The Web Service Modeling Language WSML

An Overview

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Outline

The World Wide Web

What is the WWW?

- Largest document repository ever ($>$ 8 billion Web pages indexed by Google)
- Highly distributed
  - Millions of publishers
  - No control over consistency of published content
- Web Technologies
  - HTTP for transferring documents
  - HTML for marking up documents
  - URI for addressing documents
- Most content on the Web is in natural language (HTML)
  - Natural language not suitable for machine reading
  - Current Web is "syntactic"
  - Problems in automatically:
    - Retrieving documents
    - Extracting relevant information from retrieved documents
    - Combining information from different sources

The Semantic Web

- Making the Web machine-readable
- Publishing data in machine-readable format
- Relating data on the Web to established vocabularies (ontologies)
- Ontologies specified in formal language to allow reasoning
- Ontologies enable automation in:
  - Retrieval of relevant information
  - Extracting relevant information from retrieved document
  - Combination of information from different sources (as long as they are related to the same ontology)

Web Services

- Next step in software engineering:
  - 1960s: Procedural
  - 1980s: Object Orientation
  - 1990s: Component-based
  - 2000s: Web Services
- Loosely coupled, reusable components
- Add new level of functionality to the Web
- Web Service Technologies
  - SOAP for accessing Web Services
  - WSDL for describing Web Services
  - UDDI for publishing and looking up Web Services

Web Services are not enough

- Like the current Web, Web Services are "syntactic"
- No automation in:
  - Finding services
  - Selecting services
  - Negotiation with service provider
  - Composing services
  - Executing services

Combining Semantic Web and Web Services
Semantic Web Services

- Semantic Web + Web Services = Semantic Web Services
- Using Semantic Web technologies to describe Web Services
- Enable automation in:
  - Publication
  - Discovery
  - Selection
  - Composition
  - Mediation
  - Execution

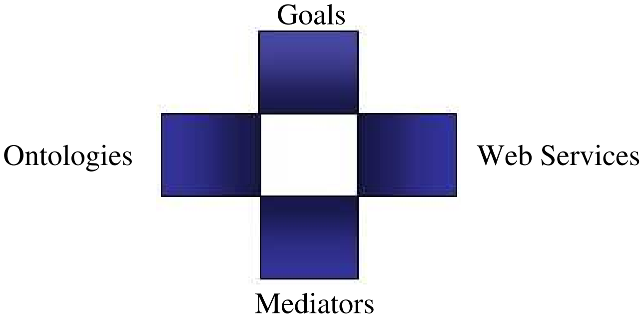
The Web Service Modeling Language WSML

1. A language for the Semantic description of Web Services
2. Based on the Web Service Modeling Ontology WSMO
3. One syntactic framework for a set of layered languages
4. Normative “human-readable” surface syntax
5. Separation of
   - Conceptual modeling
   - Logical modeling
6. Semantics based on well known formalisms
   - Description Logics
   - Logic Programming
   - Frame Logic
7. Web language
8. Frame-based syntax

The Web Service Modeling Ontology WSMO
Introduction

- An ontology for Semantic Web Services
- Provides conceptual model for SWS
- Based on the Web Service Modeling Framework WSMF
- Principles of WSMO:
  - Ontology-based descriptions
  - Strict decoupling of components
  - Strong mediation between components
  - Interface vs. Implementation

The Web Service Modeling Ontology WSMO



The Web Service Modeling Ontology WSMO

Ontologies

- Provide terminology for:
  - Data exchanged between service requesters and providers
  - Description of other WSMO elements
- Ontologies consist of:
  - Concepts
    - Attributes
  - Relations
  - Functions
  - Instances
  - Axioms

The Web Service Modeling Ontology WSMO
Web Service descriptions

- Functionality offered by the Web Service
- Functional description, in the form of a *capability*:
  - Assumptions
    - Cannot be checked
    - Usually indicate dependency on real world
  - Preconditions
    - Conditions over the input
  - Effects
    - Changes in the real world as a result of execution of the Web Service
  - Postconditions
    - Relation between the input and the output

The Web Service Modeling Ontology WSMO

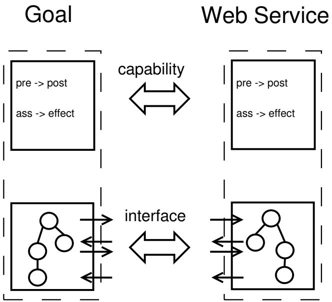
Web Service descriptions (cont'd)

- Behavioral description, in the form of an *interface*:
  - Choreography
    - How to interact with the service
  - Orchestration
    - Use of external Web Service to realize the functionality
  - Both choreography and orchestration are decompositions of the capability

The Web Service Modeling Ontology WSMO

Goals

- Functionality requested from the Web Service
- Description symmetric to Web Service description:
  - Capability
  - Interface



The Web Service Modeling Ontology WSMO

Mediators

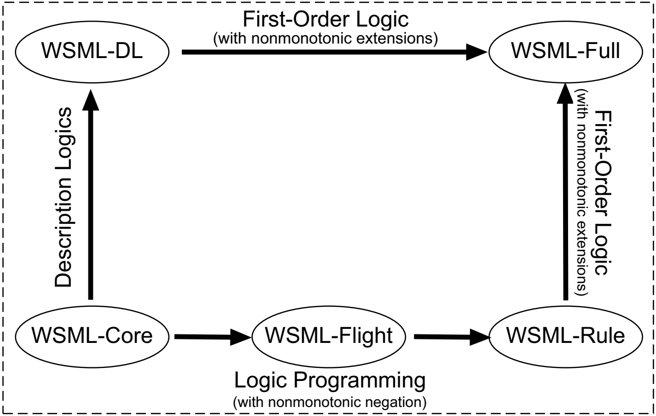
- Connect heterogeneous components
- Resolve heterogeneity in different levels
  - Data - differences in data representation
  - Protocol - differences in interaction styles
  - Process - differences in business processes

The Web Service Modeling Ontology WSMO

Types of Mediators

- OO Mediators
  - Connect ontologies to any other component (including mediators)
  - Resolve mismatches conflicts between ontologies
- WW Mediators
  - Link Web Services to services they depend on
  - Resolve representation differences through OO Mediators
- WG Mediators
  - Link Goals and Web Services
  - Resolve differences in data, protocol and process between requester and provider
- GG Mediators
  - Connect generic and refined Goals

WSML Language Variants



First Order Logic - Syntax
Symbols

Constants	$a, b, john, ...$
Function symbols	$f, g, +, married - to, ...$
Predicate Symbols	$p, q, >, marriage, ...$
Variables	$x, y, ...$
Connectives	$\neg, \wedge, \vee, \leftarrow, \rightarrow, \leftrightarrow$
Quantifiers	$\forall, \exists$
(Equality)	$=$

Terms

- Every constant is a term
  - $a, b, john$
- Every variable is a term
  - x, y
- If f is an n-place function symbol and $t_1, ..., t_n$ are terms, then $f(t_1, ..., t_n)$ is a term
  - $f(x), f(a), f(g(a))$
  - $father - of(john), married - to(mary)$

Atomic formulas

- If p is an n-place predicate symbol and $t_1, ..., t_n$ are terms, then $p(t_1, ..., t_n)$ is an atomic formula
  - $p(x), q(f(a), y)$
  - $marriage(father - of(john), mary, date(2005, 4, 6))$
- If t_1, t_2 are terms, then $t_1 = t_2$ is an atomic formula
  - $f(x) = a, married - to(mary) = father - of(john)$

Formulas

- Any atomic formula is a formula
- If A, B are formulas and $x_1, ..., x_n$ are variables then:
  - $\neg A$ is a formula
  - $A \wedge B$ is a formula
  - $A \vee B$ is a formula
  - $A \leftarrow B$ is a formula
  - $A \rightarrow B$ is a formula
  - $A \leftrightarrow B$ is a formula
  - $\forall x_1, ..., x_n : A$ is a formula
  - $\exists x_1, ..., x_n : A$ is a formula
- Examples:
  - $\forall x, y, d : marriage(x, y, d) \rightarrow married - to(x) = y \wedge married - to(y) = x$
  - $\forall x : number(x) \rightarrow \exists y : y > x$

Horn subset

- A Horn formula is a disjunction of literals with one positive literal, with all variables universally quantified:
  - $(\forall)\neg B_1 \vee ... \vee \neg B_n \vee H$
- Can be written as an implication:
  - $(\forall)B_1 \wedge ... \wedge B_n \rightarrow H$
- Horn formulas are the basis for Logic Programming

First-Order Logic - Semantics

Interpretation

- The meaning of a First-Order formula is assigned using an *interpretation*
- An interpretation $\mathcal{I}$ consists of:
  - Domain Δ: a set of objects
  - A set of relations R: $\Delta^1 \times ... \times \Delta^n$
  - A set of functions F: $\Delta^1 \times ... \times \Delta^n \mapsto \Delta$
  - A mapping function $\cdot$ which:
    - Maps constants to objects
    - Maps predicate symbols to relations
    - Maps function symbols to functions
- An interpretation is a *model* of a formula A if it makes the formula *true*:
  - $\mathcal{I} \models A$

Truth of a formula

A (atomic formula)	is true iff	$A^{\mathcal{I}}$ is in the model
$\neg A$	is true iff	$A^{\mathcal{I}}$ is *not* true
$A \wedge B$	is true iff	$A^{\mathcal{I}}$ *and* $B^{\mathcal{I}}$ are true
$A \vee B$	is true iff	$A^{\mathcal{I}}$ *or* $B^{\mathcal{I}}$ is true (or both)
$A \rightarrow B$	is true iff	in every case where $A^{\mathcal{I}}$ is true, $B^{\mathcal{I}}$ is true

What about variables?

- We have not discussed semantics of variables
- Variables *have no semantics*
- What to do with variables?
- *Assign* values to variables using an assignment B
  - e.g., $\{x \mapsto a, y \mapsto john\}$
- An interpretation $\mathcal{I}$ makes a formula A *true* under a variable assignment B:
  - $\mathcal{I} \models_B A$
- Quantifiers:
  - $\exists x A$: there exists an assignment for x which makes A true
  - $\forall x A$: for all possible assignments of x, A is true

Logic Programming - Syntax

- Any FOL term is a term in LP
- Any FOL atomic formula is an atomic formula in LP
- Any Horn formula is a rule in LP (quantification usually omitted)
  - $H \leftarrow B_1 \wedge ... \wedge B_n$
- Logic programming is a syntactic subset of FOL
- Note! Negation-as-failure in LP is an *extension* of Horn rules
  - $\neg \neq not$

Logic Programming - Semantics

Herbrand Universe and Herbrand Base

- The Herbrand Universe U_P is the set of all ground terms which can be formed from constants and function symbols in program P.
  Example:
  `a,b,f(a),f(b),f(f(a)),f(f(b)),f(f(f(a))),...`
- The Herbrand Base B_P is the set of all ground atoms which can be built from predicate symbols in P, using ground terms from U_P as arguments.
  Example: `p(a),p(b),q(a),q(b),p(f(a)),q(f(a)),...`

Logic Programming - Semantics

Herbrand Interpretation and Least Herbrand Model

- A Herbrand Interpretation IP is a subset of the Herbrand Base BP.
- A Herbrand Model MP is a Herbrand Interpretation which makes every formula true, i.e.:
  - Every fact in P is in MP, and
  - For every rule R in P holds: if every positive literal in the body is in MP, then also the head literal is in MP.

  Note: this only works for positive programs, i.e., programs without negation!
- The semantics of a program P is characterized in terms of the least Herbrand Model, which is the intersection of all possible Herbrand Models.
- Each positive program has one unique least Herbrand Model.

Relationship between FOL and LP

- Semantics LP defined in terms of minimal Herbrand model
  - Only one minimal model
- Semantics FOL defined in terms of First-Order models
  - Typically, infinitely many First-Order models

- The minimal Herbrand model is a First-Order model
- In fact, every Herbrand model is a First-Order model

- There exist First-Order models which are not Herbrand models

Entailment in FOL and LP

- General First-Order entailment:
  - $\phi \models \psi$ iff for every interpretation $\mathcal{I}$: if $\mathcal{I} \models \phi$ then $\mathcal{I} \models \psi$
  - Thus, the set of models of ϕ $M(\phi)$ is a subset of $M(\psi)$: $M(\phi) \subseteq M(\psi)$
  - e.g., $p(x) \wedge q(x) \models p(x)$
- Ground entailment:
  - $\phi \models \psi_{ground}$ iff for every interpretation $\mathcal{I}$: if $\mathcal{I} \models \phi$ then $\mathcal{I} \models \psi_{ground}$ and $\psi ground$ **does not** contain variables
  - e.g., $(p(x) \rightarrow q(x)) \wedge p(a) \models q(a)$
- Logic Programming only defines ground entailment
- Horn Logic (i.e., Horn subset of FOL) is equivalent to Logic Programming wrt. ground entailment
  - For any set of Horn formulas ϕ and a ground Horn formula ψ_{ground}: $\phi \models_{FOL} \psi_{ground}$ iff $\phi \models_{LP} \psi_{ground}$
  - $\models_{FOL}$ is classical First-Order entailment; $\models_{LP}$ is LP entailment

Description Logics

- Most DLs similar to 2-variable fragment of FOL
  - No more than 2 variables under the scope of a quantifier
    - *Exception: transitive properties*
  - Classes correspond to unary predicates
  - Properties correspond to binary predicates
  - No function symbols
- Most DLs are *decidable*
- We focus on $\mathcal{SHIQ}$ DL (close to the DL underlying OWL DL), and disregard concrete domains (e.g., int, string) for now
- $\mathcal{SHIQ} =$
  - Concept hierarchies
  - Concept conjunction, disjunction, negation
  - Rule hierarchies
  - Existential, universal quantification
  - Qualified number restrictions (minimal, maximal cardinality)
  - Symmetric, inverse, transitive properties

$\mathcal{SHIQ}$ - Syntax
Concept descriptions

$C, D \longrightarrow$	$A \mid$	(atomic concept)
	$\top \mid$	(universal concept)
	$\bot \mid$	(bottom concept)
	$C \sqcap D \mid$	(intersection)
	$C \sqcup D \mid$	(disjunction)
	$\neg C \mid$	(negation)
	$\forall R.C \mid$	(value restriction)
	$\exists R.C \mid$	(existential quantification)
	$\geqslant nR.C \mid$	(minimal cardinality)
	$\leqslant nR.C \mid$	(maximal cardinality)

$\mathcal{SHIQ}$ - Syntax

Individual assertions

$a \in C$

$\langle a, b \rangle \in R$

$\mathcal{SHIQ}$ - Syntax
Axioms

$C \sqsubseteq D$	(class subsumption)
$C \equiv D$	(equivalence)
$Q \sqsubseteq R$	(property subsumption)
$R \equiv Q^{-}$	(inverse roles)
$R \equiv R^{-}$	(symmetric roles)
$R^{+} \sqsubseteq R$	(transitive properties)

$\mathcal{SHIQ}$ Examples

- $\mathit{Human} \sqsubseteq \forall \mathit{hasChild}.\mathit{Human} \sqcap = 2 \mathit{hasParent}.\mathit{Human}$
- $\mathit{Parent} \sqsubseteq \exists \mathit{hasChild}.\top$
- $\mathit{HumanParent} \equiv \mathit{Human} \sqcap \mathit{Parent}$
- $\mathit{hasChild} \equiv \mathit{hasParent}^{-}$

if $\langle \mathit{john}, \mathit{mary} \rangle \in \mathit{hasChild}$ then $\langle \mathit{mary}, \mathit{john} \rangle \in \mathit{hasParent}$

Mapping $\mathcal{SHIQ}$ to FOL

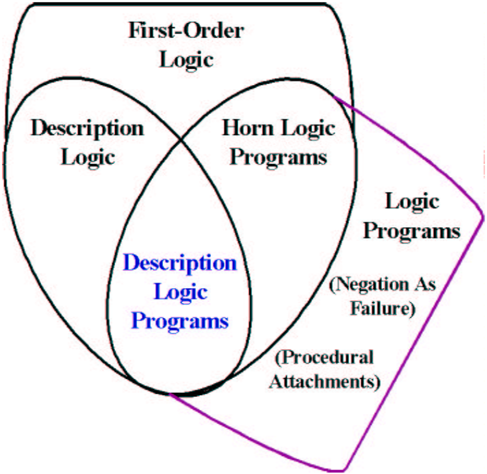
A (atomic concept)	$A(x)$
$\top$	$\top$
$\bot$	$\bot$
$C \sqcap D$	$tr(C) \wedge tr(D)$
$C \sqcup D$	$tr(C) \vee tr(C)$
$\neg C$	$\neg tr(C)$
$\forall R.C$	$\forall y : R(x, y) \rightarrow tr(C, y)$
$\exists R.C$	$\exists y : R(x, y) \wedge tr(C, y)$
$\geqslant nR.C$	$\exists y_1, \ldots, y_n : \bigwedge R(X, y_i) \wedge \bigwedge tr(C, y_i) \wedge \bigwedge y_i \neq y_j$
$\leqslant nR.C$	$\forall y_1, \ldots, y_{n+1} : \bigwedge R(X, y_i) \bigwedge tr(C, y_i) \wedge \rightarrow \bigvee y_i =$

Mapping $\mathcal{SHIQ}$ to FOL

$a \in A$	$A(a)$
$\langle a, b \rangle \in R$	$R(a, b)$

$C \sqsubseteq D$	$\forall x : tr(C, x) \rightarrow tr(D, x)$
$C \equiv D$	$\forall x : tr(C, x) \leftrightarrow tr(D, x)$
$Q \sqsubseteq R$	$\forall x, y : Q(r, y) \rightarrow R(x, y)$
$R \equiv Q^{-}$	$\forall x, y : R(x, y) \leftrightarrow Q(y, x)$
$R^{+} \sqsubseteq R$	$\forall x, y, z : R(x, y) \wedge R(y, z) \rightarrow R(x, z)$

Relation between DL and LP



Description Logic Programs

- "Intersection" of Description Logics and Logic Programming
- That part of Description Logics (OWL in particular) which can be translated to a Logic Program
- Horn Logic subset of $\mathcal{SHIQ}$, *reduced* to a Logic Program: Description Logic Program: DLP
- General idea:
  1. Translate $\mathcal{SHIQ}$ axiom to First-Order Logic
  2. Rewrite to Horn Logic
     - If rewriting not possible: formula not in DLP
  3. Reduce to Logic Program

WSML-Core

- Basic interoperability layer between Description Logics and Logic Programming paradigms
- Based on Description Logic Programs
  - Expressive intersection of Description Logic $\mathcal{SHIQ}$ and Datalog
  - Allows to take advantage of many years of established research in Databases and Logic Programming
  - Allows reuse of existing efficient Deductive Database and Logic programming reasoners
- Some limitations in conceptual modeling of Ontologies
  - No cardinality constraints
  - Only "inferring" range of attributes
  - No meta-modeling

WSML-Core Logical Expressions

- Limitations in logical expressions
  - From Description Logic point-of-view, there is a lack of:
    - Existentials
    - Disjunction
    - (Classical) negation
    - Equality
  - From Logic Programming point-of-view, there is a lack of:
    - N-ary predicates
    - Chaining variables over predicates
    - (Default) negation
    - Function symbols

WSML-DL

- Extension of WSML-Core
- Based on the Description Logic $\mathcal{SHIQ}$
  - Entailment is decidable
  - Close to DL species of Web Ontology Language OWL
  - Many efficient subsumption reasoners
- Some limitations in conceptual modeling of Ontologies
  - No cardinality constraints
  - Only "inferring" range of attributes
  - No meta-modeling
- Limitations in logical expressions
  - From Logic Programming point-of-view, there is a lack of:
    - N-ary predicates
    - Chaining variables over predicates
    - (Default) negation

WSML-Flight

- Extension of WSML-Core
- Based on the Datalog, with negation under Perfect Model Semantics
  - Ground entailment is decidable
  - Allows to take advantage of many years of established research in Databases and Logic Programming
  - Allows reuse of existing efficient Deductive Database and Logic programming reasoners
- No limitations in conceptual modeling of Ontologies
  - Cardinality constraints
  - Value constraints for attributes
  - Meta-modeling

WSML-Flight Logical Expressions

- Syntax based on Datalog fragment of F-Logic, extended with negation-as-failure
- Arbitrary Datalog rules:
  - N-ary predicates
  - Chaining variables over predicates
- From Description Logic point-of-view, there is a lack of:
  - Existentials
  - Disjunction
  - (Classical) negation
  - Equality
- From Logic Programming point-of-view, there is a lack of:
  - Function symbols

WSML-Rule

- Extension of WSML-Flight
- Based on Horn fragment of F-Logic, with negation under Perfect Model Semantics
  - Ground entailment is undecidable
  - Turing complete
  - Allows to take advantage of many years of established research in Logic Programming
  - Allows reuse of existing efficient Logic programming reasoners
- Extends WSML-Flight logical expressions with:
  - Function symbols
  - Unsafe rules
- From Description Logic point-of-view, there is a lack of:
  - Existentials
  - Disjunction
  - (Classical) negation
  - Equality

WSML-Full

- Extension of WSML-Rule *and* WSML-DL
- Based on First Order Logic with nonmonotonic extensions
  - Entailment is undecidable
  - Very expressive
- Extends WSML-DL logical expressions with:
  - Chaining variables over predicates
  - Function symbols
  - Nonmonotonic negation
  - N-ary predicates
- Extends WSML-Rule with:
  - Existentials
  - Disjunction
  - Classical negation
  - Equality
- Specification of WSML-Full is open research issue

Identifiers

- Internationalized Resource Identifiers (IRIs) are basic identifiers
  - Concepts, attributes, relations, instances, etc... are all IRIs
  - IRI is successor of URI
  - Using in newer W3C recommondations, e.g., XML, RDF
  - e.g., _"http://www.wsmo.org/wsml/wsml-syntax#", _"http://example.org/myOntology#myConcept"
- sQNames
  - Abbreviations for IRIs ("serialized QNames")
  - e.g., wsml#concept, dc#title, ont#location
- Data values
  - Elementary data values: strings, int, decimals
  - Structured data values
    - Derived from XML Schema Datatypes
    - date, float, etc...
    - e.g., _date(2005,6,23), _float(12.567)

Prologue
By Example

```
// Specification of the WSML variant
wsmlVariant _"http://www.wsmo.org/wsml/wsml-syntax/wsml-flight"
// Namespace prefix declaration
namespace {_"http://www.example.org/example#",
  dc _"http://purl.org/dc/elements/1.1/"}
// WSML specifications
ontology _"http://www.example.org/exampleOntology"
 [...]
goal _"http://www.example.org/exampleGoal"
 [...]
```

etc...

WSML Specification

A WSML specification has the following structure:

- Type of specification (Ontology/Web Service/Goal/Mediator)
- Header
  - Non-Functional Properties
  - Imported Ontologies
  - Used Mediators
- Content of the specification

Ontologies
Header

[.. prologue ..]

ontology _"http://www.example.org/ontologies/example"

nonFunctionalProperties

dc#title **hasValue** "WSML example ontology"

endNonFunctionalProperties

importsOntology {_"http://www.wsmo.org/ontologies/location"}

usesMediator {_"http://www.wsmo.org/mediators/"}

Concepts

- Form the basic terminology of the domain of discourse
- May be organized in a hierarchy (using **subConceptOf**)
- Has a number of attributes:
  - Attributes have a type:
    - Type constraint (**ofType**)
    - Type inference (**impliesType**)
  - Attributes may have cardinality constraints
  - Attributes may have a number of features:
    - Transitive
    - Symmetric
    - Reflexive
    - Inverse of another attribute

Concepts
Example

```
concept Person subConceptOf {Primate, LegalAgent}
  nfp
 // Related axiom
    dc#relation hasValue personUncle
   endnfp
 // A functional attribute (maximal cardinality=1)
   hasName ofType (0 1) _string
 // hasParent is the inverse of hasChild
   hasChild inverseOf(hasParent) ofType Person
   hasParent ofType Person
   hasBrother ofType Person
```

Relations

- Inspired by relations in mathematics
- Have arbitrary arity
- May have typing associated with its arguments
- May be organized in a hierarchy (using **subRelationOf**)

relation Marriage (ofType Person, ofType Person, ofType _date)
nfp
dc#description **hasValue** "Marriage is a relation between two persons, which are the participants in the marriage, and the date in the marriage."
endnfp

Instances

- Are the objects in the domain
- May be member of one or more concepts
- May have a number of attribute values associated with it

instance john **memberOf** Person
nfp
dc#description **hasValue** "The person John Smith"
endnfp
hasName **hasValue** "John Smith"

Relation Instances

- Are tuples in a relation

relationInstance Marriage(john,mary,_date(2005,03,03))
nfp
dc#description **hasValue** "John and Mary married on 2005-03-03."
endnfp

Axioms

- Refine concept and relation definitions in Ontologies using logical expressions
- Add arbitrary knowledge and constraints
- Allowed logical expressions depend on WSML variant

```
axiom personUncle
nfp
  dc#description hasValue "The brother of a person's parent is that
    person's uncle."
endnfp
definedBy
  ?x[hasUncle hasValue ?z] impliedBy ?x[hasParent hasValue ?y] and
    ?y[hasBrother hasValue ?z].
```

Web Services

A Web Service specification has the following structure:

- Type of specification (**webService**) and identifier
- Header
  - Non-Functional Properties
  - Imported Ontologies
  - Used Mediators
- Capability
  - Functional description of Web Service
- Interfaces
  - Behavioural description of Web Service
  - Communications pattern of Web Service

webService _"http://www.example.org/exampleService"

capability ...

interface ...

Capability

- Syntactical framework for Functional description
- Functionality defined through logical expressions:
  - Preconditions
  - Postconditions
  - Assumptions
  - Effects
- Shared variables
  - Variables shared by description elements
  - Quantified over the entire capability

Capability
Example

```
capability
  sharedVariables ?x,?y,...
  precondition
    definedBy
      ..
  postcondition
    definedBy
      ..
  assumption
    definedBy
      ..
  effect
    definedBy
      ..
```

Interfaces

- Choreography
  - Communication interface of Web Service
- Orchestration
  - Usage of external Web Services
- Currently, choreography and orchestration are external to WSML

interface
choreography _"http://example.org/choreographies/1"
orchestration _"http://example.org/orchestration/1"

Goals

- Describe requested functionality
- Description symmetric to Web Services:
  - Header
  - Capability
  - Interfaces

goal _"http://www.example.org/exampleGoal"

capability

...

interface

...

Mediators

- Mediators connect WSML elements in two ways:
  - Referencing mediators through **usesMediator**
  - Specifying **source** and **target** in mediator specification
- Mediation is achieved by mediation service (**usesService**)
  - Web Service
  - Goal

wgMediator _"http://www.example.org/exampleMediator"

source _"http://www.example.org/exampleGoal"
target _"http://www.example.org/exampleService"

usesService _"http://www.example.org/mediationService"

Logical Expression syntax

- Used for refining Ontologies and specifying Web Service functionality
- Allow to use the full expressive power of the underlying logic
- First-Order Logic with Frame syntax (F-Logic)
- Specific extensions to capture Logic Programming constructs
  - Negation-as-failure
  - LP implication
- Variables are implicitly universally quantified outside the formula
- Symbols resemble natural language and are unambiguous
- WSML variants restrict allowed logical expressions

Examples

```
// a simple rule; the brother of someone's parent is that person's
//   uncle
?x[hasUncle hasValue ?z] impliedBy ?x[hasParent hasValue ?y] and
  ?y[hasBrother hasValue ?z].

// the same person cannot be both a man and a woman (constraint)
!- ?x memberOf Man and ?x memberOf Woman.

// every person has a father
?x memberOf Person implies exists ?y (?x[father hasValue ?y]).

// a person is either a Man or a Woman
?x memberOf Person implies ?x memberOf Man or ?x memberOf Woman.
```

WSML Variants vs. Features

Feature	Core	DL	Flight	Rule	Full
Classical Negation (**neg**)	-	X	-	-	X
Existential Quantification	-	X	-	-	X
Disjunction	-	X	-	-	X
Meta Modeling	-	-	X	X	X
Default Negation (**naf**)	-	-	X	X	X
LP implication	-	-	X	X	X
Integrity Constraints	-	-	X	X	X
Function Symbols	-	-	-	X	X
Unsafe Rules	-	-	-	X	X

Table by Holger Lausen

WSML XML Syntax

- Syntax for exchange over the Web
- Translation between human-readable and XML syntax
- XML Schema for WSML has been defined

WSML XML
Example

```
<!ENTITY ex "http://www.example.org/ontologies/example#">
<!ENTITY wsml "http://www.wsmo.org/wsml/wsml-syntax#">
<wsml xmlns="&wsml;"
 variant="http://www.wsmo.org/wsml/wsml-syntax/wsml-flight">
  <importsOntology>
    http://www.wsmo.org/ontologies/location
  </importsOntology>
  <concept name="&ex;Person">
    <nonFunctionalProperties>[..]</nonFunctionalProperties>
    <attribute name="&ex;hasName" type="constraining">
      <range>&wsml;string</range>
      <maxCardinality>1</maxCardinality>
    </attribute>
       [..]
  </concept>
     [..]
</wsml>
```

WSML RDF Syntax

- Interoperability with RDF applications
- Maximal reuse of RDF and RDFS vocabulary
- WSML RDF includes most of RDF
- Translation between human-readable and RDF syntax
- For logical expressions, XML literals are used

WSML RDF
Example

```
<http://www.example.org/ontology> rdf#type wsml#ontology
<http://www.example.org/ontology> wsml#variant
    <http://www.wsmo.org/wsml/wsml-syntax/wsml-flight>
<http://www.example.org/ontology> wsml#nfp _:nfp1
_:nfp1 dc#title "WSML example ontology"^^xsd#string
<http://www.example.org/ontology> wsml#importsOntology
    <http://www.wsmo.org/ontologies/location>
<http://www.example.org/ontology> wsml#hasConcept ex#Person
ex#Person wsml#hasAttribute _:att1
_:att1 wsml#attribute ex#hasName
_:att1 wsml#ofType xsd#string
_:att1 wsml#maxCardinality "1"^^xsd:integer
<http://www.example.org/ontology> wsml#hasAxiom
    ex#personUncle
ex#personUncle rdfs#isDefinedBy
    "<impliedByLP>..</impliedByLP>"^^rdf#XMLLiteral
```

Conclusions

- WSML is a language for modeling of Semantic Web Services
- Based on the Web Service Modeling Ontology WSMO
- WSML is a Web language:
  - IRIs for object identification
  - XML datatypes
- WSML is based on well-known logical formalisms:
  - Description Logics
  - Logic Programming
  - Frame Logic
- Syntax has two parts:
  - Conceptual modeling
  - Arbitrary logical expressions
- XML and RDF syntaxes for exchange over the Web

WSML resources
http://www.wsmo.org/wsml/wsml-syntax#

Questions?