recommend to use URIs as Identifier where possible.

Subject

A topic of the content of the element. Typically, `dc:subject` will be expressed as keywords, key phrases or classification codes that describe a topic of the element. Recommended best practice is to select a value from a controlled vocabulary or formal classification scheme.

Title

A name given to an element. Typically, `dc:title` will be a name by which the element is formally known.

Transactional

It represents the transactional properties of the service.

Trust

It represents the trust worthiness of the service.

Type

The nature or genre of the content of the element. The `dc:type` includes terms describing general categories, functions, genres, or aggregation levels for content.

WSMO Recommendation: We recommend to use an URI encoding to point to the namespace or document describing the type, e.g. for a domain ontology expressed in WSMO, one would use:

<http://www.wsmo.org/2004/d2/#ontologies>.

Version

As many properties of an element might change in time, an identifier of the element at a certain moment in time is needed.

WSMO Recommendation: If applicable we recommend to use the revision numbers of a version control system. Such a system can be for example CVS (Concurrent Version System), that automatically keeps track of the different revisions of a document, an example CVS version Tag looks like: "\$Revision: 1.26 \$".

9. Conclusions and further directions

This document presented the Web Service Modeling Ontology (WSMO) for describing several aspects related to services on the web, by refining the Web Service Modeling Framework (WSMF). The definition of the missing elements (choreography and orchestration) will be provided in separate deliverables of the [WSMO working group](#), and future versions of this document will contain refinements of the mediators.

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Appendix A. Conceptual Elements of WSMO

ONLY WHEN THE MODEL IS STABLE THIS WILL BE COMPLETED.

[1] An instance can be an instance of several concepts by repeating the statement.

[2] A relation instance can be an instance of several relations by repeating the statement.

[3] One could argue that `orchestration` should not be part of a public interface because it refers to how a service is implemented. However, this is a short-term view that does not reflect the nature of fully open and flexible eCommerce. Here companies shrink to their core processes where they are really profitable in. All other processes are sourced out and consumed as eServices. They advertise their services in their capability and choreography description and they advertise their needs in the orchestration interfaces. This enables on-the-fly creation of virtual enterprises in reaction to demands from the market place. Even in the dinosaurian time of eCommerce where large companies still exist, `orchestration` may be an important aspect. The `orchestration` of a service may not be made public but may be visible to the different departments of a large organization that compete for delivering parts of the overall service. Notice that the actual business intelligence of a service provider is still hidden. It is his capability to provide a certain functionality with a choreography that is very different from the sub services and their orchestration. The ability for a certain type of process management (the overall functionality is decomposed differently in the `choreography` and the `orchestration`) is where it comes in as a Silver bullet in the process. How he manages the difference between the process decomposition at the `choreography` and the `orchestration` level is the business intelligence of the web service provider.



[webmaster](#)

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