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# The Distributed Ontology, Model, and Specification Language (DOL)

Version 0.73

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# Table of Contents

<b>Preface</b>	<b>ix</b>
OMG . . . . .	ix
OMG Specifications . . . . .	ix
Typographical Conventions . . . . .	x
Issues . . . . .	x
<b>0. Submission-Specific Material</b>	<b>xi</b>
0.1. Submission Preface . . . . .	xi
0.2. Mandatory Requirements . . . . .	xi
0.3. Optional Requirements . . . . .	xiii
0.4. Issues to be discussed . . . . .	xiv
0.5. Evaluation Criteria . . . . .	xiv
0.6. Proof of Concept . . . . .	xv
0.7. Changes to Adopted OMG Specifications . . . . .	xv
<b>1. Scope</b>	<b>1</b>
1.1. Background Information . . . . .	1
1.2. Features within Scope . . . . .	2
<b>2. Conformance</b>	<b>3</b>
2.1. Conformance of an OMS language/a logic with DOL . . . . .	3
2.1.1. Conformance of language/logic translations with DOL . . . . .	4
2.2. Conformance of a serialization of an OMS language with DOL . . . . .	5
2.3. Machine-processable description of conforming languages, logics, and serializa- tions . . . . .	7
2.4. Conformance of a document with DOL . . . . .	8
2.5. Conformance of an application with DOL . . . . .	8
<b>3. Normative References</b>	<b>9</b>
<b>4. Terms and Definitions</b>	<b>10</b>
4.1. Distributed Ontology, Modeling and Specification Language . . . . .	10
4.2. OMS . . . . .	10
4.3. Semantic Web . . . . .	12
4.4. OMS Annotation and Documentation . . . . .	13
4.5. Structured OMS . . . . .	14
4.6. Mappings Between OMS . . . . .	16
4.7. Features of OMS Languages . . . . .	18
4.8. OMS Language Serializations . . . . .	20
4.9. Logic . . . . .	20
4.10. Interoperability . . . . .	21

## Table of Contents

<b>5. Symbols</b>	<b>23</b>
<b>6. Additional Information</b>	<b>25</b>
6.1. Changes to Adopted OMG Specifications . . . . .	25
6.2. How to Read this Specification . . . . .	25
6.3. About this Specification . . . . .	25
6.4. Acknowledgments . . . . .	25
6.4.1. Submitting and supporting organizations . . . . .	25
6.4.2. Participants . . . . .	25
<b>7. Goals and Usage Scenarios</b>	<b>26</b>
7.1. Use case Onto-1: Interoperability between OWL and FOL ontologies . . . . .	26
7.2. Use Case Onto-2: Ontology integration by means of a foundational ontology . . . . .	27
7.3. Use Case Onto-3: Module extraction from large ontologies . . . . .	28
7.4. Use case Onto-4: Interoperability between closed-world data and open-world metadata . . . . .	29
7.5. Use Case Onto-5: Verification of rules translating Dublin Core into PROV . . . . .	30
7.6. Use case Spec-1: Specification Refinements . . . . .	30
7.7. Use case Spec-2: Modularity of Specifications . . . . .	31
7.8. Use case Model-1: Coherent semantics for multi-language models . . . . .	31
7.9. Use case Model-2: Consistency among UML diagrams of different types . . . . .	32
7.10. Use case Model-3: Refinements between UML diagrams of different types, and their reuse . . . . .	32
7.11. Conclusion . . . . .	32
<b>8. Design Overview</b>	<b>34</b>
8.1. Overview of DOL . . . . .	34
8.2. DOL enables expression of logically heterogeneous OMS and literal reuse of existing OMS. . . . .	36
8.3. DOL includes provisions for expressing mappings between OMS. . . . .	36
8.4. DOL enables the representation of OMS and OMS mappings at different levels of detail . . . . .	37
8.5. DOL provides a mechanism for rich annotation and documentation of OMS. . . . .	38
<b>9. DOL abstract syntax</b>	<b>39</b>
9.1. Abstract syntax categories . . . . .	39
9.2. Libraries . . . . .	39
9.3. Focused OMS . . . . .	40
9.4. OMS Mappings . . . . .	43
9.5. Queries . . . . .	45
9.6. Identifiers . . . . .	46
9.6.1. IRIs . . . . .	46
9.6.2. Abbreviating IRIs using CURIEs . . . . .	47
9.6.3. Mapping identifiers in basic OMS to IRIs . . . . .	48
9.7. Annotations . . . . .	50
<b>10. DOL text serialization</b>	<b>51</b>
10.1. Document type . . . . .	51

## Table of Contents

10.2. Concrete Syntax . . . . .	51
10.2.1. Libraries . . . . .	51
10.2.2. Focused OMS . . . . .	52
10.2.3. OMS Mappings . . . . .	54
10.2.4. Queries . . . . .	55
10.3. Identifiers . . . . .	55
10.4. Lexical Symbols . . . . .	56
10.4.1. Key Words and Signs . . . . .	56
10.5. Integration of Serializations of Conforming Languages . . . . .	56
<b>11. DOL semantics</b>	<b>58</b>
11.1. Direct semantics of DOL language constructs . . . . .	61
11.1.1. Semantics of Libraries . . . . .	62
11.1.2. Semantics of focused OMS . . . . .	63
11.1.3. Semantics of OMS Mappings . . . . .	65
11.1.4. Semantics of queries . . . . .	67
11.2. Translational semantics of DOL language constructs . . . . .	67
11.3. Collapsed Semantics of DOL language constructs . . . . .	68
11.4. OMS language translations . . . . .	68
<b>12. Keyword index</b>	<b>69</b>
 <b>Annex</b>	 <b>71</b>
<b>A. Annex (normative): RDF vocabulary for describing OMS languages conforming with DOL</b>	<b>71</b>
<b>B. Annex (normative): Conformance of OWL 2 with DOL</b>	<b>74</b>
<b>C. Annex (normative): Conformance of Common Logic with DOL</b>	<b>76</b>
<b>D. Annex (normative): Conformance of RDF and RDFS with DOL</b>	<b>78</b>
<b>E. Annex (normative): A Core Logic Graph</b>	<b>79</b>
E.1. $EL \rightarrow OWL$ and $\mathcal{EL}++ \rightarrow \mathcal{SROIQ}(D)$ . . . . .	79
E.2. $QL \rightarrow OWL$ and $DL-Lite_R \rightarrow \mathcal{SROIQ}(D)$ . . . . .	79
E.3. $RL \rightarrow OWL$ and $RL \rightarrow \mathcal{SROIQ}(D)$ . . . . .	79
E.4. $SimpleRDF \rightarrow RDF$ . . . . .	80
E.5. $RDF \rightarrow RDFS$ . . . . .	80
E.6. $SimpleRDF \rightarrow \mathcal{SROIQ}(D)$ . . . . .	80
E.7. $OWL \rightarrow FOL$ . . . . .	81
E.7.1. Translation of Signatures . . . . .	81
E.7.2. Translation of Sentences . . . . .	81
E.7.3. Translation of Models . . . . .	82
E.8. $OWL \rightarrow CL$ . . . . .	82
<b>F. Annex (informative): Extended Logic Graph</b>	<b>83</b>



## *Table of Contents*

<b>G. Annex (informative): Example Uses of all DOL Constructs</b>	<b>85</b>
G.1. Mereology: Distributed and Heterogeneous Ontologies . . . . .	86
G.2. Blocks World: Minimization . . . . .	88
G.2.1. Alignments . . . . .	89
G.3. Distributed Description Logics . . . . .	90
G.3.1. Algebra . . . . .	92
<b>H. Annex (informative): Use cases</b>	<b>93</b>
H.1. Generating multilingual labels for menus in a user interface . . . . .	93
H.2. Connecting devices of differing complexity in an Ambient Assisted Living setting	93
H.3. Interpreting the OWL formalization of the DOLCE foundational ontology in	
First-order logic . . . . .	94
H.4. Extending the OWL Time ontology to a more comprehensive coverage of time	95
H.5. Metadata in COLORE (Common Logic Repository) . . . . .	96
H.6. Extending OWL with datatypes defined in CASL . . . . .	96
<b>I. Annex (informative): Annotation Vocabularies</b>	<b>98</b>
<b>J. Annex (informative): Bibliography</b>	<b>99</b>

# Preface

## OMG

Founded in 1989, the Object Management Group, Inc. (OMG) is an open membership, not-for-profit computer industry standards consortium that produces and maintains computer industry specifications for interoperable, portable, and reusable enterprise applications in distributed, heterogeneous environments. Membership includes Information Technology vendors, end users, government agencies, and academia.

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- Business Modeling Specifications
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  - CORBA/IIOP
  - Data Distribution Services
  - Specialized CORBA
- IDL/Language Mapping Specifications
- Modeling and Metadata Specifications
  - UML, MOF, CWM, XMI
  - UML Profile
- Modernization Specifications
- Platform Independent Model (PIM), Platform Specific Model (PSM), Interface Specifications
  - CORBAServices
  - CORBAFacilities

## *Table of Contents*

- OMG Domain Specifications
- CORBA Embedded Intelligence Specifications
- CORBA Security Specifications

All of OMG's formal specifications may be downloaded without charge from our website. (Products implementing OMG specifications are available from individual suppliers.) Copies of specifications, available in PostScript and PDF format, may be obtained from the Specifications Catalog cited above or by contacting the Object Management Group, Inc. at:

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The type styles shown below are used in this document to distinguish programming statements from ordinary English. However, these conventions are not used in tables or section headings where no distinction is necessary.

Times/Times New Roman - 10 pt.: Standard body text

**Helvetica/Arial - 10 pt. Bold:** OMG Interface Definition Language (OMG IDL) and syntax elements.

**Courier - 10 pt. Bold:** Programming language elements.

Helvetica/Arial - 10 pt.: Exceptions

NOTE: Italic text represents names defined in the specification or the name of a document, specification, or other publication.

## **Issues**

The reader is encouraged to report any technical or editing issues/problems with this specification to [http://www.omg.org/report\\_issue.htm](http://www.omg.org/report_issue.htm).

# 0. Submission-Specific Material

## 0.1. Submission Preface

Fraunhofer FOKUS, MITRE, and Thematix Partners LLC are pleased to submit this joint proposal in response to the Ontology, Model and Specification Integration and Interoperability (OntoIOP) RFP (OMG document ad/2013-12-02). The submitter contacts for this submission are:

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- MITRE, Leo Obrst, lobrst@mitre.org
- Thematix Partners LLC, Elisa Kendall, ekendall@thematix.com

Clause 0 of this document contains information specific to the OMG submission process and is not part of the proposed specification. The proposed specification starts with Clause 1 “Scope”.

## 0.2. Mandatory Requirements

ID	RFP requirement	How this proposal addresses requirement
6.5.1(a)	Proposals shall provide a specification of a metalanguage for relationships between the components of logically heterogeneous OSMs, particularly, given a language translation from a language L1 to another language L2, the application of the language translation to an OSM that is written in the language L1.	
6.5.1(b)	Proposals shall provide a specification of a metalanguage for the union of OSMs written in different languages, which implicitly involves the application of suitable default translations in order to reach a common target language.	
6.5.1(c)	Proposals shall provide a specification of a metalanguage for importation in modular OSMs.	

*Continued on next page*

## 0. Submission-Specific Material

Table 0.1 – *Continued from previous page*

ID	RFP requirement	How this proposal addresses requirement
6.5.1(d)	Proposals shall provide a specification of a metalanguage for relationships between OSMs and their extracted modules e.g. the whole theory is a conservative extension of the module.	
6.5.1(e)	Proposals shall provide a specification of a metalanguage for relationships between OSMs and their approximation in less expressive languages such that the approximation is logically implied by the original theory, where the approximation generally has to be maximal in some suitable sense.	
6.5.1(f)	Proposals shall provide a specification of a metalanguage for links such as imports, interpretations, refinements, and alignments between OSMs/modules.	
6.5.1(g)	Proposals shall provide a specification of a metalanguage for combination of OSMs along links.	
6.5.2(a)	The constructs of the metalanguage shall be applicable to different logics.	
6.5.2(b)	The metalanguage shall neither be restricted to OSMs in a specific domain, nor to OSMs represented in a specific logical language.	
6.5.2(c)	The metalanguage shall not replace the object language constructs of the conforming logical languages.	
6.5.2(d)	The metalanguage shall provide syntactic constructs for (i) structuring OSMs regardless of the logic in which their sentences are formalized and (ii) basic and structured OSMs and facilities to identify them in a globally unique way.	
6.5.3(a)	An abstract syntax specified as an SMOF compliant meta model.	
6.5.3(b)	A human-readable lexical concrete syntax in EBNF and serialization in XML, for the latter XMI shall be used.	
6.5.3(c)	Complete round-trip mappings from the human-readable concrete syntax to the abstract syntax and vice versa.	

*Continued on next page*

## 0. Submission-Specific Material

Table 0.1 – *Continued from previous page*

ID	RFP requirement	How this proposal addresses requirement
6.5.3(d)	A formal semantics for the abstract syntax.	
6.5.4(a)	Existing OSMs in existing serializations shall validate as OSMs in the metalanguage with a minimum amount of syntactic adaptation.	
6.5.4(b)	It shall be possible to refer to existing files/documents from an OSM implemented in the metalanguage without the need for modifying these files/documents.	
6.5.4(c)	Translations between logical languages shall preserve (possibly to different degrees) the semantics of the logical languages. Between a given pair of logical languages, several translations are possible.	
6.5.5(a)	Informative annexes shall establish the conformance of a number of relevant logical languages. An initial set of language translations may be part of an informative annex.	
6.5.5(b)	Conformance of the following subset of logical languages shall be established: OWL2 (with profiles EL, RL, QL), CLIF, RDF, UML class diagrams.	
6.5.5(c)	Conformance of a suitable set of translations among the languages mentioned in the previous bullet point shall be established.	
6.5.6	Existing standards and best practices for allocating globally unique identifiers shall be reused. The same standards and best practices shall also be applied to associate different representations of the same content to one unique identifier.	

## 0.3. Optional Requirements

## 0. Submission-Specific Material

ID	RFP requirement	How this proposal addresses requirement
6.6.1	Submissions may include additional languages without a standardized model theory.	
6.6.2	Proposals may provide constructs for non-monotonic logics.	
6.6.3	A characterization of the trade-offs among different translations.	

## 0.4. Issues to be discussed

ID	Discussion item	Resolution
6.7.(a)	Do existing language standards need to be extended or adapted in order to make them OntoIOP conformant.	
6.7.(b)	Proposals should discuss whether the semantics of the metalanguage shall be included into the standard.	
6.7.(c)	Proposals should discuss the chosen list of logics and translations.	
6.7.(d)	Proposals should discuss a meta-ontology of logical languages and theories.	
6.7.(e)	Proposals should discuss the use of QVT for expressing logic translations.	
6.7.(f)	Proposals should discuss a meta-ontology of logical languages and theories.	
6.7.(g)	Proposals should discuss the use of QVT for expressing logic translations.	
6.7.(h)	Proposals should discuss the role of APIs.	
6.7.(i)	Proposals should discuss availability and use of tools.	
6.7.(j)	Proposals should discuss a registry of logical languages.	

## 0.5. Evaluation Criteria

## 0. Submission-Specific Material

ID	Criterion	Comment
6.8(a)	Proposals covering a broader range of features and of use cases will be favored. As a minimum, proposals shall define conformance criteria for logical languages and translations, and their proposed metalanguage shall cover some metalogical relationships and shall be applicable to multiple logics.	
6.8(b)	Proposals covering existing language standards without (or with fewer) modifications will be favored.	Any document providing an OMS in a serialization of a DOL conformant language can be used as-is in DOL, by reference to its IRI. See 10.5.
6.8(c)	Proposals establishing actually (or making this at least possible in theory) OntoIOp conformance of more logical languages and translations will be favored.	We establish conformance of OWL 2 (annex B), Common Logic (annex C), RDF and RDFS (annex D) with DOL.

1

Note(1)

## 0.6. Proof of Concept

## 0.7. Changes to Adopted OMG Specifications

This specification proposes no changes to adopted OMG specifications.

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<sup>1</sup>NOTE: in 6.8(c), also mention at least UML class diagrams



# 1. Scope

This OMG Specification specifies the Distributed Ontology, Modeling and Specification Language (DOL). DOL is designed to achieve integration and interoperability of ontologies, specifications and models (OMS for short). DOL is a language for distributed knowledge representation, system specification and model-driven development across multiple OMS, particularly OMS that have been formalized in different OMS languages. This OMG Specification responds to the OntoIOP Request for Proposals [15].

## 1.1. Background Information

Logical languages are used in several fields of computing for the development of formal, machine-processable texts that carry a formal semantics. Among those fields are 1) **O**ntologies formalizing domain knowledge, 2) (formal) **M**odels of systems, and 3) the formal **S**pecification of systems. Ontologies, models and specifications will (for the purpose of this document) henceforth be abbreviated as **OMS**.

An OMS provides formal descriptions which range in scope from domain knowledge and activities (ontologies, models) to properties and behaviors of hardware and software systems (models, specifications). These formal descriptions can be used for the analysis and verification of domain models, system models and systems themselves, using rigorous and effective reasoning tools. Since these models and systems become increasingly complex, usually a monolithic description is not feasible. **To Do:** Terry: As systems increase in complexity, it becomes concomitantly less practical to provide a logical cover for all. Instead models are developed to represent different viewpoints or perspectives on a domain or system. **Till:** "a logical cover for all" is not the point, the point is a *monolithic* description that is not feasible. Instead, different viewpoints on one domain or system are modeled. Hence, interoperability becomes a crucial issue, in particular, formal interoperability, i.e. interoperability that is based on the formal semantics of the different viewpoints. Interoperability is both about the ability to interface different domains and systems, to enable the use of several OMS in a common application scenario, as well as about coherence and consistency, ensuring at an early stage of the development that a coherent system can be reached.

ToDo

<sup>2</sup> In complex applications, which involve multiple OMS with overlapping concept spaces, data mapping may also be between different OMS, and is then called OMS alignment. While OMS alignment is most commonly studied for OMS formalized in the same OMS language, the different OMS used by complex applications may also be written in different OMS languages, even if they have different levels of expressiveness. This OMG Specification faces this diversity not by proposing yet another OMS language that would subsume all the others. Instead, it accepts the diverse reality and formulates means (on a sound and formal semantic basis) to compare and integrate OMS that are written in different formalisms. It specifies DOL (Distributed Ontology, Modeling and Specification Language), a formal language for expressing not only OMS but also mappings between OMS formalized in different OMS languages.

Note(2)

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<sup>2</sup>NOTE: @Till: the beginning of this paragraph needs revision

## 1. Scope

Thus, DOL gives interoperability a formal grounding and makes heterogeneous OMS and services based on them amenable to checking of coherence (e.g. consistency, conservativity, intended consequences, and compliance).

<sup>3</sup>

Note(3)

## 1.2. Features within Scope

The following are within the scope of this OMG Specification:

1. homogeneous OMS as well as heterogeneous OMS (the combining parts written in different languages)
2. mappings between OMS (mapping OMS symbols to OMS symbols)
3. structured and focused OMS as well as OMS networks (the latter involve several focused OMS and mappings between them)
4. translations between different OMS languages conformant with DOL (translating whole OMS to another language)
5. annotation and documentation of OMS, mappings between OMS, symbols, and sentences
6. recommendations of vocabularies for annotating and documenting OMS
7. a syntax for embedding the constructs mentioned under (1)–(5) as annotations into existing OMS
8. a syntax for expressing (1)–(4) as standoff markup that points into existing OMS
9. a formal semantics of (1)–(4)
10. criteria for existing or future OMS languages to conform with DOL

Ⓔ The following are outside the scope of this OMG Specification:

1. the (re)definition of elementary OMS languages, i.e. languages that allow the declaration of OMS symbols (non-logical symbols) and stating sentences about them
2. algorithms for obtaining mappings between OMS
3. concrete OMS and their conceptualization and application
4. mappings between services and devices, and definitions of service and device interoperability.

This OMG Specification describes the syntax and the semantics of the Distributed Ontology, Modeling and Specification Language (DOL) by defining an abstract syntax and an associated model-theoretic semantics for DOL.

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<sup>3</sup>NOTE: State somewhere: A DOL theory is at level M1 in MDA speak, the same level as an UML diagram. Also a DOL OMS network, containing interpretations, alignments between OMS etc. is at level M1. The specification of DOL lives at M2, like the UML specification. Both are written in MOF.

## 2. Conformance

This clause defines conformance criteria for languages and logics that can be used with the distributed ontology, modeling and specification language DOL, as well as conformance criteria for serializations, translations and applications. This OMG Specification describes the conformance with DOL of a number of OMS languages, namely OWL 2, Common Logic, RDF and RDFS, as well as translations among these, in its informative annexes.

It is expected that DOL will be used for more languages than this normative set of DOL-conformant languages. There will be a **registry for DOL-conformant languages and translations** hosted at <http://ontohub.org>. This will ensure that this OMG Specification remains interoperable with past, present and even future OMS languages. The registry shall also include descriptions of DOL-conformant languages and translations (as well as other information needed by implementors and users) in machine-processable form.

There will be Maintenance Authority (MA)<sup>1</sup> established to maintain the registry as an informative resource governed by the standard. The registry contents itself will not be normative; however, it is expected to become the basis for normative activities.

### 2.1. Conformance of an OMS language/a logic with DOL

Rationale: for an OMS language to conform with DOL,

- its logical language aspect either needs to satisfy certain criteria about its abstract syntax or formal semantics itself, or there must be a translation (again satisfying certain criteria) to a language that already is DOL-conforming.
- its structuring language aspect (if present) must not conflict with DOL's own structuring mechanisms
- its annotation language aspect must not conflict with DOL's meta-language constructs.

We also define different conformance levels with respect to the usage of IRIs as identifiers for all kinds of entities that the OMS language supports.

An OMS language is conformant with DOL if it satisfies the following conditions:

1. its abstract syntax is specified as an SMOF compliant meta model or as an EBNF grammar;
2. its logical language aspect (for expressing basic OMS) is conformant, and in particular has a semantics (see below),
3. it has at least one serialization in the sense of section 2.2;
4. either there exists a translation of it into a conformant language<sup>2</sup>, or:

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<sup>1</sup>or, depending on advisability, a Registration Authority

<sup>2</sup>For example, consider the translation of OBO1.4 to OWL, giving a formal semantics to OBO1.4.

## 2. Conformance

- a) the logical language aspect (for expressing basic OMS) is conformant, and in particular has a semantics (see below),
- b) the structuring language aspect (for expressing structured OMS and relations between those) is conformant (see below), and
- c) the annotation language aspect (for expressing comments and annotations) is conformant (see below).

The *logical language aspect* of an OMS language is conformant with DOL if each logic corresponding to a profile (including the logic corresponding to the whole logical language aspect) is presented as an institution [10].<sup>3</sup> Note that one OMS language can have several sublanguages or profiles corresponding to several logics (for example, OWL 2 has profiles EL, RL and QL, apart from the whole OWL 2 itself).

The *structuring language aspect* of an OMS language is conformant with DOL if it can be mapped to DOL's structuring language in a semantics-preserving way. The structuring language aspect **may** be empty.

The *annotation language aspect* of an OMS language is conformant with DOL if its constructs have no impact on the semantics. The annotation language aspect **shall** be non-empty; it **shall** provide the facility to express comments.

We define the following levels of conformance of the abstract syntax of a basic OMS language with DOL, listed from highest to lowest:

**Full IRI conformance** The abstract syntax enforces that IRIs be used for identifying all symbols and entities.

**No mandatory use of IRIs** The abstract syntax does not enforce that IRIs be used for identifying all entities. Note that this includes the case of optionally supporting IRIs without enforcing their use (such as in Common Logic).

Any conforming language and logic shall have a machine-processable description as detailed in clause 2.3.

### 2.1.1. Conformance of language/logic translations with DOL

Rationale: a translation between logics must satisfy certain criteria in order to conform with DOL. Also, a translation between OMS languages based on such logics must be consistent with the translation between these logics. Translations should not break structuring language aspects nor comments/annotations either.

A logic translation is conformant with DOL if it is presented either as an institution morphism or as an institution comorphism.

A language translation is conformant with DOL if it is a mapping between the abstract syntaxes that restricts to a conformant logic translation when restricted to the logical language aspect. Language translations **may** also translate the structuring language aspect, in this case, they **shall** preserve the semantics of the structuring language aspect. Furthermore, language translations **should** preserve comments and annotations. All comments attached to a sentence (or symbol) in the source **should** be attached to its translation in the target (if there are more than one sentences (resp. symbols) expressing the translation, to at least one of them).

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<sup>3</sup>Institutions are necessarily monotonic; conformance criteria for non-monotonic logics are still under development. However, minimization provides non-monotonic reasoning in DOL. A further possibility to include non-monotonic logics is to construe entailments between formulas as sentences of the institution.

## 2. Conformance

A logic translation **may** use infrastructure theories to axiomatize a fragment of the syntax of the source logic into the target logic <sup>4</sup>. For example, the built-in types of an OWL signature are axiomatized as datatypes in first-order logic.

### 2.2. Conformance of a serialization of an OMS language with DOL

Rationale: The main reason for the following specifications is identifier injection. DOL is capable of assigning identifiers to entities (symbols, axioms, modules, etc.) inside fragments of OMS languages that occur in a DOL document, even if that OMS language doesn't support such identifiers by its own means. Such identifiers will be visible to a DOL tool, but not to a tool that only supports the OMS language. To achieve this without breaking the formal semantics of that OMS language, we make use of annotation or commenting features that the OMS language supports, in order to place such identifiers inside annotations/ comments. Depending on the nature of the concrete given serialization of the OMS language, be it plain text, some serialization of RDF, XML, or some other structured text format, we can be more specific about what the annotation/commenting facilities of that serialization must look like in order to support this identifier injection. Well-behaved XML and RDF schemas support identifier injection in a 'nice' way (rather than using text-level comments). In the worst case we cannot inject anything into an OMS language fragment, because the OMS language serialization simply wouldn't allow us to write suitable comments, but we'd have to point into it from the outer space by using standoff markup.

Further conformance criteria in this section are introduced to facilitate the convenient reuse of verbatim fragments of OMS language inside a DOL document.

Independently from these criteria, we distinguish different levels of conformance of a serialization with respect to its means of conveniently abbreviating long IRI identifiers.

We define four levels of conformance of a serialization of an OMS language with DOL.

**XMI conformance** An XMI serialization has been automatically derived from the SMOF specification of the abstract syntax, using MOF 2 XMI Mapping.<sup>4</sup>

Note(4)

**XML conformance** The given serialization has to be specified as an XML schema, which satisfies all of the following conditions:

- The elements of the schema belong to one or more non-empty XML namespaces.<sup>5</sup>
- The schema shall not forbid attributes from foreign namespaces (here: the DOL namespace) on any elements<sup>6,7</sup>

Note(5)

Note(6)

**RDF conformance** The given serialization has to be specified as an RDF vocabulary, which satisfies all of the following conditions:

Note(7)

<sup>4</sup>Such a translation is formally represented as a theoroidal institution comorphism.

<sup>4</sup>NOTE: Christoph to all: I'm not sure how MOF and XMI works, i.e. how to inject identifiers into comments there.

<sup>5</sup>NOTE: FYI: That means that in a heterogeneous OMS we can recognize that a sentence is, e.g., stated in OWL, without explicitly "tagging" it as "OWL" (which we would have to do in the case of a serialization that is merely text conformant).

<sup>6</sup>NOTE: Christoph (2014-03-26): the rationale is that in an XML serialization we wouldn't want to inject identifiers into completely unstructured XML comments (<!-- ... -->) but rather into well-structured attributes from some DOL namespace to-be-defined (think of <axiom dol:id="foo-ax">)

<sup>7</sup>NOTE: Maybe we also need child elements from different namespaces?

## 2. Conformance

- The elements of the vocabulary belong to one or more RDF namespaces identified by absolute URIs.
- The serialization shall specify ways of giving IRIs or URIs to all structural elements of an OMS.<sup>8 5 9</sup>
- There shall be no additional rules that forbid properties from foreign namespaces (here in particular: the annotation vocabularies recommended by DOL<sup>10</sup>) to be stated about arbitrary subjects.<sup>11</sup>

Note(8)

Note(9)

Note(10)

Note(11)

**Text conformance** The given serialization has to satisfy all of the following conditions:

- The serialization conforms with the requirements for the *text/plain* media type specified in IETF/RFC 2046, section 4.1.3.
- The serialization shall provide a designated comment construct that can be placed sufficiently flexible as to be uniquely associated with any non-comment construct of the language. That means, for example, one of the following:
  - The serialization provides a construct that indicates the start and end of a comment and may be placed before/after each token that represents a structural element of an OMS.
  - The serialization provides line-based comments (ranging from an indicated position to the end of a line) but at the same time allows the flexible placement of line breaks before/after each token that represents a structural element of an OMS.

**Standoff markup conformance** An OMS language is standoff markup conformant with DOL if one of its serializations conforms with the requirements for the *text/plain* media type specified in IETF/RFC 2046, section 4.1.3. Note that conformance with *text/plain* is a prerequisite for using, for example, fragment URIs in the style of IETF/RFC 5147 for identifying text ranges.

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<sup>8</sup>NOTE: Christoph (2014-03-26): The rationale is that RDF in principle allows for identifying everything, so an RDF-based serialization of an OMS language should not forbid making use of such RDF constructs that do allow for identifying arbitrary things.

<sup>5</sup>The OWL RDF serialization, for example, does not satisfy the RDF conformance level, for the following reason. There is an `owl:imports` property but no class representing imports. Therefore, it is not possible to represent a concrete import, of an ontology  $O_1$  importing an ontology  $O_2$ , as a resource, which could have an identifier. RDF reification would allow for giving the statement  $O_1$  `owl:imports`  $O_2$  an identifier. However, the RDF triples resulting from this reification, including, e.g., the triple `:import_id rdf:predicate owl:imports`, would not match the head of any rule in the mapping from RDF graphs to the OWL structural specification [http://www.w3.org/TR/2012/REC-owl2-mapping-to-rdf-20121211/#Mapping\\_from\\_RDF\\_Graphs\\_to\\_the\\_Structural\\_Specification](http://www.w3.org/TR/2012/REC-owl2-mapping-to-rdf-20121211/#Mapping_from_RDF_Graphs_to_the_Structural_Specification)). They would thus remain left over in the RDF graph that is attempted to be parsed into an OWL ontology, and thus violate the requirement that at the end of this parsing process, the RDF graph must be empty.

<sup>9</sup>NOTE: Q-AUT: Update on 2014-10-09: Is it OK to have this footnote here? Or if not, where should it go? I believe it answers the following question:

And what if it doesn't? e.g. OWL doesn't specify IRIs for import declarations, so we can, e.g., not annotate them when using the RDF serialization of OWL. We could only do it via RDF reification, or by using an XML serialization.

<sup>10</sup>NOTE: Christoph (2014-03-26): I think we are no longer explicitly recommending annotation vocabularies such as OMV, but nevertheless an RDF serialization of an OMS language must allow annotations to things, using RDF properties that do not belong to the RDF vocabulary of the OMS language. It should treat them like OWL treats annotation properties, i.e. as not changing the formal semantics.

<sup>11</sup>NOTE: FYI: No well-behaved RDF vocabulary would do so, but we'd better be safe.

## 2. Conformance

12

Note(12)

Independently from the conformance levels given above, there is the following hierarchy of conformance w.r.t. CURIEs (compact URIs) as a means of abbreviating IRIs, listed from highest to lowest:

**Prefixed CURIE conformance** The given serialization allows non-logical symbol identifiers to have the syntactic form of a CURIE, or any subset of the CURIE grammar that allows named prefixes (`prefix:reference`). The serialization is **not required** to support CURIEs with no prefix.

Informative comment: In this case, a prefix map with multiple prefixes **may** be used to map the non-logical symbol identifiers of a basic OMS to IRIs in multiple namespaces (cf. clause 9.6.3)

**Non-prefixed names only** The given serialization only supports CURIEs with no prefix, or any subset of the grammar of the `REFERENCE` nonterminal in the CURIE grammar.

Informative comment: In this case, a binding for the empty prefix **has to** be declared, as this is the only possibility of mapping the identifiers of the basic OMS to IRIs, which are located in one flat namespace.

CURIEs that have a prefix may not be acceptable identifiers in every serialization of a basic OMS language, as the standard CURIE separator character, the colon (:), may not be allowed in identifiers.<sup>13</sup> Therefore, the declaration of DOL-conformance of the respective serialization (cf. clause 2.2) **may** define an *alternative CURIE separator character*, or it **may** forbid the use of prefixed CURIEs altogether.

Note(13)

Any conforming serialization of an OMS language shall have a machine-processable description as detailed in clause 2.3.

### 2.3. Machine-processable description of conforming languages, logics, and serializations

Rationale: When a parser processes a DOL OMS found somewhere, which refers to modules in OMS languages, or includes them verbatim, the parser needs to know what language to expect; further DOL-supporting software needs to know, e.g., what other DOL-conforming languages the module in the given OMS language can be translated to. Therefore we require that all languages/logics/serializations that conform with DOL describe themselves in a machine-comprehensible way.

For any conforming OMS language, logic, and serialization of an OMS language, it is required that it be assigned an HTTP IRI, by which it can be identified. It is also required that a machine-processable description of this language/logic/serialization be retrievable by dereferencing this IRI, according to the linked data principles. At least there has to be an RDF description in terms of the vocabulary specified in annex A, which has to be made available in the RDF/XML serialization when a client requests content of the MIME type *application/rdf+xml*. Descriptions of the language/logic/serialization in further representations, having different content types, may be provided.<sup>14</sup>

Note(14)

<sup>12</sup>NOTE: FYI: The latter two seem trivial, but we need them to rule out ad hoc diagrams drawn on a napkin

<sup>13</sup>NOTE: Q-ALL: I recall that in the 2012-04-18 teleconference we agreed on this – but does it really make sense? Are there any relevant OMS language serializations that do not allow : in identifiers (or that do allow it theoretically but discourage it in practice) but allow some other non-letter character?

<sup>14</sup>NOTE: FYI: that opens the door for, e.g., OMDoc

## 2.4. Conformance of a document with DOL

Rationale: for exchanging DOL documents with other users/tools, nothing that has a formal semantics must be left implicit. One DOL tool may assume that by default any OMS fragments inside a DOL document are in some fixed OMS language unless specified otherwise, but another DOL tool can't be assumed to understand such DOL documents. Defaults are, however, practically convenient, which is the reason for having the following section about the conformance of an *application*.

A document conforms with DOL if it contains a DOL text that is well-formed according to the grammar. That means, in particular, that any information related to logics has to be made explicit (as foreseen by the DOL abstract syntax specified in clause 9), such as:

- the logic of each OMS that is part of the DOL document,
- the translation that is employed between two logics (unless it is one of the default translations specified in annex E)

However, details about aspects of an OMS that do not have a formal, logic-based semantics, may be left implicit. For example, a conforming document may omit explicit references to matching algorithms that have been employed in obtaining an alignment.

## 2.5. Conformance of an application with DOL

In practice, DOL-aware *applications* may also deal with documents that are not conforming with DOL according to the criteria established in clause 2.4. However, an application only *conforms* with DOL if it is capable of producing DOL-conforming documents as its output when requested.

We expect most DOL-aware applications to support a fixed (possibly extensible) set of OMS languages conforming with DOL. It is, for example, possible that a DOL-aware application only supports OWL and Common Logic. In that case, the application may process documents that mix OWL and Common Logic ontologies *without* explicitly declaring the respective logics, as the respective syntaxes of OWL and Common Logic can be distinguished by examining the different keywords. However, for DOL conformance, that application has to be capable of exporting documents with explicit references to the logics used.

<sup>15</sup>

Note(15)

<sup>16</sup>

Note(16)

<sup>15</sup>NOTE: applications need to strip DOL annotations from embedded fragments in other OMS languages

<sup>16</sup>NOTE: applications need to be able to expand CURIes into IRIs when requested



## 3. Normative References

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14. W3C/TR REC-rdf-schema:2004RDF Vocabulary Description Language 1.0: RDF Schema. W3C Recommendation, 10 February 2004. <http://www.w3.org/TR/2004/REC-rdf-schema-20040210/>
15. W3C/TR REC-rdf-mt:2004RDF Semantics. W3C Recommendation, 02 February 2004. <http://www.w3.org/TR/2004/REC-rdf-mt-20040210/>

17 18 19

Note(17)

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<sup>17</sup>NOTE: more, see RFP

Note(18)

<sup>18</sup>NOTE: introduce a separate reference scheme for normative references

<sup>19</sup>NOTE: Q-ALL: I have listed them roughly in the order of occurrence: OK?

Note(19)

## 4. Terms and Definitions

20

Note(20)

For the purposes of this document, the following terms and definitions apply.

### 4.1. Distributed Ontology, Modeling and Specification Language

**distributed ontology, modeling and specification language; DOL** language for formalizing *libraries* of *focused OMS* and *OMS networks*, whose syntax and semantics are specified in this OMG Specification

**NOTE** When viewed as an *OMS language*, DOL has *OMS* as its *non-logical symbols*, and *OMS mappings* as its *sentences*.

**library** collection of named *focused OMS* and *OMS networks*, possibly written in different *OMS languages*, linked by named *OMS mappings*

### 4.2. OMS

**OMS (ontology, specification or model)** collection of expressions (like *non-logical symbols*, *sentences* and *structuring elements*) in a given *OMS language* (or several such languages).

**NOTE** An *OMS* can be written in different *OMS language serializations*.

**OMS language** language equipped with a formal, declarative, logic-based semantics, plus non-logical *annotations*

**NOTE** An OMS language is used for the formal specification of *OMS*.

**EXAMPLE** OMS languages include OWL, Common Logic, F-logic, UML class diagrams, RDFS, and OBO.

**non-logical symbol; OMS symbol** atomic expression or syntactic constituent of an *OMS* that requires an interpretation through a *model*

**NOTE** This differs from the notion of “atomic sentence”: such sentences may involve several non-logical symbols.

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<sup>20</sup>**NOTE:** OMG specifications shall not contain glossaries, hence always refer to this section if definitions of terms are needed.

#### 4. Terms and Definitions

EXAMPLE Non-logical symbols in OWL W3C/TR REC-owl2-syntax:2009 (there called “entities”) comprise

- individuals (denoting objects from the domain of discourse),
- classes (denoting sets of objects; also called concepts), and
- properties (denoting binary relations over objects; also called roles).

This is opposed to logical symbols in OWL, e.g. those for intersection and union of classes.

EXAMPLE Non-logical symbols in Common Logic ISO/IEC 24707:2007 comprise

- names (denoting objects from the domain of discourse),
- sequence markers (denoting sequences of objects).

This is opposed to logical symbols in Common Logic, e.g. logical connectives and quantifiers.

**vocabulary; signature** set (or otherwise structured entity) <sup>21</sup> of *non-logical symbols* of an *OMS* Note(21)

NOTE The signature of a term is the set of all non-logical symbols occurring in the *term*. The signature of an *OMS language* is the set of all non-logical symbols possible in that language.

NOTE The signature of an OMS is usually uniquely determined.

**model** semantic interpretation of all *non-logical symbols* of a *signature*

NOTE A model of an OMS is a model of the signature of the OMS that moreover *satisfies* all the *axioms* of the OMS.

NOTE This term is not to be confused with model in the sense of modeling (i.e., the “M” in OMS).

**term** syntactic expression either consisting of a single *non-logical symbol* or recursively composed of other terms (a.k.a. its subterms)

**sentence** term that is either true or false in a given *model*, i.e. which is assigned a truth value in this *model*.<sup>22</sup>

Note(22)

NOTE In a *model*, on the one hand, a sentence is always true or false. In an *OMS*, on the other hand, a sentence can have several logical statuses: it can be an axiom, if postulated to be true; a theorem, if proven from other axioms and theorems; a conjecture, if expecting to be proven from other axioms and theorems; or have another of many possible statuses.

NOTE A sentence can conform to one or more signatures (namely those signatures containing all non-logical symbols used in the sentence).

NOTE It is quite common that sentences are required to be closed (i.e. have no free variables). However, this depends on the OMS language at hand.

**axiom** *sentence* postulated to be valid (i.e. true in every *model*)

**theorem** *sentence* that has been proven from other *axioms* and *theorems*

<sup>21</sup>NOTE: What about 'collection'? Structure is not important here.

<sup>22</sup>NOTE: FYI: From Common Logic, I changed “unit of logical text” to “term”.

## 4. Terms and Definitions

**satisfaction relation** relation between models and sentences indicating which sentences hold true in the model

**logical theory** *signature equipped with a set of sentences over the signature*

**entailment; specialization** relation between two OMS expressing that the second one is logically implied by the first one

NOTE The converse is generalization.

**query language** *OMS language specifically dedicated to queries*

EXAMPLE SPARQL, Prolog

NOTE There are also general purpose OMS languages, which can express both OMS and queries.

**query** sentence containing query variables that can be instantiated by a substitution

**query variable** symbol that will be used in a query and a substitution

NOTE From an abstract point of view, query variables are just symbols; they are used in a way that they will be substituted using a substitution. Many OMS languages have special notations for (query) variables.

NOTE Usually, query variables are the free variables of a sentence; there «««< Local Changes can be other (bou===== can be other (bound) variables.

NOTE If there are no variables in an OMS language, constants can be used as query variables.

**substitution** logical OMS mapping that maps query variables of one OMS to complex terms of another OMS

**answer substitution** substitution that, when applied to a given query, turns the latter into a logical consequence of a given OMS <sup>23</sup>

Note(23)

### 4.3. Semantic Web

**resourceweb** something that can be globally identified

NOTE IETF/RFC 3986:2005, Section 1.1 deliberately defines a resource as “in a general sense [...] whatever might be identified by [an IRI]”. The original source refers to URIs, but DOL uses the compatible IRI standard IETF/RFC 3987:2005 for identification.

EXAMPLE Familiar examples include an electronic document, an image, a source of information with a consistent purpose (e.g., “today’s weather report for Los Angeles”), a service (e.g., an HTTP-to-SMS gateway), and a collection of other resources. A resource is not necessarily accessible via the Internet; e.g., human beings, corporations, and bound books in a library can also be resources. Likewise, abstract concepts can be resources, such as the operators and

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<sup>23</sup>NOTE: we have to revisit this once we design the abstract syntax of queries etc.

#### 4. Terms and Definitions

operands of a mathematical equation, the types of a relationship (e.g., “parent” or “employee”), or numeric values (e.g., zero, one, and infinity). IETF/RFC 3986:2005, Section 1.1

**element (of an OMS)** any *resource* in an *OMS* (e.g. a *non-logical symbol*, a *sentence*, a *correspondence*, the *OMS* itself, ...) or a named set of such *resources*.

**linked data** structured data that is published on the Web in a machine-processable way, according to principles specified in [28, 5]

NOTE The linked data principles (adapted from [28] and its paraphrase at [42]) are the following:

1. Use IRIs as names for things.
2. Use HTTP IRIs so that these things can be referred to and looked up (“dereferenced”) by people and user agents.<sup>1</sup>
3. Provide useful machine-processable (plus optionally human-readable) information about the thing when its IRI is dereferenced, using standard formats.
4. Include links to other, related IRIs in the exposed data to improve discovery of other related information on the Web.

NOTE RDF, serialized as RDF/XML [19], is the most common format for publishing linked data. However, its usage is not mandatory.

NOTE Using HTTP content negotiation [14] it is possible to serve representations in different formats from the same URL.

### 4.4. OMS Annotation and Documentation

**annotation** additional information without a logical semantics that is attached to an *element* of an *OMS*

NOTE Formally, an annotation is given as a (subject, predicate, object) triple as defined by SOURCE: W3C/TR REC-rdf-concepts:2004, Section 6. The subject of an annotation is an *element* of an OMS. The predicate is an RDF property defined in an external OMS and describes in what way the annotation object is related to the annotation subject.

NOTE According to note 4.4 it is possible to interpret annotations under an RDF semantics. “Without a logical semantics” in this definition means that annotations to an OMS are not considered sentences of that OMS.

**OMS documentation** set of all *annotations* to an *OMS*, plus any other documents and explanatory comments generated during the entire OMS building process

NOTE Adapted from [39]

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<sup>1</sup>I.e., the IRI is treated as a URL (uniform resource locator).

## 4.5. Structured OMS

**basic OMS, flat OMS** *signature* equipped with a set of *sentences* and *annotations*, which may be used as a building block for a larger *OMS*

NOTE The sentences must use only those non-logical symbols that are present in the signature.

**structured OMS** *OMS* that results from other (basic and structured) *OMS* by *import*, *union*, *combination*, *renaming* or other structuring operations

**focused OMS** *OMS* that has a single *signature* and model class (or *logical theory*) over that signature as its semantics

NOTE A focused *OMS* is either a basic or structured *OMS*.

NOTE The term “focused *OMS*” emphasizes the fact that the *OMS*, while possibly involving many *OMS* as parts, has a single resulting *logical theory*. This is in contrast to *OMS network*, which do not have such a unique result, but rather comprise a network of *OMS* and *mappings*. See [36].

**flattenable OMS** *OMS* that can be seen, by purely syntactical means, to be logically equivalent to a flat *OMS*

NOTE More precisely, an *OMS* is flattenable if and only if it is either a basic *OMS* or it is an *extension*, *union*, translation, *module extraction*, *approximation*, *filtering*, or reference of named *OMS* involving only flattenable *OMS*.

**elusive OMS** *OMS* that is not flattenable

**subOMS** *OMS* whose sets of *non-logical symbols* and *sentences* are subsets of those present in a given larger *OMS*

**extension** *OMS* whose sets of *non-logical symbols* and *sentences* are supersets of those present in a given smaller *OMS*

**extension mapping** inclusion *mapping* between two *OMS* where the sets of *non-logical symbols* and *sentences* of the second *OMS* are supersets of those present in the first *OMS*

NOTE The second *OMS* is said to extend the first, and is an extension of the first *OMS*.

**consequence-theoretic conservative extension** *extension* that does not add new *theorems* (in terms of the unextended *signature*)

NOTE An extension  $O_2$  of an *OMS*  $O_1$  is a consequence-theoretic conservative extension, if all properties formulated in the signature of  $O_1$  hold for  $O_1$  whenever they hold for  $O_2$ .

#### 4. Terms and Definitions

**model-theoretic conservative extension** *extension* that does not lead to a restriction of class of *models* of an *OMS*

NOTE An extension  $O_2$  of an *OMS*  $O_1$  is a model-theoretic conservative extension, if all properties formulated in the signature of  $O_1$  hold for  $O_1$  whenever they hold for  $O_2$ .

NOTE Any model-theoretic conservative extension is also a consequence-theoretic one.

**conservative extension** *consequence-theoretic* or *model-theoretic conservative extension*

NOTE If used without qualification, the consequence-theoretic version is meant.

**monomorphic extension** *extension* whose newly introduced *non-logical symbols* are interpreted in a way unique up to isomorphism

NOTE An extension  $O_2$  of an *OMS*  $O_1$  is a monomorphic extension, if each model of  $O_1$  can be expanded to a model of  $O_2$  that is unique up to isomorphism.

NOTE Each monomorphic extension is also a model-theoretic conservative extension but not vice versa.

**definitional extension** *extension* whose newly introduced *non-logical symbols* are interpreted in a unique way

NOTE An extension  $O_2$  of an *OMS*  $O_1$  is a definitional extension, if each model of  $O_1$  can be uniquely expanded to a model of  $O_2$ .

NOTE  $O_2$  being a definitional extension of  $O_1$  implies a bijective correspondence between the classes of models of  $O_2$  and  $O_1$ .

NOTE Each definitional extension is also a monomorphic extension but not vice versa.

**weak definitional extension** *extension* whose newly introduced *non-logical symbols* can be interpreted in at most one way

NOTE An extension  $O_2$  of an *OMS*  $O_1$  is a weak definitional extension, if each model of  $O_1$  can be expanded to at most one model of  $O_2$ .

NOTE An extension is definitional if and only if it is both weakly definitional and model-theoretically conservative.

**implied extension** *model-theoretic conservative extension* that does not introduce new *non-logical symbols*

NOTE A conservative extension  $O_2$  of an *OMS*  $O_1$  is an implied extension, if and only if the signature of  $O_2$  is the signature of  $O_1$ .  $O_2$  is an implied extension of  $O_1$  if and only if the model class of  $O_2$  is the model class of  $O_1$ .

NOTE Each implied extension is also a definitional extension but not vice versa.

**module** *subOMS* that *conservatively extends* to the whole *OMS*

NOTE The conservative extension can be either model-theoretic or consequence-theoretic; without qualification, the consequence-theoretic version is used. <sup>24</sup>

Note(24)

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<sup>24</sup>NOTE: this is about coverage only. Should we also care about safety?

## 4. Terms and Definitions

**module extraction** activity of obtaining from an *OMS* concrete *modules* to be used for a particular purpose (e.g. to contain a particular sub-*signature* of the original *OMS*)

NOTE Cited and slightly adapted from [39]

NOTE The goal of module extraction is “decomposing an *OMS* into smaller, more manageable modules with appropriate dependencies” [38]

EXAMPLE Consider an OWL DL ontology about wines, from which we would like to extract a module about white wines. That module would contain the declaration of the non-logical symbol “white wine”, all declarations of non-logical symbols related to “white wine”, and all sentences about all of these non-logical symbols.

**approximant** approximation (in the sense of a logically implied theory, possibly after suitable translation) of an *OMS* in a smaller *signature* or *OMS language*

**maximum approximant** best possible (in the sense of a maximum set of logical consequences) *approximant* of an *OMS* in a smaller *signature* or *OMS language*

NOTE Technically, a maximum approximant is a uniform interpolant, see [31].

**closed world assumption** presumption that what is not known to be true, is false

**minimization; circumscription** way of implementing the *closed world assumption* by restricting the *models* to those that are minimal

NOTE See [33], [29].

## 4.6. Mappings Between OMS

**OMS mapping ; linkOMS** relationship between two *OMS*

**logical OMS mapping** *OMS mapping* that has a formal, logic-based semantics

NOTE Logical OMS mappings are given as sets of *symbol map items*, which generate *signature morphisms*.

NOTE Some specific kinds of logical OMS mappings will be introduced below.

**symbol map item** pair of symbols of two *OMS*, indicating how a symbol from the first *OMS* is mapped by a signature morphism to a symbol of the second *OMS*

NOTE A symbol map item is given as  $s_1 \mapsto s_2$ , where  $s_1$  is a symbol from the *source* *OMS* and  $s_2$  is a symbol from the *target* source of the *OMS* mapping.

**interpretation; view; refinement** *logical OMS mapping* that postulates a specialization relation between two *OMS* along a morphism between their signatures

NOTE An interpretation typically leads to proof obligations, i.e. one has to prove that translations of axioms of the source *OMS* along the morphism accompanying the interpretation are theorems in the target *OMS*.



#### 4. Terms and Definitions

NOTE When an interpretation is given as a set of correspondences, these are given as tuples, where the type of relationship is given by the specific kind of interpretation.<sup>25</sup>

Note(25)

**equivalence** *logical OMS mapping* ensuring that two *OMS* share the same definable concepts

NOTE Two *OMS* are equivalent if they have a common definitional extension. The *OMS* may be written in different *OMS* languages.

**interface signature** *signature* mediating between an *OMS* and a *module* of that *OMS* in the sense that it contains those *non-logical symbols* that the *sentences* of the *module* and the *sentences* of the *OMS* have in common

NOTE Adapted from [13]

**module relation** *logical OMS mapping* stating that one *OMS* is a *module* of the other one.

**import** *logical OMS mapping* between two *OMS* such that one *OMS* behaves as if it were included into the other

NOTE Semantically, an import of  $O_2$  into  $O_1$  is equivalent to the verbatim inclusion of  $O_2$  in place of the import declaration

NOTE The purpose of  $O_2$  importing  $O_1$  is to make non-logical symbols and sentences of  $O_1$  available in  $O_2$ .

NOTE Importing  $O_1$  into  $O_2$  turns  $O_2$  into an extension of  $O_1$ .

NOTE An owl:import in OWL is an import.

**renaming** assignment of new names to some *non-logical symbols* of an *OMS*

NOTE A renaming results in a *logical OMS mapping* between the original and the renamed *OMS*.

**reduction** *logical OMS mapping* reducing an *OMS* to a smaller *signature*

**alignment** flexible *OMS mapping* expressing a collection of semantic relations between entities of the two *OMS*

NOTE Alignments consist of *correspondences*, each of which may have a confidence value. If all confidence values are 1, the alignment can be given a formal, logic-based semantics.

**correspondence** relationship between an *non-logical symbol*  $e_1$  from an *OMS*  $O_1$  and an *non-logical symbol*  $e_2$  from an *OMS*  $O_2$ , or between an *non-logical symbol*  $e_1$  from  $O_1$  and a *term*  $t_2$  formed from *non-logical symbols* from  $O_2$

NOTE A correspondence is given as a quadruple  $(e_1, R, \left\{ \begin{smallmatrix} e_2 \\ t_2 \end{smallmatrix} \right\}, c)$ , where  $R$  denotes the type of relationship that is asserted to hold between the two non-logical symbols/terms, and  $0 \leq c \leq 1$  is a confidence value.  $R$  and  $c$  may be omitted: When  $R$  is omitted, it is implied from the context as being the equivalence relation, unless another default relation has been explicitly specified; when  $c$  is omitted, it defaults to 1.

---

<sup>25</sup>NOTE: I don't understand this sentence.

## 4. Terms and Definitions

**NOTE** A confidence value of 1 does not imply logical equivalence (cf. [27] for a worked-out example).

**matching** algorithmic procedure that generates an *alignment* for two given *OMS*

**NOTE** For both matching and alignment, see [9, 25].

**union** aggregation of several *OMS* to a new *OMS*, without any renaming<sup>26</sup>

Note(26)

**OMS network; distributed OMS; hyperontology** graph with *OMS* as nodes and *OMS mappings* as edges, showing how the *OMS* are interlinked<sup>27</sup>

Note(27)

**NOTE** The opposite of an *OMS network* is a *focused OMS*, which focuses on the specification of a single *logical theory*.

**NOTE** An *OMS network* is a diagram of *OMS* in the sense of category theory, but different from a diagram in the sense of model-driven architecture.

**NOTE** The links between the nodes of a distributed *OMS* can be given using interpretations or alignments. Imports between the nodes of a distributed *OMS* are automatically included in the distributed *OMS*. By including an interpretation or an alignment in a distributed *OMS*, the involved nodes are automatically included.

**EXAMPLE** Consider two ontologies and an *interpretation* between them. In the distributed *OMS* of the interpretation there are two nodes, one for each ontology, and one edge from the source ontology to the target ontology of the interpretation.

**combination** aggregation of all the *OMS* in an *OMS network*, where *non-logical symbols* are shared according to the *OMS mappings* in the *OMS network*

**EXAMPLE** Consider an ontology involving a concept *Person*, and another one involving *Human being*, and an *alignment* that relates these to concepts. In the combination of the ontologies along the alignment, there is only one concept, representing both *Person* and *Human being*.

**sharing** property of *OMS symbols* being mapped to the same symbol when computing a *combination* of an *OMS network*

**NOTE** Sharing is always relative to a given *OMS network* that relates different *OMS*. That is, two given *OMS symbols* can share with respect to one *OMS network*, and not share with respect to some other *OMS network*.

## 4.7. Features of OMS Languages

**OMS language translation** mapping from constructs in the source *OMS language* to their equivalents in the target *OMS language*

**NOTE** An *OMS language translation* shall satisfy the property that the result of a translation is a well-formed text in the target language.

---

<sup>26</sup>NOTE: why is this here?

<sup>27</sup>NOTE: Is “hyperontology” a synonym for “OMS network”, or rather for “heterogeneous OMS”?

#### 4. Terms and Definitions

**OMS language graph** graph of *OMS languages* and *OMS language translations*, typically used in a *heterogeneous environment*

**NOTE** In an OMS language graph, some of the OMS language translations can be marked to be *default translations*.

**default translation** specially marked *OMS language translation* or *logic translation* that will be used whenever a translation is needed and no explicit translation is given

**heterogeneous environment** environment for the expression of homogeneous and *heterogeneous OMS*, comprising a *logic graph*, an *OMS language graph* and a *supports relation*

**NOTE** Although in principle, there can be many heterogeneous environments, for ensuring *interoperability*, there will be a global heterogeneous environments (maintained in some registry), with subenvironments for specific purposes. <sup>28</sup>

Note(28)

**sublanguage** syntactically specified subset of a given language, consisting of a subset of its terminal and nonterminal symbols and grammar rules

**language aspect** set of language constructs of a given language, not necessarily forming a sublanguage

**logical language aspect** the (unique) *language aspect* of an *OMS language* that enables the expression of *non-logical symbols* and *sentences* in a logic

**structuring language aspect** the (unique) *language aspect* of an *OMS language* that covers *structured OMS* as well as the relations of *basic OMS* and *structured OMS* to each other, including, but not limited to *imports*, *OMS mappings*, *conservative extensions*, and the handling of prefixes for CURIEs

**annotation language aspect** the (unique) *language aspect* of an *OMS language* that enables the expression of comments and annotations

**profile** (syntactic) *sublanguage* of an *OMS language* interpreting according to a particular *logic* that targets specific applications or reasoning methods

**EXAMPLE** Profiles of OWL 2 include OWL 2 EL, OWL 2 QL, OWL 2 RL, OWL 2 DL, and OWL 2 Full.

**NOTE** Profiles typically correspond to *sublogics*.

**NOTE** Profiles can have different *logics*, even with completely different semantics, e.g. OWL 2 DL versus OWL 2 Full.

**NOTE** The logic needs to support the language.

---

<sup>28</sup>**NOTE:** In the semantics, there also is a binary supports relation between OMS languages and serializations.

## 4.8. OMS Language Serializations

**serialization** specific syntactic encoding of a given *OMS language*

NOTE Serializations serve as standard formats for exchanging OMS between tools.

EXAMPLE OWL uses the term “serialization”; the following are standard OWL serializations: OWL functional-style syntax, OWL/XML, OWL Manchester syntax, plus any standard serialization of RDF (e.g. RDF/XML, Turtle, ...). However, RDF/XML is the only one tools are required to implement.

EXAMPLE Common Logic uses the term “dialect”; the following are standard Common Logic dialects: Common Logic Interchange Format (CLIF), Conceptual Graph Interchange Format (GCIF), eXtended Common Logic Markup Language (XCL).

**document** result of serializing an OMS using a given serialization

**standoff markup** way of providing *annotations* to subjects in external resources, without embedding them into the original resource (here: *OMS*)

## 4.9. Logic

**logic** specification of valid reasoning that comprises *signatures*, *sentences*, *models*, and a *satisfaction relation* between *models* and *sentences*

NOTE Most OMS languages have an underlying logic.

EXAMPLE  $\mathcal{SROIQ}(D)$  is the logic underlying OWL 2 DL.

NOTE See annex A for the organization of the relation between OMS languages and their logics and serializations.

**supports relation** relation between *OMS languages* and *logics* expressing the *logical language aspect* of the former, namely that the constructs of the former lead to a *logical theory* in the latter

**institution** metaframework mathematically formalizing the notion of a *logic*

NOTE See clause 11 for a formal definition.

**logic translation** mapping of a source *logic* into a target *logic* (mapping *signatures*, *sentences* and *models*) that keeps or encodes the logical content of *OMS*

**logic reduction** mapping of a source *logic* onto a (usually less expressive) target *logic* (mapping *signatures*, *sentences* and *models*) that simply forgets those parts of the logical structure not fitting the target *logic*

**sublogic** a *logic* that is a syntactic restriction of another logic, inheriting its semantics

## 4. Terms and Definitions

**logic graph** graph of *logics*, *logic translations* and *logic reductions*, typically used in a *heterogeneous environment*

**NOTE** In a logic graph, some of the logic translations and reductions can be marked to be *default translations*.<sup>29</sup>

Note(29)

**homogeneous OMS** OMS whose parts are all formulated in one and the same *logic*

**NOTE** Opposite of *heterogeneous OMS*.

**heterogeneous OMS** OMS whose parts are formulated in different *logics*

**NOTE** Opposite of *homogeneous OMS*.

**EXAMPLE**<sup>30</sup>

Note(30)

**logic approximation** mapping of a source *logic* onto a (usually less expressive) target *logic* that tries to approximate the OMS expressed in the source *logic* with means of the expressivity of the target *logic*

**NOTE** A unique maximal approximation need not exist.

**NOTE** The target logic typically is a *sublogic* of the source logic.

### 4.10. Interoperability

<sup>31</sup>

Note(31)

<sup>32</sup>

Note(32)

<sup>33</sup>

Note(33)

<sup>29</sup>**NOTE:** Hopefully it is OK to subsume the notion of logic reduction under the term “translation” here.

<sup>30</sup>**NOTE:** See section G.1.

<sup>31</sup>**NOTE:** TODO: possibly define some notion of “interoperability” that is tailored to this OMG Specification.

At least we need to be able to speak about overall consistency, alignments, etc.

<sup>32</sup>**NOTE:** FYI: Definitions in earlier drafts were not quite helpful:

- OMS integration := “combination of different OMS into a coherent whole, via alignments”
- OMS interoperability := “relation among OMS (via OMS alignments) with the goal of using them jointly in an application scenario”

AENOR commented on the latter: “The definition of this term needs some revision and more precision in the document as for the real criteria that shall be applied to evaluate the degree of interoperability between OMS.”

<sup>33</sup>**NOTE:** Frank Farance cited the following from ISO/IEC 2381-1 Information Technology Vocabulary – Part 1: Fundamental Terms:

01.01.47

interoperability

The capability to communicate, execute programs, or transfer data among various functional units in a manner that requires the user to have little or no knowledge of the unique characteristics of those units.

01.01.40

functional unit

An entity of hardware or software, or both, capable of accomplishing a specified purpose.

... and the following from the FDIS 20944-1 Information technology – Metadata Registries Interoperability and Bindings (MDR-IB)– Part 1: Framework, common vocabulary, and common provisions for conformance

3.21.12.4

data interoperability

interoperability concerning the creation, meaning, computation, use, transfer, and exchange of data

#### 4. Terms and Definitions

**logically interoperable** property of *structured OMS*, which may be written in different *OMS languages* <sup>34</sup>based on different *logics*, of being usable jointly in a coherent way (via suitable *OMS language translations*), such that the notions of their overall consistency and logical entailment have a precise logical semantics

Note(34)

NOTE TODO Michael: explain the relationship to other notions of interoperability (from existing standards)

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##### 3.21.12.5

metadata interoperability

interoperability concerning the creation, meaning, computation, use, transfer, and exchange of descriptive data

<sup>34</sup>NOTE: TODO: phrase this more precisely, based on the previously introduced terms

## 5. Symbols

As listed below, these symbols and abbreviations are generally for the main clauses of the OMG Specification. Some annexes may introduce their own symbols and abbreviations which will be grouped together within that annex.

CASL	Common Algebraic Specification Language, specified by the Common Framework Initiative
CGIF	Conceptual Graph Interchange Format
CL	Common Logic
CLIF	Common Logic Interchange Format
CORBA	Common Object Request Broker Architecture
CURIE	Compact URI expression
CWM	Common Warehouse Metamodel
DDL	Distributed description logic
DOL	Distributed Ontology, Modeling and Specification Language
DTV	Date-Time Vocabulary
EBNF	Extended Backus-Naur Form
E-connections	a modular ontology language (closely related to DDL)
F-logic	frame logic, an object-oriented ontology language
IDL	Interface Definition Language
IIOP	Internet Inter-ORB Protocol
IRI	Internationalized Resource Identifier
MDA	Model Driven Architecture
MOF	Meta-Object Facility
OCL	Object Constraint Language
OWL 2	Web Ontology Language (W3C), version 2: family of knowledge representation languages for authoring ontologies
OWL 2 DL	description logic profile of OWL 2
OWL 2 EL	a sub-Boolean profile of OWL 2 (used often e.g. in medical ontologies)
OWL 2 Full	the language that is determined by RDF graphs being interpreted using the OWL 2 RDF-Based Semantics [18]
OWL 2 QL	profile of OWL 2 designed to support fast query answering over large amounts of data
OWL 2 RL	fragment of OWL 2 designed to support rule-based reasoning
OWL 2 XML	XML-based serialization of the OWL 2 language
P-DL	Package-based description logic
PIM	Platform-independent Model
PSM	Platform-specific Model
RDF	Resource Description Framework, a graph data model
RDFS	RDF Schema
RDFa	a set of XML attributes for embedding RDF graphs into XML documents
RDF/XML	an XML serialization of the RDF data model

## 5. Symbols

RIF	Rule Interchange Format
SBVR	Semantics of Business Vocabulary and Business Rules
SMOF	MOF Support for Semantic Structures
UML	Unified Modeling Language
URI	Uniform Resource Identifier
URL	Uniform Resource Locator
W3C	World Wide Web Consortium
XMI	XML Metadata Interchange
XML	eXtensible Markup Language



## **6. Additional Information**

### **6.1. Changes to Adopted OMG Specifications**

This specification does not require or request any change to any other OMG specification.

### **6.2. How to Read this Specification**

### **6.3. About this Specification**

### **6.4. Acknowledgments**

#### **6.4.1. Submitting and supporting organizations**

The following OMG members are submitting this specification:

- Fraunhofer FOKUS
- MITRE
- Thematix Partners LLC

The following organizations are supporting this specification:

- Otto-von-Guericke University Magdeburg
- Athan Services

#### **6.4.2. Participants**

The following people contributed directly to the development of this specification.

- Tara Athan, Athan Services
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## 7. Goals and Usage Scenarios

There are many domains in which multiple OMS are needed, in some cases axiomatized in the same language, and in other cases axiomatized in different logical languages. This leads to several challenges in the design and deployment of OMS, which have been addressed by current research in ontological engineering, formal software specification and formal modeling:

- How can we support sharability and reusability of OMS within the same domain?
- How can we merge OMS in different domains, particularly in the cases in which the OMS are axiomatized in different logical languages?
- What notions of modularity play a role when only part of an OMS is being shared or reused?
- What are the relationships between versions of an OMS axiomatized in different logical languages?

To illustrate these challenges, in this section we present a set of use cases which highlight different aspects of a theme common to ontology design, formal specification, and model-driven development: the use of heterogeneous formal representations leads to interoperability challenges. There are ad-hoc solutions to these challenges, and specialized languages and tools are used in practice. However, absent an approach like DOL, there is no standardized approach or representation metalanguage to enable more accurate and consistent alignment, integration, and mapping among these specifications and the tools that implement them.

### 7.1. Use case Onto-1: Interoperability between OWL and FOL ontologies

In order to achieve interoperability, during ontology development it is often necessary to describe concepts in a language more expressive than OWL. Therefore, it is common practice to informally annotate OWL ontologies with FOL axioms (e.g., Keet's mereotopological ontology [Part-Whole], Dolce Lite [Dolce-lite], BFO-OWL). OWL is used because of better tool support, FOL because of greater expressiveness. However, relegating FOL axioms to informal annotations means that these are not available for machine processing. Another example of this problem is the following: For formally representing concept schemes (including taxonomies, thesauri and classification schemes) and provenance information there are the two W3C standards SKOS (Simple Knowledge Organization System) and PROV, as well as <sup>35</sup>ISO and other domain-specific standards for metadata representation. The semantics for the SKOS and PROV languages are largely specified as OWL ontologies; however, as OWL cannot capture the full semantics, the rest is specified using some informal first-order rules. In other words, valid instance models that use SKOS or PROV may be required to satisfy both OWL and FOL

Note(35)

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<sup>35</sup>NOTE: CL: Did we mean something like "ISO 12345" here, i.e. some specific ISO standard that we reference by number?

axioms. When solving reasoning tasks over either SKOS or PROV ontologies, OWL reasoners are not able to consider the FOL axioms. Hence, the information contained in these axioms is lost.

DOL allows the user to replace such informal annotations by formal axioms in a suitable ontology language. The relation between the OWL ontology and the FOL axioms is that of a heterogeneous import. In the result, both the OWL and the FOL axioms are amenable to, e.g., automated consistency checks and theorem proving. Hence, all available information can be used in the reasoning process.

### 7.2. Use Case Onto-2: Ontology integration by means of a foundational ontology

One major use case for ontologies in industry is to achieve interoperability and data integration. However, if ontologies are developed independently and used within the same domain, the differences between the ontologies may actually impede interoperability. One strategy to avoid this problem is the use of a shared foundational ontology (e.g., DOLCE or BFO), which can be used to harmonize different domain ontologies. One challenge for this approach is that foundational ontologies typically rely on expressive ontology languages (e.g., Common Logic), while domain ontologies may be represented in languages that are optimized for performance (e.g., OWL EL). For this reason, currently the role of the foundational ontology is mainly to provide a conceptual framework that may be reused by the domain ontologies; further, watered-down versions of the foundational ontologies in OWL (like DOLCE-lite or the OWL version of BFO) are used as basis for the development of domain ontologies, be this as is, in an even less expressive version (e.g., a DOLCE-lite in OWL 2 EL), or only a relevant subset thereof (e.g., only the branch of endurants). A sample orchestration of interactions between the foundational and domain ontologies in various languages is depicted in Figure 8.1 below.

DOL provides the framework for integrating different domain ontologies, aligning these to foundational ontologies [Alignment1-2] and combining the aligned ontologies into a coherent integrated ontology – even across different ontology languages. Thus, DOL enables ontology developers to utilize the complete, and most expressive, foundational ontologies for ontology integration and validation purposes.

The foundational ontology (FO) repository Repository of Ontologies for MULTiple USes (ROMULUS)<sup>1</sup> contains alignments between a number of foundational ontologies, expressing semantic relations between the aligned entities. We select three such ontologies, containing spatial and temporal concepts: DOLCE<sup>2</sup>, GFO<sup>3</sup> and BFO<sup>4</sup>, and present alignments between them using DOL syntax:

```
%prefix(
    gfo: <http://www.onto-med.de/ontologies/>
    dolce: <http://www.loa-cnr.it/ontologies/>
    bfo: <http://www.ifomis.org/bfo/>
) %
logic OWL
```

<sup>1</sup>See <http://www.thezfiles.co.za/ROMULUS/home.html>

<sup>2</sup>See <http://www.loa.istc.cnr.it/DOLCE.html>

<sup>3</sup>See <http://www.onto-med.de/ontologies/gfo/>

<sup>4</sup>See <http://www.ifomis.org/bfo/>

## 7. Goals and Usage Scenarios

```
alignment DolceLite2BFO :
  dolce:DOLCE-Lite.owl
  to
  bfo:1.1 =
  endurant = IndependentContinuant,
  physical-endurant = MaterialEntity,
  physical-object = Object,   perdurant = Occurrent,
  process = Process,         quality = Quality,
  spatio-temporal-region = SpatiotemporalRegion,
  temporal-region = TemporalRegion,   space-region = SpatialRegion

alignment DolceLite2GFO :
  dolce:DOLCE-Lite.owl to gfo:gfo.owl =
  particular = Individual, endurant = Presential,
  physical-object = Material_object, amount-of-matter = Amount_of_substrate,
  perdurant = Occurrent,   quality = Property,
  time-interval = Chronoid, generic-dependent < necessary_for,
  part < abstract_has_part, part-of < abstract_part_of,
  proper-part < has_proper_part,   proper-part-of < proper_part_of,
  generic-location < occupies,     generic-location-of < occupied_by

alignment BFO2GFO :
  bfo:1.1 to gfo:gfo.owl =
  Entity = Entity, Object = Material_object,
  ObjectBoundary = Material_boundary, Role < Role ,
  Occurrent = Occurrent, Process = Process, Quality = Property
  SpatialRegion = Spatial_region, TemporalRegion = Temporal_region
```

We can then combine the ontologies while taking into account the semantic dependencies given by the alignments using DOL combinations:

```
ontology Space =
combine BFO2GFO, DolceLite2GFO, DolceLite2BFO
```

### 7.3. Use Case Onto-3: Module extraction from large ontologies

Especially in the biomedical domain, ontologies tend to become very large (e.g., SNOMED CT, FMA) with over 100000 concepts and relationships. Yet, none of these ontologies covers all aspects of a domain, and frequently provide coverage at various levels of specificity, with excessive detail in some areas that may not be required for all usage scenarios. Often, for a given knowledge representation problem in industry, only relevant knowledge from two such large reference ontologies needs to be integrated, so a comprehensive integration would be both unfeasible and unwieldy. Hence, parts (modules) of these ontologies are obtained by selecting the concepts and relationships (roles) relevant for the intended application. An integrated version will then be based on these excerpts from the original ontologies (i.e., modules). For example, the Juvenile Rheumatoid Arthritis ontology JRAO has been created using modules from the NCI thesaurus and GALEN medical ontology. (See <sup>36</sup>Figure 7.1) DOL supports the description of such subsets (modules) of ontologies, as well as their alignment and integration.

Note(36)

<sup>36</sup>NOTE: CL: can we please have a vector graphic here?

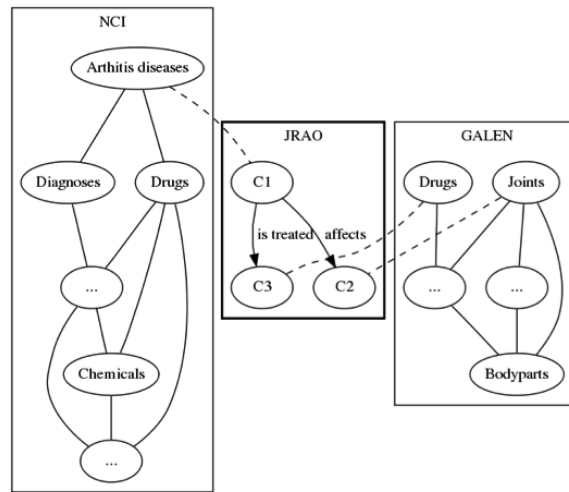


Figure 7.1.: JRAO – Example for Module Extraction

#### 7.4. Use case Onto-4: Interoperability between closed-world data and open-world metadata

Data collection has become easier and much more widespread over the years. This data has to be assigned a meaning somehow, which occurs traditionally in the form of metadata annotations. For instance, consider geographical datasets derived from satellite data and raw sensor readings. Current implementations in, e.g., ecological economics[?] require manual annotation of datasets with the information relevant for their processes. While there have been attempts to standardize such information[?], metadata for datasets of simulation results are more difficult to standardize. Moreover, it is resource-consuming to link the data to the metadata, to ensure the metadata itself is of good quality and consistent, and to actually exploit the metadata when querying the data for data analysis.

The data is usually represented in a database or RDF triple store, which work with a closed world assumption on the dataset, and are not expressive enough to incorporate the metadata ‘background knowledge’, such as the conditions for validity of the physical laws in the model of the object of observation. These metadata require a more expressive language, such as OWL or Common Logic, which operate under an open-world semantics. However, it is unfeasible to translate the whole large dataset into OWL or first-order logic. To ‘meet in the middle’, it is possible to declare bridge rules (i.e., a mapping layer) that can link the metadata to the data. This approach can be used for intelligent data analysis that combines the data and metadata through querying the system. It enables the analysis of the data on the conceptual layer, instead of users having to learn the SQL/SPARQL query languages and how the data is stored. There are various tools and theories to realize this, which is collectively called Ontology-Based Data Access/Management, see also [OBDA].

The languages for representing the metadata or ontology, for representing the bridge rules

## 7. Goals and Usage Scenarios

or mapping assertions, and for representing the data are different yet they need to be orchestrated and handled smoothly in the system, be this for data analytics for large enterprises, for formulating policies, or in silico biology in the sciences.

DOL provides the framework for expressing such bridge rules in a systematic way, maintaining these, and building tools for them.

### 7.5. Use Case Onto-5: Verification of rules translating Dublin Core into PROV

The Dublin Core Metadata terms, which have been formalized as an RDF Schema vocabulary, developed initially by the digital library community, are less comprehensive but more widely used than PROV (cf. Use Case Onto-1). The rules for translating Dublin Core to the OWL subset of PROV (and, with restrictions, vice versa) are not known to yield valid instances of the PROV data model, i.e. they are not known to yield OWL ontologies consistent with respect to the OWL axioms that capture part of the PROV data model. This may disrupt systems that would like to reason about the provenance of an entity, and thus the assessment of the entity's quality, reliability or trustworthiness. The Dublin Core to PROV ontology translation<sup>5</sup> is expressed partly by a symbol mapping and partly by FOL rules. These FOL rules are implemented by CONSTRUCT patterns in the SPARQL RDF query language.<sup>6</sup> SPARQL has a formal specification of the evaluation semantics of its algebraic expressions, which is different from the model-theoretic semantics of the OWL and RDFS languages; nevertheless SPARQL CONSTRUCT is a popular and immediately executable syntax for expressing translation rules between ontologies in RDF-based languages in a subset of FOL. DOL not only supports the reuse of the existing Dublin Core RDFS and PROV OWL ontologies as modules of a distributed ontology (= OMS network), but it is also able to support the description of the FOL translation rules in a sufficiently expressive ontology language, e.g. Common Logic, and thus enable formal verification of the translation from Dublin Core to PROV.

### 7.6. Use case Spec-1: Specification Refinements

Especially in safety-critical areas such as medical systems, the automotive industry, avionics and the aerospace industry, but also for microprocessor design, often a formal software and hardware development process is used in order to ensure the correct functioning of systems. Typically, a requirement specification is refined into a design specification and then an implementation, often involving several intermediate steps (see, e.g. the V-model [V-model], although this does not require formal specification). There are numerous specification formalisms in use, including the OMG's SysML language; moreover, often during development, the formalism needs to be changed (e.g. from a specification to a programming language, or from a temporal logic to a state machine). For each of these formalisms, notions of refinement have been defined and implemented. However, the lack of a standardized, logically sound language and methodology for such refinement hinders interoperability among different development efforts and the reuse of refinements. DOL provides the capability to represent refinement that is

---

<sup>5</sup><http://www.w3.org/TR/2013/NOTE-prov-dc-20130430/>

<sup>6</sup>E.g., <http://www.w3.org/TR/2013/NOTE-prov-dc-20130430/#dct-creator>

equally applicable to all DOL-conforming logical languages, and that covers at least the most relevant of the industrial use cases of specification refinement.

### 7.7. Use case Spec-2: Modularity of Specifications

In the context of use case Spec-1, often specifications become so large that it is necessary to structure them in a modular way, both for human readability, maintainability, and for more efficient tool support. The lack of a standard for such modular structuring hinders interoperability among different development efforts and the reuse of specifications. DOL provides a notion of structured modular specification that is equally applicable to all DOL-conforming logical languages.

### 7.8. Use case Model-1: Coherent semantics for multi-language models

37

Note(37)

Often a single problem area within a given domain must be described using several formalisms, due to user community requirements, expressiveness, tool support and usage, and so forth. A challenge is that typically the different formalizations are written by different people using different logics, and, thus, their overall consistency is hard to maintain. The need for the use of multiple ontology languages, even within the OMG community, is also reflected by the OMG Ontology Definition Metamodel (ODM), which provides a number of syntactic transformations between such languages. One example is the OMG Date-Time Vocabulary (DTV). DTV has been formulated in different languages, each of which addresses different audiences:

- SBVR: business users
- UML (class diagrams and OCL): software implementers
- OWL: ontology developers and users
- Common Logic: (foundational) ontology developers and users

With DOL, one can, e.g.,

- formally relate the different formalizations used for DTV, relate the different formalizations using translations,
- check consistency across the different formalizations (using suitable tools),
- extract sub-modules covering specific aspects, and
- specify the OWL version to be an approximation of the Common Logic version (using a heterogeneous interpretation of OMS).

Note that the last point does not specify what information is lost in the approximation. Indeed, DOL provides the means to specify requirements on the approximation, e.g., that it maximally preserves the information.

---

<sup>37</sup>NOTE: Isn't this one about ontologies,too?

## 7.9. Use case Model-2: Consistency among UML diagrams of different types

A typical UML model involves diagrams of different types. Such UML models may have intrinsic errors because diagrams of different types may specify conflicting requirements. Typical questions that arise in this context are, e.g.,

- whether the multiplicities in a class diagram are consistent with each other
- whether the attributes and operations in a state machine are available in a class diagram
- whether the sequential composition of actions in an interaction diagram is justified by an accompanying OCL specification,
- whether cooperating state machines comply with pre-/post-conditions and invariants
- if the behavior prescribed in an interaction diagram is realizable by several state machines cooperating according to a composite structure diagram.

Such questions are currently hard to answer in a systematic manner. One method to answer these questions and find such errors is a check for semantic consistency. Under some restrictions, the proof of semantic consistency can be (at least partially) performed using model-checking tools like Hugo/RT [?]. Once a formal semantics for the different diagram types has been chosen (see, e.g. [?]), it is possible to use DOL to specify in which sense the diagrams need to be consistent, and check this by suitable tools.

## 7.10. Use case Model-3: Refinements between UML diagrams of different types, and their reuse

A problem is a lack of reusability of refinements: Consider a controller for an elevator, which is specified with a UML protocol state machine, enriched with UML sequence diagrams and OCL constraints. Assume further that this model is not directly implemented, but first refined to a UML behavior state machine (which then can be automatically or semi-automatically transformed into some implementation using standard UML tools). However, there is no standardized language to express, document and maintain the refinement relation itself (UML only allows very simple refinements, namely between state machines). This hinders both the reuse of such refinements in different contexts, as well as the interoperability of tools proving such refinements to be correct. DOL addresses these problems by providing a standardized notation with formal semantics for such refinements. Refinements expressed in this language could, e.g., be parameterized and reused in different contexts.

## 7.11. Conclusion

In the next sections, we discuss the metalanguage DOL, its features that enable the support of a variety of formalisms, with syntax, well-defined semantics and model theory. DOL distills best practices of modularity and metarelations (such as refinement and alignment) across the three areas of ontology design, formal specification, and model-driven development. It provides the ability to specify the basis for formal interoperability even among heterogeneous OMS and OMS networks. DOL enables the solutions of the problems described in the use cases above. It also



## *7. Goals and Usage Scenarios*

enables the development of OMS libraries, tools and workflows that allow a better exchange and reuse of OMS. Eventually, this will also lead to better, easier developed and maintained systems based on these OMS.

## 8. Design Overview

This clause is informative. Its purpose is to briefly describe the the overall guiding principles and constraints of DOL's syntax and semantics. We give an overview of the most important and innovative language constructs of DOL. Details can be found in clause 9.

DOL gives interoperability a formal grounding and makes heterogeneous OMS and OMS networks and services based on them amenable to checking of coherence (e.g. consistency, conservativity, intended consequences, and compliance). OMS languages are declarative languages for making ontological distinctions formally precise, for modeling a domain in an unambiguous way, or for expressing algebraic specifications of software. OMS languages are distinguished by the following features:

**Logic** Most commonly, OMS languages are based on a description logic or some other subset of first-order logic, but in some cases, also higher-order, modal, paraconsistent and other logics are used.

**Modularity** A means of structuring an OMS into reusable parts, reusing parts of other OMS, mapping imported symbols to those in the importing OMS, and asserting additional properties about imported symbols.

**Annotation** A means of attaching human-readable descriptions to OMS symbols, addressing knowledge engineers and service developers, but also end users of OMS-based services.<sup>38</sup>

Note(38)

Whereas the first feature determines the expressivity of the language and the possibilities for automated reasoning (decidability, tractability, etc.), the latter two intend to facilitate OMS engineering as well as the engineering of OMS-based software.

Acknowledging the wide tool support that conforming established languages such as OWL, Common Logic, MOF, or CASL<sup>39</sup> enjoy, existing OMS in these languages remain as they are within the DOL framework. DOL enhances their modularity and annotation facilities to a superset of the modularity and annotation facilities they provide themselves. DOL's modularity and annotation constructs can either be embedded into existing OMS as non-disruptive annotations, or they can be provided as standoff markup, pointing to the OMS they talk about; DOL specifies a syntax and semantics for both variants. DOL's modularity constructs are semantically well-founded within a library of formal relationships between the logics underlying the different supported OMS languages.

Note(39)

### 8.1. Overview of DOL

<sup>40</sup>

DOL is a language enabling OMS interoperability. DOL is

Note(40)

<sup>38</sup>NOTE: TODO Christoph: reformulate. DOL enables the use of annotations

<sup>39</sup>NOTE: review language list when annexes are finished

<sup>40</sup>NOTE: TM: rewrite

## 8. Design Overview

**free** DOL is freely available for unrestricted use.

**generally applicable** DOL is neither be restricted to OMS in a specific domain, nor to foundational OMS, nor to OMS represented in a specific OMS language, nor to OMS stored in any specific repositories.

**open** DOL supports mapping, integrating, and annotating OMS across arbitrary internet locations. It makes use of existing open standards wherever suitable. The criteria for extending DOL (see next item) are transparent and explicit.

**extensible** DOL provides a framework into which any existing, and, desirably, any future OMS language can be plugged.

DOL is applicable to any OMS language that has a formal, logic-based semantics or a semantics defined by translation to another OMS language with such a formal semantics. The annotation framework of DOL is additionally applicable to the non-logical constructs of such languages. This OMG Specification specifies formal criteria for establishing the conformance of an OMS language with DOL. Annexes establish the conformance of a number of relevant OMS languages with DOL; a registry shall offer the possibility to add further (also non-standardized) languages:<sup>41</sup> DOL provides syntactic constructs for structuring OMS regardless of the logic

Note(41)

their sentences are formalized in. DOL does not provide its own constructs for expressing sentences. Instead, it *inherits* the logical language aspects of conforming OMS languages. It is possible to literally include sentences expressed in such OMS languages in a DOL OMS. DOL provides an initial vocabulary for expressing relations in correspondences (as part of alignments between OMS). Additionally, it provides a means of reusing relation types defined externally of this OMG Specification. DOL does not provide an annotation vocabulary, i.e. it neither provides annotation properties nor datatypes to be used with literal annotation objects. Instead, an informative annex recommends existing annotation vocabularies for use with DOL.

<sup>42</sup> In the interest of wide applicability and tool support, DOL supports multiple alternative serializations. In particular, there is a text serialization targeting human readers and writers, as well as serializations optimized for machine processability. The **text serialization** in particular offers a syntax for abbreviating identifiers of resources within OMS in a way that does not require authors to write down their full global identifiers. An OMS implemented in DOL can comprise parts formalized in any OMS language; any serialization of DOL can literally include such parts, regardless of the OMS language serialization they have been written in. <sup>43</sup> Additionally, an OMS implemented in DOL can refer to any external OMS formalized in any OMS language, as long as they can be identified in a globally unique way. Existing OMS in existing XML serializations (e.g. XCL) or text serializations (e.g. OWL Manchester Syntax) validate as DOL OMS with a minimum amount of syntactic adaptation. Existing OMS files/documents are usable in a DOL context without the need for modification.

Note(42)

DOL does not provide a new elementary OMS language, but provides a layer to be used on top of existing elementary OMS languages which enables OMS engineers to formally express mappings between OMS written in different languages and stored at different Web locations. The purpose of such OMS networks is enabling a greater extent of interoperability between data and services in complex application settings.

Note(43)

The following features are essential to the design of this OMG Specification:

<sup>41</sup>NOTE: John Sowa: Make it modular with a simple core that can run efficiently on small systems, but can grow indefinitely to support as much as anyone could desire.

<sup>42</sup>NOTE: Q-ALL: We need to revise this following the agreement to drop the XML and RDF serializations.

<sup>43</sup>NOTE: FYI: advanced namespacing is the solution that addresses this requirement

- DOL is a language covering OMS modularity, OMS heterogeneity, and OMS mapping. In particular, it enables writing structured OMS (thereby reusing existing OMS), OMS involving different languages, as well as complex mappings and relations between OMS.
- DOL is a declarative language with a formal semantics.
- DOL provides a superset of the modularization, Web awareness and annotation facilities of a number of commonly used OMS languages, including OWL [40], RDF [41], Common Logic [?] and UML [16].<sup>1</sup>
- DOL is an open, extensible standard that is not restricted to a fixed set of supported OMS language but specifies criteria for any existing or future OMS language to conform with DOL.
- Existing OMS in languages conforming with DOL remain as they are; they can be enriched with DOL's modularity and annotation constructs in a non-disruptive way.

44

Note(44)

## 8.2. DOL enables expression of logically heterogeneous OMS and literal reuse of existing OMS.

DOL is a mechanism for expressing logically heterogeneous OMS. It can be used to combine sentences and structured OMS expressed in different conforming OMS languages and logics into single documents or modules. With DOL, sentences or structured OMS of previously existing OMS in conforming languages can be reused by literally including them into a DOL OMS. A minimum of wrapping constructs and other annotations (e.g., for identifying the language of a sentence) are provided.<sup>45</sup> See the abstract syntax category `OMS` in clause 9.

Note(45)

## 8.3. DOL includes provisions for expressing mappings between OMS.

DOL provides a syntax for expressing mappings between OMS – logical OMS Mappings as well as alignments. One use case illustrating both is sketched in Figure 8.1. This OMG Specification defines a set of logical OMS mapping types and a set of non-logical OMS mapping types.

Logical OMS mappings supported by DOL include:

- imports (particularly including imports that lead to conservative extensions), see the abstract syntax categories `OMSRef` and `ExtensionOMS` in clause 9.
- interpretations (both between focused OMS and OMS networks), see the abstract syntax category `IntprDefn` in clause 9.

---

<sup>1</sup>See clause ?? for details.

<sup>44</sup>NOTE: reformulate this, see RFP

<sup>45</sup>NOTE: TODO: Figure out what this feedback item from Michael Grüninger (?) means: say that there should be a syntax for relationships btw. OMS as well as a syntax for heterogeneous OMS. (If you write down an OMS, it might involve constructs that only exist in OWL)

## 8. Design Overview

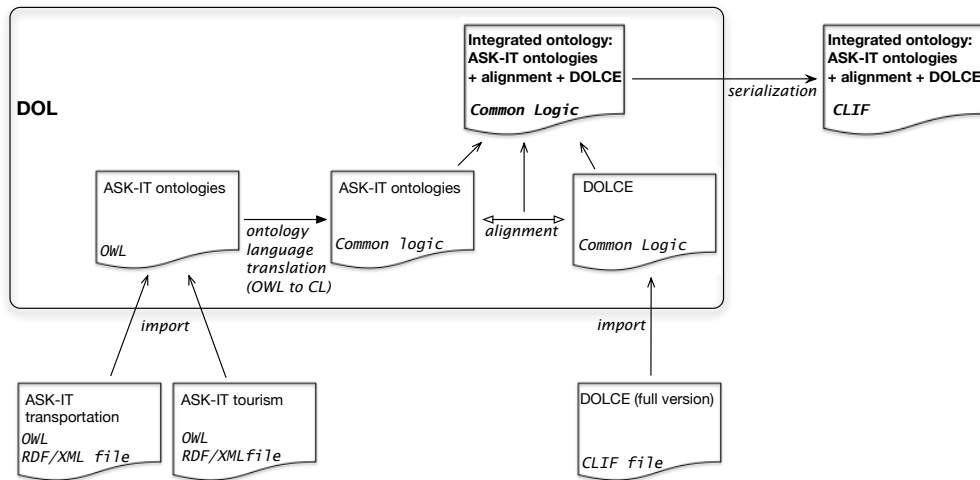


Figure 8.1.: Mapping between two OMS formulated in different OMS languages

- mappings between OMS and their modules, see the abstract syntax category `ModuleRelDefn` in clause 9.

DOL allows such links to express signature translations in such OMS mappings; see the abstract syntax category `SymbolMapItems` in clause 9.

DOL need not be able to fully represent logical translations but is capable of referring to them.

<sup>46</sup>

Note(46)

DOL can also be used to combine or merge OMS along such OMS mappings, see the rule for `combination` for the abstract syntax category `OMS` in clause 9.

### 8.4. DOL enables the representation of OMS and OMS mappings at different levels of detail

OMS and OMS mappings expressed in DOL can be based on a number of implicit assumptions about which OMS language translation or which ontology matcher has been employed. Depending on the OMS engineering workflow or application setting, it can be useful to keep these assumptions implicit or to make them explicit. DOL allows such assumptions to remain implicit, if desired. However, it also enables the user to capture these assumptions explicitly as annotations to the OMS. This OMS Specification specifies a translation that expands any DOL OMS with implicit assumptions into its explicit counterpart. To Do: Terry: (Is this true? if so, rewrite). Perhaps: This OMS Specification provides a means to specify a translation to expand any DOL OMS with implicit assumptions into an explicit counterpart. (is such a translation counterpart necessarily unique, either syntactically or semantically? If a semantically

ToDo

<sup>46</sup>NOTE: Q-AUT: We had this comment here; what does it mean? "DOL only maps symbols to expressions"

preserving syntax change occurs to the original, will the counterpart change?)

The following list covers the possible cases where DOL provides a choice between representing information implicitly or explicitly:

**default OMS language translations** A heterogeneous OMS can import several (focused) OMS expressed in different conforming logics, for which suitable translations have been defined in the logic graph provided in annex E or in an extension to it that has been provided when establishing the conformance of some other logic with DOL. Determining the semantics of the heterogeneous OMS requires a translation into a common target language to be applied (cf. clause 11). This translation is determined via a lookup in the transitive closure of the logic graph. Depending on the reasoners available in the given application setting, it can, however, be necessary to employ a different translation. Authors can express which one to employ. In a multi-step translation, it is possible to implicitly apply as many default translations as possible, and to concentrate on making explicit only those translations that deviate from the default.<sup>47</sup>

Note(47)

**different matching algorithms** OMS alignments, which DOL is able to express, may have been obtained by running different OMS matching algorithms. If, in a given OMS engineering workflow, the information on which algorithm has been applied is clear from the context, it is possible to omit it in the alignment expressed in DOL. Otherwise, e.g. if the next person working on the OMS requires that information, it is possible to make it explicit.<sup>48</sup>

Note(48)

49

Note(49)

### 8.5. DOL provides a mechanism for rich annotation and documentation of OMS.

<sup>50</sup> DOL supports annotations in the full generality specified in clause 4.4. The DOL serializations further support the fine-grained embedding of annotations into OMS.

Note(50)

The DOL serializations also supports the annotation of existing OMS via non-intrusive stand-off markup, which points to the annotation subjects from external documentation files or from special embedded comments, extending the comment syntax of the respective OMS language; for XML serializations of OMS languages, RDFa extensions are specified, so that DOL RDF can be embedded.

A list of RDF vocabularies for annotating OMS is recommended as an annex to this OMG Specification.

<sup>47</sup>NOTE: Q-AUT: Will this situation be the same for default approximations, or to we need to add an extra item to the list?

<sup>48</sup>NOTE: TM: the alignment itself should be there explicitly. right? But then the information about the matching algorithm that has produced it is a mere annotation without semantics, isn't it?

CL: I agree with you. OK, so we will replace this with approximation algorithms.

<sup>49</sup>NOTE: TODO: ask Michael Grüninger for his mereology example in CL

<sup>50</sup>NOTE: Q-ALL: I think that now that we have agreed on dumping the RDF and XML serializations of DOL, this requirement can no longer be satisfied. Or maybe it can be satisfied in a trivial way (nonetheless requiring this section to be shortened): DOL provides the mechanism for identifying anything of relevance in a library, it will do so by IRIs, and with RDF there is an established mechanism for annotating things identified by IRIs. Still I believe this requirement is an important selling point.

## 9. DOL abstract syntax

### 9.1. Abstract syntax categories

DOL provides abstract syntax categories for

- libraries (items in libraries are: OMS definitions, OMS mapping definitions, queries, and qualifications choosing the logic, OMS language and/or serialization)
- **focused OMS** (which can be basic OMS in some OMS language, or unions, translations, minimizations, combinations, approximations of OMS, among others)
- OMS mappings
- **queries**
- identifiers
- annotations

Additionally, the categories of the abstract syntaxes of any conforming OMS languages (cf. clause 2.1) are also DOL abstract syntax categories.

The following subclauses, one per abstract syntax category, specify the abstract syntax of DOL in EBNF. Note that we deviate from the EBNF specification in ISO/IEC 14977:1996 in favor of a more modern and concise EBNF syntax.<sup>1</sup>

### 9.2. Libraries

A library (`Library`) consists of a collection of (named) focused OMS and mappings between these. More specifically, a library consists of a name, followed by a list of `LibraryItems`. A `LibraryItem` is either a definition of a focused OMS (`OMSDefn`), **a definition of a library (`LibraryDefn`)**, a mapping between OMS (`MappingDefn`), a definition related to queries (`QueryRelatedDefn`) or a `Qualification` selecting a specific OMS language, logic and/or syntax that is used to interpret the subsequent `LibraryItems`. Alternatively, a library can also be the verbatim inclusion of an OMS written in an OMS language that conforms with DOL (`OMSInConformingLanguage`; cf. 2.1).

```
Library          ::= [PrefixMap] LibraryDefn
                  | OMSInConformingLanguage
LibraryDefn      ::= library LibraryName LibraryItem*
OMSInConformingLanguage ::= <language specific>
LibraryItem      ::= LibImport
                  | OMSDefn
```

---

<sup>1</sup>More precisely, ISO/IEC 14977:1996 requires commas between the (non-)terminals of a right-hand side, which we omit for the sake of better readability. Also, we replace the separator = between left and right hand-side of a rule with `::=`, and use the notation `N+` of one or more repetitions of `N`.

## 9. DOL abstract syntax

```

| NetworkDefn
| MappingDefn
| QueryRelatedDefn
| Qualification
LibImport      ::= lib-import LibraryName
Qualification  ::= LanguageQual | LogicQual | SyntaxQual
LanguageQual   ::= lang-select LanguageRef
LogicQual      ::= logic-select LogicRef
SyntaxQual     ::= syntax-select SyntaxRef
LibraryName    ::= IRI

```

51

Note(51)

At the beginning of a library, one can declare a `PrefixMap` for abbreviating long IRIs; see clause 9.6 for details.

Inside a library, one can defined OMS networks (`NetworkDefn`). A `NetworkDefn` names an OMS network consisting of focused OMS and OMS mappings. OMS networks may build on previously-defined OMS networks, and they can be used in combinations.

```

NetworkDefn      ::= network-defn NetworkName [ConsStrength] Network
NetworkName      ::= IRI
Network          ::= network NetworkElements ExcludeExtensions
NetworkElements  ::= network-elements NetworkElement*
NetworkElement    ::= network-element [Id] OMSOrMappingorNetworkRef
ExcludeExtensions ::= exclude-imports OMSOrMappingorNetworkRef*
OMSOrMappingorNetworkRef ::= IRI

```

### 9.3. Focused OMS

A focused OMS (OMS) can be one of the following:

- a basic OMS `BasicOMS` written inline, in a conforming serialization of a conforming OMS language<sup>2</sup>,
- a translation of an OMS into a different signature or OMS language,
- a reduction of an OMS to a smaller signature and/or less expressive logic (that is, some non-logical symbols are hidden, but the semantic effect of sentences involving these is kept),
- a module extracted from an OMS, using a restriction signature,

<sup>51</sup>NOTE: FYI: Things changed from HetCASL:

- logic-select now mandatory (no default logic) and tree-scoped MC: what does this mean? To make Hets-lib conform with this, we should have .het files equivalent to .dol files with logic selected to be CASL
- download-items (encourage linked data best practices instead)
- item-name-map (to be replaced by namespaces??)
- lib-version (to be replaced by metadata annotations, e.g. OMV)
- indirect-mapping (will always use full IRIs, and abbreviate them by syntactic namespaces)

<sup>2</sup>In this place, any OMS in a conforming serialization of a conforming OMS language is permitted. However, DOL's module sublanguage should be given preference over the module sublanguage of the respective conforming OMS language; e.g. DOL's extension construct should be preferred over OWL's import construct.



## 9. DOL abstract syntax

- an approximation of an OMS, in a subsignature or sublogic, with the effect that sentences not expressible in the subsignature resp. sublogic are replaced with a suitable approximation,
- a filtering of an OMS, with the effect that some signature symbols and axioms are removed from the OMS,
- a union of several OMS,
- an extension of an OMS with a basic or a minimizable OMS, optionally named and/or marked as conservative, monomorphic, definitional or implied,
- a reference to an OMS existing on the Web,
- an OMS qualified with the OMS language that is used to express it,
- a combination of OMS (technically, this is a colimit, see [43]),<sup>3</sup>
- a minimization of an OMS, forcing the subsequently declared non-logical symbols to be interpreted in a minimal way, while the non-logical symbols declared so far are fixed (alternatively, the non-logical symbols to be minimized and to be varied can be explicitly declared). Variants are maximization, freeness (minimizing also data sets and equalities on these), and cofreeness (maximizing also data sets and equalities on these),
- the application of a substitution to a sentence.

```

BasicOMS          ::= OMSInConformingLanguage
MinimizableOMS    ::= BasicOMS | oms-ref OMSRef [ImportName]
ExtendingOMS      ::= MinimizableOMS | minimize MinimizableOMS
OMS               ::= ExtendingOMS
                   | minimize-symbols OMS Minimization
                   | translation OMS Translation
                   | reduction OMS Reduction
                   | module-extract OMS Extraction
                   | approximation OMS Approximation
                   | filtering OMS Filtering
                   | union OMS [ConsStrength] OMS
                   | extension OMS ExtensionOMS
                   | qual-oms Qualification* OMS
                   | bridge OMS Translation* OMS
                   | combination Network
                   | application SubstName Sentence
Minimization      ::= MinType CircMin CircVars
MinType           ::= minimize | maximize | free | cofree
CircMin           ::= Symbol Symbol*
CircVars          ::= Symbol*
Translation       ::= renaming LogicTranslation* [SymbolMapItems]
LogicTranslation  ::= logic-translation OMSLangTrans
Reduction         ::= hidden LogicReduction* [SymbolItems]
                   | revealed SymbolMapItems
LogicReduction    ::= logic-reduction OMSLangTrans
SymbolItems       ::= symbol-items (Symbol Symbol*)

```

<sup>3</sup>A combination of OMS also takes all mappings into these OMS into consideration—unless these are explicitly excluded.

## 9. DOL abstract syntax

```

SymbolMapItems      ::= symbol-map-items (SymbolOrMap SymbolOrMap*)
Extraction          ::= extraction [QualInterfaceSignature]
Approximation       ::= approximation QualInterfaceSignature [LogicRef]
Filtering           ::= select BasicOMS | reject BasicOMS
ExtensionOMS        ::= [ExtConsStrength] [ExtensionName] ExtendingOMS
ConsStrength        ::= Conservative
                    | monomorphic
                    | weak-definitional
                    | definitional
ExtConsStrength     ::= ConsStrength | implied
Conservative        ::= consequence-conservative | model-conservative
QualInterfaceSignature ::= keep-signature InterfaceSignature
                    | remove-signature InterfaceSignature
InterfaceSignature  ::= SymbolItems
ImportName          ::= IRI
ExtensionName       ::= IRI

```

An OMS definition `OMSDefn` names a focused OMS.

It can be optionally marked as consistent, monomorphic or having a unique model using `ConsStrength`.<sup>4</sup> An `SymbolItems`, used in an OMS Reduction, is a list of non-logical symbols that are to be hidden. A `LogicReduction` denotes a logic reduction to a less expressive OMS language. A `SymbolMapItems`, used in OMS Translations, maps symbols to symbols<sup>52</sup>, or a logic translation. An OMS language translation `OMSLangTrans` can be either specified by its name, or be inferred as the default translation between to a given target (the source will be inferred as the OMS language of the current OMS).

Note(52)

```

OMSDefn            ::= oms-defn OMSName [ConsStrength] OMS
Symbol             ::= IRI
SymbolMap          ::= symbol-map Symbol Symbol
SymbolOrMap        ::= Symbol | SymbolMap
Term               ::= <an expression specific to a basic OMS language>
Sentence           ::= <an expression specific to a basic OMS language>
OMSName            ::= IRI
OMSRef             ::= IRI
ExtensionRef       ::= IRI
LoLaRef           ::= LanguageRef | LogicRef
LanguageRef        ::= IRI
LogicRef           ::= IRI
SyntaxRef          ::= IRI
OMSLangTrans       ::= named-trans OMSLangTransRef | default-trans LoLaRef

```

<sup>4</sup>More precisely, 'consequence-conservative' here requires the OMS to have a non-trivial set of logical consequences, while 'model-conservative' requires its satisfiability. 'definitional' expresses the unique model property; this may be interesting for OMS (e.g. returned by model finders) that are used to describe single models.

<sup>52</sup>NOTE: FYI: On 2012-07-18 we decided not to specify lambda-style symbol-to-term mappings for now. Would be convenient, but specifying its semantics in an OMS language independent way would require additional institution infrastructure – and the same effect can be achieved by auxiliary definitional extensions, cf. Colore (so promote this, informatively, as a “best practice”?) TM: Alternatively, we could use a recent notion of institutional monad. This builds an extended signature with all terms. Then one can use ordinary signature morphisms into such extended signatures.

```
OMSLangTransRef ::= IRI
```

## 9.4. OMS Mappings

A OMS mapping provides a connection between two OMS. A OMS mapping definition is the definition of either a named interpretation (`IntprDefn`, `Entailment` or `EquivDefn`), a named declaration of the relation between a module of an OMS and the whole OMS (`ModuleRelDefn`), or a named alignment (`AlignDefn`).

The `SymbolMapItems` in an interpretation always must lead to a signature morphism; a proof obligation expressing that the (translated) source OMS logically follows from the target OMS is generated. An entailment is a variant where all symbols are mapped identically, while an equivalence states that the model classes of two OMS are in bijective correspondence.

Interpretations, entailments and equivalences between OMS networks are also possible. An interpretation between OMS networks has to specify both a mapping between the nodes of the OMS network, as well as, for each node, a symbol map from the OMS of that node to the target OMS to which it is mapped.

In contrast to this functional style of mapping symbols, an alignment provides a relational connection between two OMS, using a set of `Correspondences`. Each correspondence may relate some OMS non-logical symbol to another one (possibly given by a term) with an optional confidence value. Moreover, the relation between the two non-logical symbols can be explicitly specified (like being equal, or only being subsumed) in a similar way to the `Alignment API` [?]. The relations that can be used in a correspondence are equivalence, disjointness, subsumption, membership (the last two with a variant for each direction) or a user-defined relation that is stored in a registry and must be prefixed with `purl.net/DOL`. A default correspondence can be used; it is applied to all pairs of non-logical symbols with the same local names. The default relation in a correspondence is equivalence, unless a different relation is specified in a surrounding `'CorrespondenceBlock'`. Using an `AlignCard`, left and right injectivity and totality of the alignment can be specified (the default is left-injective, right-injective, left-total and right-total). With `AlignSem`, different styles of networks of aligned ontologies (to be interpreted in a logic-specific way) of alignments can be specified (whether a single domain is assumed, all domains are embedded into a global domain, or whether several local domains are linked (“contextualized”) by relations).

A `ModuleRelDefn` declares that a certain OMS actually is a module of some other OMS with respect to the `InterfaceSignature`.

```
MappingDefn      ::= IntprDefn
                  | Entailment
                  | EquivDefn
                  | ModuleRelDefn
                  | AlignDefn

IntprDefn        ::= intpr-defn IntprName [Conservative] IntprType
                  [SymbolMapItems]
                  | refinement IntprName Refinement

IntprName        ::= IRI
IntprType        ::= intpr-type OMS OMS
Refinement       ::= ref-oms OMS
                  | ref-network Network
                  | ref-composition Refinement Refinement
```

## 9. DOL abstract syntax

```

RefMap          ::= refmap-oms LogicTranslation* [SymbolMapItems]
                  | refmap-network NodeMap*
NodeMap         ::= node-map OMSName OMSName LogicTranslation*

Entailment      ::= entailment EntailmentName EntailmentType
EntailmentType  ::= oms-oms-entailment OMS OMS
                  | network-oms-entailment Network OMS
                  | network-network-entailment Network Network
EntailmentName  ::= IRI
EquivDefn       ::= equiv-defn EquivName EquivType
EquivName       ::= IRI
EquivType       ::= oms-equiv OMS OMS OMS
                  | network-equiv Network Network Network
ModuleRelDefn   ::= module-defn ModuleName [Conservative]
                  InterfaceSignature
ModuleName       ::= IRI
ModuleType      ::= module-type OMS OMS
AlignDefn       ::= align-defn AlignName [AlignCard] AlignType
                  Correspondence*5
AlignName       ::= IRI
AlignCards      ::= AlignCardForward AlignCardBackward
AlignCardForward ::= align-card-forward AlignCard
AlignCardBackward ::= align-card-backward AlignCard
AlignCard       ::= injective-and-total
                  | injective
                  | total
                  | neither-injective-nor-total
AlignType       ::= align-type OMS OMS
AlignSem        ::= single-domain
                  | global-domain
                  | contextualized-domain
Correspondence  ::= CorrespondenceBlock
                  | SingleCorrespondence
                  | default-correspondence
CorrespondenceBlock ::= correspondence-block [RelationRef]
                  Correspondence Correspondence*
SingleCorrespondence ::= correspondence SymbolRef [RelationRef]
                  TermOrSymbolRef [CorrespondenceID]
CorrespondenceID ::= IRI
SymbolRef        ::= IRI
TermOrSymbolRef  ::= Term | SymbolRef
RelationRef      ::= subsumes
                  | is-subsumed
                  | equivalent

```

<sup>5</sup>Note that this grammar uses “type” as in “the type of a function”, whereas the Alignment API uses “type” for the totality/injectivity of the relation/function. For the latter, this grammar uses “cardinality”.

## 9. DOL abstract syntax

```

| incompatible
| has-instance
| instance-of
| default-relation
| IRI
Confidence ::= Double

```

Double ::= < a number  $\in [0, 1]$  >

A symbol map in an interpretation is **required** to cover all non-logical symbols of the source OMS; the semantics specification in clause 11 makes this assumption<sup>6</sup>. Applications **shall** implicitly map those non-logical symbols of the source OMS, for which an explicit mapping is not given, to non-logical symbols of the same (local) name in the target OMS, wherever this is uniquely defined – in detail:

**Require:**  $O_s, O_t$  are OMS

**Require:**  $M \subseteq \Sigma(O_s) \times \Sigma(O_t)$  maps non-logical symbols (i.e. elements of the signature) of  $O_s$  to non-logical symbols of  $O_t$

**for all**  $e_s \in \Sigma(O_s)$  not covered by  $M$  **do**

$n_s \leftarrow \text{localname}(e_s)$

$N_t \leftarrow \{\text{localname}(e) \mid e \in \Sigma(O_t)\}$

**if**  $N_t = \{e_t\}$  **then** {i.e. if there is a unique target}

$M \leftarrow M \cup \{(e_s, e_t)\}$

**end if**

**end for**

**Ensure:**  $M$  completely covers  $\Sigma(O_s)$

The local name of a non-logical symbol is determined as follows<sup>7</sup>:

**Require:**  $e$  is a non-logical symbol (identified by an IRI; cf. clause 9.6)

**if**  $e$  has a fragment  $f$  **then** {production ifragment in IETF/RFC 3987:2005}

**return**  $f$

**else**

$n \leftarrow$  the longest suffix of  $e$  that matches the Nmtoken production of XML W3C/TR REC-xml:2008

**return**  $n$

**end if**

### 9.5. Queries

Queries are a means to extract information from an OMS. DOL' QueryDefns cover “select”-type queries that deliver an answer substitution for the query variables. (Answer) substitutions can be stored separately, using a SubstDefn. A ResultDefn expresses that certain answer

<sup>6</sup>Mapping a non-logical symbol twice is an error. Mapping two source non-logical symbols to the same target non-logical symbol is legal, this then is a non-injective OMS mapping.

<sup>7</sup>In practice, this can often have the effect of undoing an IRI abbreviation mechanism that was used when writing the respective OMS (cf. clause 9.6). In general, however, functions that turn abbreviations into IRIs are not invertible. For this reason, the implicit mapping of non-logical symbols is specified independently from IRI abbreviation mechanisms possibly employed in the OMS.

## 9. DOL abstract syntax

substitutions are the result of a query. Optionoally, a result can be expressed to be complete, meaning that it comprises all answer substitutions to the query.

```
QueryRelatedDefn ::= QueryDefn | SubstDefn | ResultDefn
QueryDefn        ::= select-query-defn QueryName Vars Sentence
                                   [Translation]
SubstDefn        ::= subst-defn SubstName OMS OMS SymbolMap
ResultDefn       ::= result-def ResultName SubstName SubstName*
                                   [Complete]

QueryName        ::= IRI
SubstName        ::= IRI
ResultName       ::= IRI
Vars             ::= Symbol*
Complete        ::= complete
```

## 9.6. Identifiers

This section specifies the abstract syntax of identifiers of DOL OMS and their elements.

### 9.6.1. IRIs

In accordance with best practices for publishing OMS on the Web, identifiers of OMS and their elements **should** not just serve as *names*, but also as *locators*, which, when dereferenced, give access to a concrete representation of an OMS or one of its elements. (For the specific case of RDFS and OWL OMS, these best practices are documented in [20]. The latter is a specialization of the linked data principles, which apply to any machine-processable data published on the Web [28].) It is recommended that publicly accessible DOL OMS be published as linked data.

Therefore, in order to impose fewer conformance requirements on applications, DOL commits to using IRIs for identification IETF/RFC 3987:2005. It is **recommended** that libraries use IRIs that translate to URLs when applying the algorithm for mapping IRIs to URIs specified in IETF/RFC 3987:2005, Section 3.1. DOL descriptions of any element of a library that is identified by a certain IRI **should** be *located* at the corresponding URL, so that agents can locate them. As IRIs are specified with a concrete syntax only in IETF/RFC 3987:2005, DOL adopts the latter into its abstract syntax as well as all of its concrete syntaxes (serializations)

In accordance with semantic web best practices such as the OWL Manchester Syntax [17], this OMG Specification does not allow relative IRIs, and does not offer a mechanism for defining a base IRI, against which relative IRIs could be resolved.

Concerning these languages, note that they allow arbitrary IRIs in principle, but in practice they strongly recommend using IRIs consisting of two components [20]:

**namespace** an IRI that identifies the complete OMS (a *basic OMS* in DOL terminology), usually ending with # or /

**local name** a name that identifies a non-logical symbol within an OMS

```
IRI    ::= full-iri FullIRI | curie CURIE8
FullIRI ::= < as defined by the IRI production in IETF/RFC 3987:2005 >
```

---

<sup>8</sup>specified below in clause 9.6.2

### 9.6.2. Abbreviating IRIs using CURIEs

As IRIs tend to be long, and as syntactic mechanisms for abbreviating them have been standardized, it is **recommended** that applications employ such mechanisms and support expanding abbreviative notations into full IRIs. For specifying the *semantics* of DOL, this OMG Specification assumes full IRIs everywhere, but the DOL abstract *syntax* adopts CURIEs (compact URI expressions) as an abbreviation mechanism, as it is the most flexible one that has been standardized to date.

The CURIE abbreviation mechanism works by binding prefixes to IRIs. A CURIE consists of a *prefix*, which may be empty, and a *reference*. If there is an in-scope binding for the prefix, the CURIE is valid and expands into a full IRI, which is created by concatenating the IRI bound to the prefix and the reference.

DOL adopts the CURIE specification of RDFa Core 1.1 W3C/TR REC-rdfa-core-20120607, Section 6 with the following changes:

- DOL does not support the declaration of a “default prefix” mapping (covering CURIEs such as `:name`).
- DOL does support the declaration of a “no prefix” mapping (covering CURIEs such as `name`). **If there is no explicit declaration for the “no prefix”, it defaults to a context-sensitive expansion mechanism, which always prepends the library IRI (in the context of a structured OMS where named OMS is referenced) resp. the current OMS IRI (in the context of a basic OMS) to a symbol name. Both the separator between the library and the OMS name and that between the OMS name and the symbol name can be declared (using the keyword *separators*), and both default to `“/”`.**
- DOL does not make use of the `safe_curie` production.
- DOL does not allow binding a relative IRI to a prefix.
- Concrete syntaxes of DOL are encouraged but **not required** to support CURIEs.<sup>9</sup>

CURIEs can occur in any place where IRIs are allowed, as stated in clause 9.6.1. Informatively, we can restate the CURIE grammar supported by DOL as follows:

```

CURIE    ::= [Prefix] Reference
Prefix   ::= NCName ':' < see “NCName” in W3C/TR REC-xml-names:2009, Section 3 >
Reference ::= Path [Query] [Fragment]
Path     ::= ipath-absolute | ipath-rootless | ipath-empty < as defined in IETF/RFC 3987 >
Query    ::= '?' iquery < as defined in IETF/RFC 3987 >
Fragment ::= '#' ifragment < as defined in IETF/RFC 3987 >

```

Prefix mappings can be defined at the beginning of a library (specified in clause 9.2; these apply to all parts of the library, including basic OMS as clarified in clause 9.6.3). Their syntax is:

<sup>9</sup>This is a concession to having an RDF-based concrete syntax among the normative concrete syntaxes. RDFa is the only standardized RDF serialization to support CURIEs so far. Other serializations, such as RDF/XML or Turtle, support a subset of the CURIE syntax, whereas some machine-oriented serializations, including N-Triples, only support full IRIs.

## 9. DOL abstract syntax

```
PrefixMap      ::= prefix-map PrefixBinding*
PrefixBinding  ::= prefix-binding BoundPrefix IRIBoundToPrefix

BoundPrefix    ::= bound-prefix [Prefix]
IRIBoundToPrefix ::= full-iri FullIRI
Separators     ::= separators String String
String         ::= < any list of unicode characters >
```

Bindings in a prefix map are evaluated from left to right. Authors **should not** bind the same prefix twice, but if they do, the later binding wins.

### 9.6.3. Mapping identifiers in basic OMS to IRIs

While DOL uses IRIs as identifiers throughout, basic OMS languages do not necessarily do; for example:

- OWL W3C/TR REC-owl2-syntax:2009, Section 5.5 does use IRIs.
- Common Logic ISO/IEC 24707:2007 supports them but does not enforce their use.
- F-logic [26] does not use them at all.

However, DOL OMS mappings as well as certain operations on OMS require making unambiguous references to non-logical symbols of basic OMS (*SymbolRef*). Therefore, DOL provides a function that maps global identifiers used within basic OMS to IRIs. This mapping affects all non-logical symbol identifiers (such as class names in an OWL ontology), but not locally-scoped identifiers such as bound variables in Common Logic ontologies. DOL reuses the CURIE mechanism for abbreviating IRIs for this purpose (cf. clause 9.6.2).

CURIEs that have a prefix may not be acceptable identifiers in every serialization of a basic OMS language, as the standard CURIE separator character, the colon (:), may not be allowed in identifiers. Therefore, the declaration of DOL-conformance of the respective serialization (cf. clause 2.2) **may** define an *alternative CURIE separator character*, or it **may** forbid the use of prefixed CURIEs altogether.

The IRI of a non-logical symbol identifier in a basic OMS *O* is determined by the following function:

**Require:** *D* is a library

**Require:** *O* is a basic OMS in serialization *S*

**Require:** *id* is the identifier in question, identifying a symbol in *O* according to the specification of *S*

**Ensure:** *i* is an IRI

**if** *id* represents a full IRI according to the specification of *S* **then**

*i* ← *id*

**else**

    {first construct a pattern *cp* for CURIEs in *S*, then match *id* against that pattern}

**if** *S* defines an alternative CURIE separator character *cs* **then**

*sep* ← *cs*

**else if** *S* forbids prefixed CURIEs **then**

*sep* ← undefined

**else**

*sep* ← : {the standard CURIE separator character}

**end if**



## 9. DOL abstract syntax

{The following statements construct a modified EBNF grammar of CURIes; see ISO/IEC 14977:1996 for EBNF, and clause 9.6.2 for the original grammar of CURIes.}

```

if sep is defined then
  cp  $\leftarrow$  [NCName, sep], Reference
else
  cp  $\leftarrow$  Reference
end if
if id matches the pattern cp, where ref matches Reference then
  if the match succeeded with a non-empty NCName pn then
    p  $\leftarrow$  concat(pn, :)
  else
    p  $\leftarrow$  no prefix
  end if
  if O binds p to an IRI pi according to the specification of S then
    nsi  $\leftarrow$  pi
  else
    P  $\leftarrow$  the innermost prefix map in D, starting from the place of O inside D, and going
    up the abstract syntax tree towards the root of D
    while P is defined do
      if P binds p to an IRI pi then
        nsi  $\leftarrow$  pi
        break out of the while loop
      end if
      P  $\leftarrow$  the next prefix map in D, starting from the place of the current P inside D,
      and going up the abstract syntax tree towards the root of D
    end while
    return an error
  end if
  i  $\leftarrow$  concat(nsi, ref)
else
  return an error
end if
end if
return i

```

This mechanism applies to basic OMS given inline in a library document (*BasicOMS*), not to OMS in external documents (*OMSInConformingLanguage*); the latter **shall be self-contained**.<sup>53</sup>

While CURIes used for identifying parts of a library (cf. clause 9.6.2) are merely syntactic sugar, the prefix map for a basic OMS is essential to determining the semantics of the basic OMS within the library. Therefore, any DOL serialization **shall** provide constructs for expressing such prefix maps, even if the serialization does not support prefix maps otherwise.

<sup>53</sup>

Note(53)

<sup>53</sup>NOTE: TODO: somewhere we need to mention semantic annotations to embedded fragments in conforming OMS languages, e.g. %implied

## 9.7. Annotations

<sup>54</sup> <sup>55</sup> Annotations always have a subject, which is identified by an IRI. Where the given OMS language does not provide a way of assigning IRIs to a desired subject of an annotation (e.g. if one wants to annotate an import in OWL), a library may employ RDF annotations that use XPointer or IETF/RFC 5147 as means of non-destructively referencing pieces of XML or text by URI.<sup>10</sup>

Note(54)

Note(55)

---

<sup>54</sup>NOTE: this subclause will be moved to annex M

<sup>55</sup>NOTE: TODO: Properly integrate this text from our LaRC 2011 paper

<sup>10</sup>We intend to utilise the extensibility of the XPointer framework by developing additional XPointer schemes, e.g. for pointing to subterms of Common Logic sentences.

## 10. DOL text serialization

+

### 10.1. Document type

**MIME type** *application/dol+text*<sup>56</sup>

Note(56)

**Filename extension** .dol<sup>57</sup>

Note(57)

### 10.2. Concrete Syntax

At several places, the concrete syntax uses the non-terminal 'end' to mark the end of a definition or declaration. Tools may make this 'end' optional. However, in this standard, we insist on the 'end', because it may be needed to effectively disambiguate heterogeneous texts.

#### 10.2.1. Libraries

```
Library                ::= [PrefixMap] LibraryDefn
                        | OMSInConformingLanguage
LibraryDefn            ::= 'library' LibraryName LibraryItem*
OMSInConformingLanguage ::= < language and serialization specific >
LibraryItem            ::= LibImport
                        | OMSDefn
                        | NetworkDefn
                        | MappingDefn
                        | QueryRelatedDefn
                        | Qualification
LibImport              ::= 'import' LibraryName
Qualification          ::= LanguageQual | LogicQual | SyntaxQual
LanguageQual           ::= 'language' LanguageRef
LogicQual              ::= 'logic' LogicRef
SyntaxQual             ::= 'serialization' SyntaxRef
LibraryName            ::= IRI
```

---

<sup>56</sup>NOTE: FYI: just a placeholder so far, needs discussion

<sup>57</sup>NOTE: the most intuitive one, but gives the text serialization a privileged role over the others

## 10. DOL text serialization

```

PrefixMap          ::= '%prefix(' PrefixBinding* ')%'
PrefixBinding      ::= BoundPrefix IRIBoundToPrefix [Separators]
BoundPrefix        ::= ':' | Prefix<see definition in clause 9.6.2>58
IRIBoundToPrefix   ::= '<' FullIRI '>'
Separators         ::= 'separators' String String
NetworkDefn        ::= NetworkKeyword NetworkName '='
                    Network
NetworkKeyword      ::= 'network'
NetworkName        ::= IRI
Network            ::= NetworkElements ExcludeExtensions
NetworkElements    ::= NetworkElement ( ',' NetworkElement )*
NetworkElement     ::= [Id ':'] OMSOrMappingorNetworkRef
ExcludeExtensions  ::= 'excluding' ExtensionRef ( ',' ExtensionRef )*
OMSOrMappingorNetworkRef ::= IRI
Id                 ::= Letter LetterOrDigit*

```

Note(58)

Note that we denote the empty prefix (called “no prefix” in W3C/TR REC-rdfa-core-20120607, Section 6) by a colon inside the prefix map, but completely omit it in CURIEs. This is the style of the OWL Manchester syntax [17] but differs from the RDFa Core 1.1 syntax.

### 10.2.2. Focused OMS

```

BasicOMS           ::= OMSInConformingLanguage
MinimizableOMS     ::= BasicOMS | OMSRef [ImportName]
ExtendingOMS       ::= MinimizableOMS
                    | MinimizeKeyword '{' MinimizableOMS '}'
                    | OMS Extraction
OMS                ::= ExtendingOMS
                    | OMS Minimization
                    | OMS Translation
                    | OMS Reduction
                    | OMS Approximation
                    | OMS Filtering
                    | OMS 'and' [ConsStrength] OMS
                    | OMS 'then' ExtensionOMS
                    | Qualification* ':' GroupOMS
                    | OMS 'bridge' Translation* OMS
                    | 'combine' NetworkElements [ExcludeExtensions]
                    | 'apply' SubstName Sentence
                    | GroupOMS
Minimization       ::= MinimizeKeyword CircMin [CircVars]
MinimizeKeyword    ::= 'minimize'
                    | 'closed-world'
                    | 'maximize'

```

<sup>58</sup>NOTE: Q-AUT: I think that, in contrast to OWL Manchester, we can allow prefix names that match keywords of the DOL syntax, as we are enclosing the whole prefix map into an annotation construct – right?

## 10. DOL text serialization

```

      | 'free'
      | 'cofree'
CircMin      ::= Symbol Symbol*
CircVars     ::= 'vars' (Symbol Symbol*)
GroupOMS     ::= '{' OMS '}' | OMSRef
Translation  ::= 'with' LogicTranslation* SymbolMapItems
              | 'with' LogicTranslation LogicTranslation*
LogicTranslation ::= 'translation' OMSLangTrans
Reduction     ::= 'hide' LogicReduction* SymbolItems
              | 'hide' LogicReduction LogicReduction*
              | 'reveal' SymbolMapItems
LogicReduction ::= 'along' OMSLangTrans
SymbolItems    ::= Symbol ( ',' Symbol )*
SymbolMapItems ::= SymbolOrMap ( ',' SymbolOrMap )*
Extraction     ::= 'extract' [InterfaceSignature]
              | 'remove' [InterfaceSignature]
Approximation  ::= 'forget' InterfaceSignature ['with' LogicRef]
              | 'keep' InterfaceSignature ['with' LogicRef]
Filtering      ::= 'select' BasicOMS | 'reject' BasicOMS
ExtensionOMS   ::= [ExtConsStrength] [ExtensionName] ExtendingOMS
ConsStrength   ::= Conservative | '%mono' | '%wdef' | '%def'
ExtConsStrength ::= ConsStrength | '%implied'
Conservative   ::= '%ccons' | '%mcons'
InterfaceSignature ::= SymbolItems
ImportName     ::= '%(' IRI ')%'
ExtensionName  ::= '%(' IRI ')%'
OMSKeyword     ::= 'ontology'
              | 'onto'
              | 'specification'
              | 'spec'
              | 'model'
              | 'OMS'
OMSDefn        ::= OMSKeyword OMSName '=' [ConsStrength] OMS 'end'
Symbol         ::= IRI
SymbolMap      ::= Symbol '|->' Symbol
SymbolOrMap    ::= Symbol | SymbolMap
OMSName        ::= IRI
OMSRef         ::= IRI
ExtensionRef    ::= IRI
LanguageRef    ::= IRI
LogicRef       ::= IRI
SyntaxRef      ::= IRI
LoLaRef        ::= LanguageRef | LogicRef

OMSLangTrans ::= OMSLangTransRef | '|->' LoLaRef
OMSLangTransRef ::= IRI

```

**10.2.3. OMS Mappings**

```

MappingDefn      ::= IntprDefn
                  | Entailment
                  | EquivDefn
                  | ModuleRelDefn
                  | AlignDefn
IntprDefn        ::= IntprKeyword IntprName [Conservative] ':'
                  'end'
                  | IntprKeyword IntprName [Conservative] ':'
                  '=' LogicTranslation* [SymbolMapItems]

                  | IntprKeyword IntprName '=' Refinement 'end'
IntprKeyword     ::= 'interpretation' | 'view' | 'refinement'
IntprName        ::= IRI
IntprType        ::= GroupOMS 'to' GroupOMS
Refinement       ::= OMS
                  | Network
                  | Refinement 'then' Refinement
                  | OMS 'refined' [RefMap] 'to' Refinement
RefMap           ::= 'via' LogicTranslation* [SymbolMapItems]
                  | 'via' NodeMap ( ',' NodeMap )*
NodeMap          ::= OMSName '|->' OMSName

Entailment       ::= 'entailment' EntailmentName '=' EntailmentType
EntailmentName   ::= IRI
EntailmentType   ::= GroupOMS 'entails' OMS
                  | Network 'entails' OMS
                  | Network 'entails' Network
EquivDefn        ::= 'equivalence' EquivName ':' EquivType 'end'
EquivName        ::= IRI
EquivType        ::= GroupOMS '<->' GroupOMS '=' OMS
                  | Network '<->' Network '=' Network
ModuleRelDefn    ::= 'module' ModuleName [Conservative] ':'
                  'for' InterfaceSignature
ModuleName        ::= IRI
ModuleType        ::= OMS 'of' OMS
AlignDefn        ::= 'alignment' AlignName [AlignCards] ':'
                  'end'
                  | 'alignment' AlignName [AlignCards] ':'
                  '=' Correspondence ( ',' Correspondence )*
                  AlignSem 'end'
AlignName         ::= IRI
AlignCards        ::= AlignCardForward AlignCardBackward

```

<sup>59</sup>NOTE: %safe is more a statement about an import of a module, and hence should be a statement in an OMS network. Recall: ModuleProperties = '%safe';

## 10. DOL text serialization

```
AlignCardForward    ::= AlignCard
AlignCardBackward   ::= AlignCard
AlignCard            ::= '1' | '?' | '+' | '*'
AlignType            ::= GroupOMS 'to' GroupOMS
AlignSem             ::= 'SingleDomain'
                     | 'GlobalDomain'
                     | 'ContextualizedDomain'
Correspondence       ::= CorrespondenceBlock | SingleCorrespondence | '*'
CorrespondenceBlock ::= 'relation' [RelationRef] [Confidence] '{'
                     ( ',' Correspondence )* '}'
SingleCorrespondence ::= SymbolRef [RelationRef] [Confidence]
                     [CorrespondenceId]
CorrespondenceId     ::= '%(' IRI ')%'
SymbolRef            ::= IRI
TermOrSymbolRef      ::= Term | SymbolRef
RelationRef          ::= '>' | '<' | '=' | '%' | 'ni' | 'in' | IRI
Confidence           ::= Double
```

Double ::= < a number  $\in [0,1]$  >

### 10.2.4. Queries

**new!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!**

```
QueryRelatedDefn ::= QueryDefn | SubstDefn | ResultDefn
QueryDefn         ::= 'query' QueryName '=' 'select' Vars 'where' Sentence
                     OMS ['along' Translation]
SubstDefn         ::= 'substitution' SubstName ':' OMS 'to' OMS '=' SymbolMap
ResultDefn        ::= 'result' ResultName SubstName ( ',' SubstName )*
                     QueryName ['%complete']
QueryName         ::= IRI
SubstName         ::= IRI
ResultName        ::= IRI
Vars              ::= Symbol ( ',' Symbol )*
```

## 10.3. Identifiers

```
IRI                ::= '<' FullIRI '>' | CURIE
FullIRI            ::= < an IRI as defined in IETF/RFC 3987:2005 >
CURIE              ::= [Prefix] Reference
Prefix             ::= NCName ':' < see "NCName" in W3C/TR REC-xml-names:2009, Section 3 >
Reference          ::= Path [Query] [Fragment]
Path               ::= ipath-absolute | ipath-rootless | ipath-empty < as defined in IETF/RFC 3987 >
```

## 10. DOL text serialization

Query ::= '?' iquery< as defined in IETF/RFC 3987 >  
Fragment ::= '#' ifragment< as defined in IETF/RFC 3987 >

In a CURIE without a prefix, the `reference` part is **not allowed** to match any of the keywords of the DOL syntax (cf. clause ).

### 10.4. Lexical Symbols

The character set for the DOL text serialization is the UTF-8 encoding of Unicode ISO/IEC 10646. However, OMS can always be input in the Basic Latin subset, also known as ASCII.<sup>60</sup> For enhanced readability of OMS, the DOL text serialization particularly supports the native Unicode glyphs that represent common mathematical operators.

Note(60)

#### 10.4.1. Key Words and Signs

The lexical symbols of the DOL text serialization include various key words and signs that occur as terminal symbols in the context-free grammar in annex 10.2. Key words and signs that represent mathematical signs are displayed as such, when possible, and those signs that are available in the Unicode character set may also be used for input.

##### Key Words

Key words are always written lowercase. The following key words are reserved, and are not available for use as complete identifiers<sup>61</sup>, although they can be used as parts of tokens:

Note(61)

and end hide interpretation library logic minimize network  
model onto ontology spec specification reveal then to vars view with

##### Key Signs

Table 10.1 following key signs are reserved, and are not available for use as complete identifiers. Key signs that are outside of the Basic Latin subset of Unicode may alternatively be encoded as a sequence of Basic Latin characters.

### 10.5. Integration of Serializations of Conforming Languages

Any document providing an OMS in a serialization of a DOL conformant language can be used as-is in DOL, by reference to its IRI.

<sup>60</sup>NOTE: TODO: maybe we need to say something about encoding IRIs as URIs in the latter case

<sup>61</sup>NOTE: TODO: figure out what that actually means. If we use OWL Manchester's style of abbreviating IRIs, it probably means that in the worst case some IRIs can't be abbreviated but must be given as complete global IRIs



## 10. DOL text serialization

Table 10.1.: Key Signs

Sign	Unicode Code Point	Basic Latin substitute
{	U+007B LEFT CURLY BRACKET	
}	U+007D RIGHT CURLY BRACKET	
:	U+003A COLON	
=	U+003D EQUALS SIGN	
,	U+002C COMMA	
↦	U+21A6 RIGHTWARDS ARROW FROM BAR	->
→	U+2192 RIGHTWARDS ARROW	->

# 11. DOL semantics

We pursue a threefold approach of assigning a semantics to the DOL abstract syntax:

**Direct Model-Theoretic Semantics** On the level of basic OMS, this semantics reuses the existing semantics of the involved logics, as well as translations between these logics. The semantics of structured DOL OMS and OMS mappings is specified on top of this.

**Translational Semantics** The semantics of Common Logic is employed for all basic OMS languages, taking advantage of the fact that Common Logic is a common translation target for many OMS languages. In detail, the translational semantics first translates the DOL abstract syntax into the abstract syntax of  $DOL(CL)$ , where  $DOL(CL)$  is the homogeneous restriction of DOL to libraries with all parts written in Common Logic only. The latter is interpreted as in the case of the direct semantics, with basic OMS interpreted in terms of the existing Common Logic semantics.

**Collapsed Semantics** The collapsed semantics extends the translational semantics to a semantics that is fully given specified in Common Logic. It further translates the abstract syntax  $DOL(CL)$  to Common Logic, and then reuses the semantics of Common Logic, without employing a separate semantics for the DOL language. Here, the meta and object levels are collapsed into Common Logic, but may still be distinguished by a closer look into the Common Logic theory.

The model-theoretic nature of the semantics ensures a better representation of the model theory than a theory-level semantics would do. In particular, Theorem 13 of [35] ensures that models classes of logical theories represented in Common Logic can be recovered through a model translation. This is of particular importance when studying model-theoretic properties like finite model or tree model properties.

We now specify the theoretical foundations of the semantics of DOL. Since DOL involves heterogeneous OMS, the semantics is parameterized over an arbitrary but fixed *heterogeneous environment*. This notion is defined below and it corresponds to a graph of OMS languages and OMS language translations and reductions. Below, also notions of *institution* and institution *comorphism* and *morphism* are defined, which provide formalizations of the terms *logic*, resp. *logic translation*, resp. *logic reduction*.

Details of the mapping of the abstract syntax into the semantic domains given by the heterogeneous logic environment will be provided later.

We recall the notion of satisfaction system [7], called ‘rooms’ in the terminology of [11]. They capture the Tarskian notion of satisfaction of a sentence in a model. For the semantics of minimization, we assume a pre-order on models.<sup>62</sup>

Note(62)

**Definition 1** A triple  $\mathcal{R} = (Sen, \mathcal{M}, \models)$  is called a **satisfaction system**, or **room**, if  $\mathcal{R}$  consists of

- a set  $Sen$  of **sentences**,

<sup>62</sup>NOTE: Till, do you have a reason to want to have rooms in this document? I would keep technical concepts to a minimum.

## 11. DOL semantics

- a pre-ordered class  $\mathcal{M}$  of **models**, and
- a binary relation  $\models \subseteq \mathcal{M} \times \text{Sen}$ , called the **satisfaction relation**.

While this signature-free treatment enjoys simplicity and is wide-spread in the literature, many concepts and definitions found in logics, e.g. the notion of a conservative extension, involve the *vocabulary* or *signature*  $\Sigma$  used in sentences. Signatures can be extended with new non-logical symbols; abstractly, this leads to an ordering relation on signatures.

**Definition 2** An **institution** [12] is a quadruple  $I = (\text{Sign}, \text{Sen}, \text{Mod}, \models)$  consisting of the following:

- a category  $\text{Sign}$  of signatures and signature morphisms,
- a functor  $\text{Sen} : \text{Sign} \rightarrow \text{Set}^1$  giving, for each signature  $\Sigma$ , the set of sentences  $\text{Sen}(\Sigma)$ , and for each signature morphism  $\sigma : \Sigma \rightarrow \Sigma'$ , the sentence translation map  $\text{Sen}(\sigma) : \text{Sen}(\Sigma) \rightarrow \text{Sen}(\Sigma')$ , where often  $\text{Sen}(\sigma)(\varphi)$  is written as  $\sigma(\varphi)$ ,
- a functor  $\text{Mod} : \text{Sign}^{\text{op}} \rightarrow \text{Cat}^2$  giving, for each signature  $\Sigma$ , the category of models  $\text{Mod}(\Sigma)$ , and for each signature morphism  $\sigma : \Sigma \rightarrow \Sigma'$ , the reduct functor  $\text{Mod}(\sigma) : \text{Mod}(\Sigma') \rightarrow \text{Mod}(\Sigma)$ , where often  $\text{Mod}(\sigma)(M')$  is written as  $M' \upharpoonright_{\sigma}$ , and  $M' \upharpoonright_{\sigma}$  is called the  $\sigma$ -reduct of  $M'$ , while  $M'$  is called a  $\sigma$ -expansion of  $M' \upharpoonright_{\sigma}$ ,
- a satisfaction relation  $\models_{\Sigma} \subseteq |\text{Mod}(\Sigma)| \times \text{Sen}(\Sigma)$  for each  $\Sigma \in |\text{Sign}|$ ,

such that for each  $\sigma : \Sigma \rightarrow \Sigma'$  in  $\text{Sign}$  the following **satisfaction condition** holds:

$$(\star) \quad M' \models_{\Sigma'} \sigma(\varphi) \text{ iff } M' \upharpoonright_{\sigma} \models_{\Sigma} \varphi$$

for each  $M' \in |\text{Mod}(\Sigma')|$  and  $\varphi \in \text{Sen}(\Sigma)$ , expressing that truth is invariant under change of notation and context.  $\square$

**Definition 3 (Propositional Logic)** The signatures of propositional logic are sets  $\Sigma$  of propositional symbols, and signature morphisms are just functions  $\sigma : \Sigma_1 \rightarrow \Sigma_2$  between these sets. A  $\Sigma$ -model is a function  $M : \Sigma \rightarrow \{\text{True}, \text{False}\}$ , and the reduct of a  $\Sigma_2$ -model  $M_2$  along a signature morphism  $\sigma : \Sigma_1 \rightarrow \Sigma_2$  is the  $\Sigma_1$ -model given by the composition of  $\sigma$  with  $M_2$ .  $\Sigma$ -sentences are built from the propositional symbols with the usual connectives, and sentence translation is replacing the propositional symbols along the morphism. Finally, the satisfaction relation is defined by the standard truth-tables semantics. It is straightforward to see that the satisfaction condition holds.

**Definition 4 (Common Logic - CL)** A common logic signature  $\Sigma$  (called *vocabulary* in Common Logic terminology) consists of a set of names, with a subset called the set of discourse names, and a set of sequence markers. A  $\Sigma$ -model consists of a set  $UR$ , the universe of reference, with a non-empty subset  $UD \subseteq UR$ , the universe of discourse, and four mappings:

- *rel* from  $UR$  to subsets of  $UD^* = \{ \langle x_1, \dots, x_n \rangle \mid x_1, \dots, x_n \in UD \}$  (i.e., the set of finite sequences of elements of  $UD$ );
- *fun* from  $UR$  to total functions from  $UD^*$  into  $UD$ ;
- *int* from names in  $\Sigma$  to  $UR$ , such that  $\text{int}(v)$  is in  $UD$  if and only if  $v$  is a discourse name;

<sup>1</sup>Set is the category having all small sets as objects and functions as arrows.

<sup>2</sup>Cat is the category of categories and functors. Strictly speaking, Cat is not a category but only a so-called quasicategory, which is a category that lives in a higher set-theoretic universe.

## 11. DOL semantics

- *seq* from sequence markers in  $\Sigma$  to  $UD^*$ .

A  $\Sigma$ -sentence is a first-order sentence, where predications and function applications are written in a higher-order like syntax:  $t(s)$ . Here,  $t$  is an arbitrary term, and  $s$  is a sequence term, which can be a sequence of terms  $t_1 \dots t_n$ , or a sequence marker. A predication  $t(s)$  is interpreted by evaluating the term  $t$ , mapping it to a relation using *rel*, and then asking whether the sequence given by the interpretation  $s$  is in this relation. Similarly, a function application  $t(s)$  is interpreted using *fun*. Otherwise, interpretation of terms and formulae is as in first-order logic. A further difference is the presence of sequence terms (namely sequence markers and juxtapositions of terms), which denote sequences in  $UD^*$ , with term juxtaposition interpreted by sequence concatenation. Note that sequences are essentially a non-first-order feature that can be expressed in second-order logic. For details, see [?].

A CL signature morphism consists of two maps between the sets of names and of sequence markers, such that the property of being a discourse name is preserved and reflected.<sup>3</sup> Model reducts leave *UR*, *UD*, *rel* and *fun* untouched, while *int* and *seq* are composed with the appropriate signature morphism component.

Further examples of institutions are:  $SR\mathcal{O}I\mathcal{Q}(D)$ , Common Logic, unsorted first-order logic, many-sorted first-order logic, and many others. Note that reduct is generally given by forgetting parts of the model.

Assume an arbitrary institution.

A **theory** is a pair  $(\Sigma, \Delta)$  where  $\Sigma$  is a signature and  $\Delta$  is a set of  $\Sigma$ -sentences. A theory  $(\Sigma, \Delta)$  is **consistent** if there exists a  $\Sigma$ -model  $M$  such that  $M \models \varphi$  for  $\varphi \in \Delta$ . **Semantic entailment** is defined as usual: for a theory  $\Delta \subseteq \text{Sen}$  and  $\varphi \in \text{Sen}$ , we write  $\Delta \models \varphi$ , if all models satisfying all sentences in  $\Delta$  also satisfy  $\varphi$ .

Institution comorphisms capture the intuition of encoding or embedding a logic into a more expressive one.

**Definition 5 (Institution Comorphism)** Given two institutions  $I$  and  $J$  with  $I = (\text{Sign}^I, \text{Mod}^I, \text{Sen}^I, \models^I)$  and  $J = (\text{Sign}^J, \text{Mod}^J, \text{Sen}^J, \models^J)$ , an **institution comorphism** from  $I$  to  $J$  consists of a functor  $\Phi : \text{Sign}^I \rightarrow \text{Sign}^J$ , and natural transformations  $\beta : \text{Mod}^J \circ \Phi \Rightarrow \text{Mod}^I$  and  $\alpha : \text{Sen}^I \Rightarrow \text{Sen}^J \circ \Phi$ , such that

$$M' \models_{\Phi(\Sigma)}^J \alpha_\Sigma(\varphi) \Leftrightarrow \beta_\Sigma(M') \models_\Sigma^I \varphi.$$

holds, called the **satisfaction condition**.

Here,  $\Phi(\Sigma)$  is the translation of the signature  $\Sigma$  from institution  $I$  to institution  $J$ ,  $\alpha_\Sigma(\varphi)$  is the translation of the  $\Sigma$ -sentence  $\varphi$  to a  $\Phi(\Sigma)$ -sentence, and  $\beta_\Sigma(M')$  is the translation (or perhaps better: reduction) of the  $\Phi(\Sigma)$ -model  $M'$  to a  $\Sigma$ -model.

Institution morphisms capture the intuition of projecting from a more expressive logic to a less expressive one.

**Definition 6 (Institution Morphism)** Given two institutions  $I$  and  $J$  with  $I = (\text{Sign}^I, \text{Mod}^I, \text{Sen}^I, \models^I)$  and  $J = (\text{Sign}^J, \text{Mod}^J, \text{Sen}^J, \models^J)$ , an **institution morphism** from  $I$  to  $J$  consists of a functor  $\Phi : \text{Sign}^I \rightarrow \text{Sign}^J$ , and natural transformations  $\beta : \text{Mod}^I \Rightarrow \text{Mod}^J \circ \Phi$  and  $\alpha : \text{Sen}^J \circ \Phi \Rightarrow \text{Sen}^I$ , such that

$$M \models_\Sigma^I \alpha_\Sigma(\varphi) \Leftrightarrow \beta_{\Phi(\Sigma)}(M) \models_{\Phi(\Sigma)}^J \varphi.$$

holds, called the **satisfaction condition**.

<sup>3</sup>That is, a name is a discourse name if and only if its image under the signature morphism is.

## 11.1. Direct semantics of DOL language constructs

The semantics of DOL is based on a fixed (but in principle arbitrary) heterogeneous logical environment. The semantic domains are based on this heterogeneous logical environment. A specific heterogeneous logical environment is given in the annexes.

A heterogeneous logical environment is given by a collection of OMS languages and OMS language translations<sup>4</sup>, a collection of institutions, institution morphisms and institution comorphisms (serving as logics, logic reductions and logic translations), and a collection of serializations. Moreover, there is a binary supports relation between OMS languages and institutions, and a binary supports relation between OMS languages and serializations.

We assume that for each institution in the heterogeneous logical environment there is a trivial signature  $\emptyset$  with model class  $\mathcal{M}_\emptyset$ .<sup>64</sup> Moreover, we assume that for each signature  $\Sigma$ , there is a set of non-logical symbols  $ent(\Sigma)$ , such that  $\Sigma \leq \Sigma'$  implies  $ent(\Sigma) \subseteq ent(\Sigma')$ .<sup>65</sup>

Note(64)

Note(65)

We assume that for each institution, there exist (possibly partial) union and difference operations on signatures. Some of the comorphisms are marked as default translations.

This concludes the definition of heterogeneous logical environment and the assumptions made about it.

DOL follows a model-theoretic approach on semantics: the semantics of OMS will be defined as a class of models over some signature of an institution. This is called *model-level* semantics. In some cases, but not in all, we can also define a *theory-level* semantics of an OMS as a set of sentences over some signature of an institution. The two semantics are related by the fact that, when both the model-level and the theory-level semantics of an OMS are defined, they are compatible in the sense that the class of models given by the model-level semantics is exactly the model class of the theory given by the theory-level semantics.

We will use the notations  $sem^T(O)$  and  $sem^M(O)$  for the theory-level and model-level semantics of an OMS  $O$ , respectively. Thus,  $sem^T(O)$  will be a triple  $(I, \Sigma, \Delta)$  and  $sem^M(O)$ , a triple  $(I, \Sigma, \mathcal{M})$ , where  $I$  is an institution,  $\Sigma$  is a signature of  $I$ ,  $\Delta$  is a set of  $\Sigma$ -sentences and  $\mathcal{M}$  a class of  $\Sigma$ -models. The compatibility mentioned above can be then formally expressed as follows. Let  $O$  be a OMS such that  $sem^T(O) = (I, \Sigma, \Delta)$ . Then

$$sem^M(O) = \{I, \Sigma, \{M \in \text{Mod}^I(\Sigma) \mid M \models^I \Delta\}\}.$$

We assume a *language-specific semantics* of basic OMS, inherited from the OMS language. For a basic OMS  $O$  in a language  $L$  based on an institution  $I$  we denote by  $sem_L^T(O)$  the theory-level language-specific semantics of  $O$  and by  $sem_L^M(O)$ , the model-level language-specific semantics of  $O$ .

The semantics of OMS generally depends on a global environment  $\Gamma$  mapping IRIS to semantics of OMS (given below), and a current triple  $L$  consisting of the current language,

<sup>63</sup>NOTE: Introduce exactness

<sup>4</sup>The terms *OMS language* and *serialization* are not defined formally. For this semantics, it suffices to know that there is a language-specific semantics of basic OMS as defined below.

<sup>64</sup>NOTE: require initiality?

<sup>65</sup>NOTE: this must be updated, we have institutions now.

logic and serialization.<sup>566 67</sup>

Note(66)

Note(67)

### 11.1.1. Semantics of Libraries

We define the semantics of DOL constructs regarding libraries.

$$\boxed{\text{sem}_{\Gamma}(\text{LibraryDefn}) = \Gamma'}$$

$\text{sem}(\Gamma, L, \text{'library' } , \text{ LibraryName } , DI_1, \dots, DI_n) = (\Sigma, M)$   
 where  $\text{sem}(\dots \text{sem}(\text{sem}(\Gamma, L, DI_1), DI_2), \dots, DI_n) = (\Gamma', L')$ <sup>68</sup>

Note(68)

$$\boxed{\text{sem}(\Gamma, L, \text{OMSInConformingLanguage}) = \Gamma'}$$

where  $\Gamma' = \Gamma[\text{IRI} \mapsto (L, \Sigma, \mathcal{M})]$ ,  
 $(\Sigma, \mathcal{M}) = \text{sem}(L, \text{OMSInConformingLanguage})$   
 and IRI is the IRI of OMSInConformingLanguage.

$$\boxed{\text{sem}(L, \text{Qualification}) = L'}$$

$\text{sem}((\text{lang}, \text{logic}, \text{ser}), \text{'lang-select' } , \text{ LanguageRef}) = (\text{LanguageRef}, \text{logic}', \text{ser}')$   
 where  $\text{logic}' = \begin{cases} \text{logic}, & \text{if LanguageRef supports logic} \\ \text{default logic for LanguageRef}, & \text{otherwise} \end{cases}$

$\text{ser}' = \begin{cases} \text{ser}, & \text{if LanguageRef supports ser} \\ \text{default serialization for LanguageRef}, & \text{otherwise} \end{cases}$

$\text{sem}((\text{lang}, \text{logic}, \text{ser}), \text{'logic-select' } , \text{ LogicRef}) = (\text{lang}', \text{LogicRef}, \text{ser})$   
 where  $\text{lang}' = \begin{cases} \text{lang}, & \text{if lang supports LogicRef} \\ \text{the unique language supporting LogicRef}, & \text{otherwise} \end{cases}$

Note that “the unique language supporting LogicRef” may be undefined; in this case, the semantics of the whole ‘logic-select’ , LogicRef construct is undefined.

$\text{sem}((\text{lang}, \text{logic}, \text{ser}), \text{'logic-select' } , \text{ SyntaxRef}) = (\text{lang}, \text{logic}, \text{SyntaxRef})$

The semantics is defined only if lang supports SyntaxRef.

$$\boxed{\text{sem}(L, \text{Qualification}^*) = L'}$$

$$\text{sem}(L, Q_1 \dots Q_n) = \text{sem}(\dots \text{sem}(\text{sem}(L, Q_1), Q_2), \dots, Q_n)$$

$$\boxed{\text{sem}(\Gamma, L, \text{LibraryItem}) = (\Gamma', L')}$$

$\text{sem}(\Gamma, L, \text{Qualification}) = (\Gamma, L')$  where  $L' = \text{sem}(L, \text{Qualification})$ .

Equations for OMSDefn and MappingDefn are given below.

<sup>5</sup>The initial  $L$  is obtained from the file name extension of the file containing a particular library, while  $\Gamma$  is obtained by looking up IRIs in the internet and applying the semantics to thus obtained OMS.

<sup>66</sup>NOTE: Q-AUT: @TM: Please decide if you like the stuff from ‘network-defn’. I have now used literal ISO-conforming EBNF syntax here, which means that keywords are enclosed in single quotes, and all tokens separated by commas.

<sup>67</sup>NOTE: @MC: explain what the purpose of a global env is

<sup>68</sup>NOTE: LibraryName is not used. How could we use it? It seems that the individual OMS are directly named with IRIs, and the LibraryName is not relevant for that? Answer from telco: The LibraryName is an IRI that should (as a good practice, but not enforced) agree with the IRI of the document. Indeed, this applies to any usage of IRI in the standard. This should be stated in the standard (Christoph). (This is known as “linked data compliance”, a good practice to be encouraged but not to be enforced, as it would break a lot of old OMS)

### 11.1.2. Semantics of focused OMS

$$\boxed{sem(\Gamma, L, (\Sigma, \mathcal{M}), \text{MinimizableOMS}) = (I, \Sigma', \mathcal{M}')$$

In the context of a global environment  $\Gamma$ , the current language, logic and serialization  $L$ , and a local environment  $(\Sigma, \mathcal{M})$  (of previously declared non-logical symbols), an OMS (`MinimizableOMS`)  $O$  is interpreted as an institute  $\mathcal{I} = \text{logic}(\Gamma, L, O)$ , a signature  $\Sigma = \text{sig}(\Gamma, L, O)$  in institute  $\mathcal{I}$  and a class of models  $\mathcal{M} = \text{Mod}(\Gamma, L, O)$  over signature  $\Sigma$ . We combine this into  $sem(\Gamma, L, O) = (\text{logic}(\Gamma, L, O), \text{sig}(\Gamma, L, O), \text{Mod}(\Gamma, L, O))$ .

For an OMS `BasicOMS` with current language, logic and serialization  $L$ , the theory-level semantics are defined as follows:

$$\boxed{sem^T(\text{BasicOMS}) = sem_L(\text{BasicOMS})}$$

The model-level semantics of `BasicOMS` are then obtained:

$$\boxed{sem^M(\text{BasicOMS}) = (I, \Sigma, M)}$$

where  $M = \{M \in \text{Mod}(\Sigma) \mid M \models \Delta\}$ .

$$\boxed{sem^M('oms-ref' , \text{OMSRef}) = \Gamma(\text{OMSRef})}$$

$$\boxed{sem^M('oms-ref' , \text{OMSRef}, \text{ImportName}) = \Gamma(\text{OMSRef})}$$

Note that  $\Gamma(\text{OMSRef})$  may be undefined. That is, if a reference (IRI) to an OMS is not defined, the semantics of the enclosing DOL construct is undefined.

$$\boxed{sem^M(\text{ExtendingOMS}) = (I, \Sigma', \mathcal{M}')$$

The semantics for minimization selects the models that are minimal in the class of all models with the same interpretation for the local environment (= fixed non-logical symbols, in the terminology of circumscription).

$$\boxed{sem('minimize' , \text{MinimizableOMS}) = (I, \Sigma', \mathcal{M}'')}$$

where  $(\Sigma', \mathcal{M}') = sem^M(\text{MinimizableOMS})$  and  $\mathcal{M}'' = \{M \in \mathcal{M}' \mid M \text{ is minimal in } \{M' \in \mathcal{M}' \mid M'|_{\Sigma} = M|_{\Sigma}\}\}$

$$\boxed{sem^M(\Gamma, L, \text{OMS}) = (I, \Sigma, \mathcal{M})}$$

OMS is interpreted in a context similar to that for `MinimizableOMS`; the difference being that there is no local environment.

$$\boxed{sem('minimize-symbol' , \text{OMS} , \text{CircMin} , \text{CircVars}) = (I, \Sigma, \mathcal{M}')$$

## 11. DOL semantics

where

$$\begin{aligned} (I, \Sigma, \mathcal{M}) &= \text{sem}^M(\text{OMS}), & \Sigma_{\min} &= \text{sem}(\text{CircMin}, \Sigma, \\ \Sigma_{\text{var}} &= \text{sem}(\text{CircVars}, \Sigma), & \Sigma_{\text{fixed}} &= \Sigma \setminus (\Sigma_{\min} \cup \Sigma_{\text{var}}) \end{aligned}$$

and

$$\mathcal{M}' = \{M \in \mathcal{M} \mid M|_{\Sigma_{\min} \cup \Sigma_{\text{fixed}}} \text{ is minimal in } \{M' \in \mathcal{M} \mid M'|_{\Sigma_{\text{fixed}}} = M|_{\Sigma_{\text{fixed}}}\}\}$$

$$\boxed{\text{sem}^M('translation', \text{OMS}, \text{Translation}) = (J, \Phi(\Sigma), \{M \mid \beta(M) \in \mathcal{M}\})}$$

where  $(I, \Sigma, \mathcal{M}) = \text{OMS}$  and  $\text{sem}(\text{Translation}) = (\Phi, \alpha, \beta) : I \rightarrow J$ .

$$\boxed{\text{sem}^M('reduction', \text{OMS}, \text{Reduction}) = (J, \Sigma', \{\beta(M)|_{\Sigma'} \mid M \in \mathcal{M}\})}$$

where  $(I, \Sigma, \mathcal{M}) = \text{sem}(\Gamma, L, \text{OMS})$

and  $\text{sem}(\text{Reduction}) = ((\Phi, \alpha, \beta) : I \rightarrow J, \Sigma')$

$$\boxed{\text{sem}^T('module\ extract', \text{OMS}, \text{Extraction}) = \text{TODO}}$$

$$\boxed{\text{sem}^M('module\ extract', \text{OMS}, \text{Extraction}) = \text{TODO}}$$

$$\boxed{\text{sem}^M('approximation', \text{OMS}, \text{Approximation}) = \text{TODO}}$$

69

Note(69)

$$\boxed{\text{sem}^T('filtering', \text{OMS}, \text{Filtering}) = \text{TODO}}$$

$$\boxed{\text{sem}^M('filtering', \text{OMS}, \text{Filtering}) = \text{TODO}}$$

$$\boxed{\text{sem}^T('union', O_1, [\text{ConstStrength}], O_2) = (I, \Sigma_1 \cup \Sigma_2, \Delta_1 \cup \Delta_2)}$$

where  $\text{sem}^T(O_i) = (I, \Sigma_i, \Delta_i)$ , for  $i = 1, 2$ .

$$\boxed{\text{sem}^M('union', \text{OMS}, [\text{ConstStrength}], \text{OMS}) = (I, \Sigma_1 \cup \Sigma_2, \mathcal{M}_1 \cup \mathcal{M}_2)}$$

where  $\text{sem}^M(O_i) = (I_i, \Sigma_i, \mathcal{M}_i)$ , for  $i = 1, 2$ .<sup>70</sup> <sup>71</sup>

Note(70)

$$\boxed{\text{sem}^T('extension', \text{OMS}, \text{ExtensionOMS}) = (I, \Sigma_1 \cup \Sigma_2, \Delta_1 \cup \Delta_2)}$$

Note(71)

where  $\text{sem}^T(\text{OMS}) = (I, \Sigma_1, \Delta_1)$ ,  $\text{sem}^T(\text{ExtensionOMS}) = (I, \Sigma_2, \Delta_2)$ <sup>72</sup>

Note(72)

<sup>69</sup>NOTE: TODO: specify semantics of approximation

<sup>70</sup>NOTE: ConstStrength is not used in de definition, there are missing cases

<sup>71</sup>NOTE: something has to be said about  $I$

<sup>72</sup>NOTE: needs to be revised



## 11. DOL semantics

$$\boxed{sem^M('extension', OMS, ExtensionOMS) = (I, \Sigma_1 \cup \Sigma_2, \mathcal{M}')}$$

where

$$\begin{aligned} sem^M(OMS) &= (I, \Sigma_1, \mathcal{M}_1), \\ sem^T(ExtensionOMS) &= (I, \Sigma_2, \Delta_2), \quad \text{and} \\ \mathcal{M}' &= \{M \in Mod(\Sigma_1 \cup \Sigma_2) \mid M \models \Delta_2, M|_{\Sigma} \in \mathcal{M}_1\} \end{aligned}$$

73

Note(73)

$$\boxed{sem^T('qual-oms', \{Qualification\}, OMS) = TODO}$$

$$\boxed{sem^M('qual-oms', \{Qualification\}, OMS) = TODO}$$

$$\boxed{sem^T('bridge', OMS_1, \{Translation\}, OMS_2) = TODO}$$

$$\boxed{sem^M('bridge', OMS_1, \{Translation\}, OMS_2) = TODO}$$

$$\boxed{sem^T('combination', Network) = TODO}$$

$$\boxed{sem^M('combination', Network) = TODO}$$

$$\boxed{sem^T('application', Substname, Sentence) = TODO}$$

$$\boxed{sem^M('application', Substname, Sentence) = TODO}$$

### 11.1.3. Semantics of OMS Mappings

$$\boxed{sem(L, \Sigma, Translation) = \rho}$$

$$sem(L, \Sigma, 'renaming' LT_1 \dots LT_n('symbol-map-items' E_1 \dots E_m)) = \rho = (\Phi, \alpha, \beta)$$

where  $\rho = sem(LT_n) \circ \dots \circ sem(LT_1)$

The semantics is defined only if  $E_1 \dots E_m$  occur in  $\Phi(\Sigma)$ .

$$\boxed{sem(L, \Sigma, SymbolMapItems) = \Sigma' \text{ where } \Sigma' \geq \Sigma}$$

True renamings are not possible without institutional logics, only the presence of non-logical symbols in a signature can be checked.

$$sem(L, \Sigma, 'symbol-map-items' E_1 \dots E_n) = \begin{cases} \Sigma & \text{if } E_1, \dots, E_n \text{ are contained in } \Sigma \\ \text{undefined} & \text{otherwise} \end{cases}$$

$$\boxed{sem(\Gamma, L, (\Sigma, \mathcal{M}), ExtensionOMS) = (\Sigma', \mathcal{M}')}$$

<sup>73</sup>NOTE: According to the intended semantics, extensions are defined for OMS  $O_1, O_2$ , such that  $O_2$  is basic, this is however not the case in the current abstract syntax: see productions for `ExtensionOMS`

## 11. DOL semantics

$$\text{sem}(\Gamma, L, (\Sigma, \mathcal{M}), [\text{ConsStrength}], [\text{ExtensionName}], \text{ExtendingOMS}) = (\Sigma', \mathcal{M}') \quad \text{where } (\Sigma', \mathcal{M}') = \text{sem}(\Gamma, L, (\Sigma, \mathcal{M}), \text{ExtendingOMS})$$

If `ConsStrength` is 'model-conservative' or 'implied', the semantics is only defined if each model in  $\mathcal{M}$  is the  $\Sigma$ -reduct of some model in  $\mathcal{M}'$ . In case that `ConsStrength` is 'implied', it is furthermore required that  $\Sigma = \Sigma'$ . If `ConsStrength` is 'consequence-conservative', the semantics is only defined if for each  $\Sigma$ -sentence  $\varphi$ ,  $\mathcal{M}' \models \varphi$  implies  $\mathcal{M} \models \varphi$ . If `ConsStrength` is 'definitional', the semantics is only defined if each model in  $\mathcal{M}$  is the  $\Sigma$ -reduct of a unique model in  $\mathcal{M}'$ .

$$sem(\Gamma, L, \text{OMSDefn}) = (\Gamma', L)$$

An OMS definition extends the global environment:

$$\begin{aligned} & sem(\Gamma, L, 'oms-defn', OMSName, [ConsStrength], OMS) \quad 74 \\ & = (\Gamma[OMSName \mapsto sem(\Gamma, L, OMS)], L) \end{aligned} \quad \text{Note(74)}$$

If `ConsStrength` is 'conservative', the semantics is only defined if  $\text{sem}(\Gamma, L, \text{OMS}) \neq \emptyset$ . If `ConsStrength` is 'conservative', the semantics is only defined if  $\text{sem}(\Gamma, L, \text{OMS})$  is a singleton.

$$sem(\text{LogicRef}) = L$$

$L$  is the institute from the heterogeneous logical environment named by `LogicRef`.

$$sem(L, \text{OMSLangTrans}) = \rho$$

$sem(L, 'named-trans', \text{OMSLangTransRef}) = \rho$  where  $\rho$  is the institute comorphism from the heterogeneous logical environment named by `OMSLangTransRef`. This is defined only if the domain of  $\rho$  is  $L$ .

$sem(L, 'qual-trans', OMSLangTransRef\ LR_1\ LR_2) = \rho$  where  $\rho$  is the institute comorphism from the heterogeneous logical environment named by `OMSLangTransRef`. This is defined only if  $\rho : sem(LR_1) \rightarrow sem(LR_2)$  and  $L = sem(LR_1)$ .

$sem(L, 'anonymous-trans' \ LR_1 \ LR_2) = \rho$  where  $\rho$  is the unique institute comorphism from the heterogeneous logical environment running from  $sem(LR_1)$  to  $sem(LR_2)$ . This is defined only if  $L = sem(LR_1)$ .

$sem(L, 'default-trans' , LolaRef) = \rho$  where  $\rho$  is the unique institute comorphism from the heterogeneous logical environment running from  $L$  to  $sem(LolaRef)$ .

$$sem(\Gamma, L, \text{MappingDefn}) = (\Gamma', L)$$

See equations for `IntprDefn`, `EquivDefn` and `AlignDefn`.

$$\overline{sem(\Gamma, L, \text{IntprDefn})} = (\Gamma', L)$$

$${}^{76} \text{sem}(\Gamma, L, \text{'intpr-defn'} , \text{IntprName} , ( \text{'intpr-type'} O_1 O_2 )) = \text{Note}(76) \\ (\Gamma[\text{IntprName} \mapsto (\Sigma_1, \Sigma_2)], L) \text{ where}$$

<sup>74</sup>NOTE: Should we allow for overriding existing OMS definitions? Or should `OMSName` be new?

<sup>75</sup>NOTE: We need some “algorithm” for handling `LolaRefs` that are actually `LanguageRefs`, not `LogicRefs`. Suppose a translation `lang1`→`lang2` is referenced, let `e(lang)` be the logic that exactly captures the expressivity of `lang`. For `lang1`→`lang2` there might be a “language-side” default translation, which does not have a corresponding “logic-side” mapping at all, or whose exactly corresponding “logic-side” mapping is not the default for `e(lang1)`→`e(lang2)`.

<sup>76</sup>NOTE: Q-AUT: Optional [ Conservative ] argument is missing.

## 11. DOL semantics

- $(\Sigma_1, \mathcal{M}_1) = \text{sem}(\Gamma, L, O_1)$ ;
- $(\Sigma_2, \mathcal{M}_2) = \text{sem}(\Gamma, L, O_2)$ ;
- the semantics is defined only if  $\mathcal{M}_2|_{\Sigma_1} \subseteq \mathcal{M}_1$ .

$$\boxed{\text{sem}(\Gamma, L, \text{EquivDefn}) = (\Gamma', L)}$$

$\text{sem}(\Gamma, L, \text{'equiv-defn' } , \text{EquivName } , ( \text{'equiv-type' } O_1 O_2 ) O_3 ) = (\Gamma[\text{EquivName} \mapsto (\Sigma_1, \Sigma_2, \Sigma_3)], L)$  where

- $(\Sigma_1, \mathcal{M}_1) = \text{sem}(\Gamma, L, O_1)$ ;
- $(\Sigma_2, \mathcal{M}_2) = \text{sem}(\Gamma, L, O_2)$ ;
- $(\Sigma_3, \mathcal{M}_3) = \text{sem}(\Gamma, L, O_3)$ ;
- the semantics is defined only if for  $i = 1, 2$ ,  $\Sigma_i \leq \Sigma_3$  and each model in  $\mathcal{M}_i$  can be uniquely expanded to a model in  $\mathcal{M}_3$ .

$$\boxed{\text{sem}(\Gamma, L, \text{AlignDefn}) = (\Gamma', L)}$$

Alignments are interpreted only syntactically:

<sup>77</sup>  $\text{sem}(\Gamma, L, \text{'align-defn' } , \text{AlignName } , [ \text{AlignCard } ] , \text{AlignType } , \{ \text{Correspondence } \}) = (\Gamma[\text{AlignName} \mapsto \{ \text{Correspondence } \}], L)$  Note(77)

### 11.1.4. Semantics of queries

## 11.2. Translational semantics of DOL language constructs

The translational semantics uses Common Logic as a foundational framework for the library, modeling and specification language DOL, similar to what set theory provides for general mathematical theories. This semantics assumes that each involved OMS language is mapped to CL by a weakly exact translation. The semantics is defined by first translating a heterogeneous OMS to CL, and then using the direct semantics for the result.

Note that since the result of translating a DOL OMS entirely to CL is homogeneous, the clause for logic translation of the direct semantics will not be used. Using default logic translations and compositions of these, many logics can be mapped to Common Logic, while the DOL constructs like interpretations stay the same.<sup>6</sup>

We define the syntactic translation  $CL_\rho$  of DOL OMS, depending on a logic translation  $\rho : L \rightarrow \text{CL}$ , to Common Logic below. (The translations of the other syntactic categories are straightforward.)

$$CL_\rho(\langle \Sigma, \Delta \rangle) = \langle \Phi(\Sigma), \alpha(\Delta) \rangle, \text{ where } \rho = (\Phi, \alpha, \beta)$$

$$CL_\rho(O \text{ with logic } \rho') = CL_{\rho \circ \rho'}(O)$$

$$^{78} CL_\rho(O \text{ then } CS \langle \Sigma, \Delta \rangle) = CL_\rho(O) \text{ then } CS CL_\rho(\langle \Sigma, \Delta \rangle)$$

$$CL_\rho(\text{OMSRef}) = \text{OMSRef}$$

$$CL_\rho(\text{logic LogicRef } O) = CL_{\text{default}(\text{LogicRef}, \text{CL})}(O)$$

Note(78)

<sup>77</sup>NOTE: Q-AUT: Semantics does not yet cover optional [ AlignCard ].

<sup>6</sup>The translational semantics is not applicable for logics without a default translation of Common Logic.

<sup>78</sup>NOTE: Extend this to all DOL constructs

### 11.3. Collapsed Semantics of DOL language constructs

The collapsed semantics requires the representation of the meta level within CL. For this purpose, the model-level semantics introduced in the previous section should be complemented by a theory-level semantics: a library then denotes a basic theory in some logic (which amounts to flattening out all structure), plus some conditions for conservativity and relative interpretations. For each logic, one needs to axiomatize a specific partial order of signatures in CL, plus a set of sentences equipped with a logical consequence relation. In order to avoid the formalization of models and the satisfaction relation (which would require the inclusion of a set theory like ZFC), a sound and complete calculus is axiomatized for each logic. For each logic translation, the signature and sentence translations need to be axiomatized. We require that this axiomatization is done in such a way that the resulting semantics is compatible with the translational semantics. Although this formalization is doable in principle, we refrain from providing the (massive) details.

<sup>79</sup>

Note(79)

### 11.4. OMS language translations

The concept of OMS language translation has been formalized as institute comorphism.  
Provide some examples  
special cases to be described

---

<sup>79</sup>NOTE: Q-ALL: The collapsed semantics is still very vague, and is more a research plan than a definite proposal. Any ideas how to make this more precise?

## **12. Keyword index**

/to be supplemented in the final version/

# **Annex**

# A. Annex (normative): RDF vocabulary for describing OMS languages conforming with DOL

This annex specifies an RDF vocabulary, formalized in RDFS W3C/TR REC-rdf-schema:2004, for describing OMS languages that conform with DOL, and their features, including logics and serializations. This vocabulary shares its namespace (<http://purl.net/dol/1.0/rdf#>) with the DOL RDF vocabulary for serializing DOL OMS (cf. annex ??).<sup>80</sup>

Note(80)

The tables in this annex list the classes and properties of the RDF vocabulary for describing OMS languages. All class and properties are assumed to be in the DOL RDF namespace unless stated otherwise.

Table A.1 lists the classes of the RDF vocabulary for describing OMS languages. Each row of the table translates into the following RDF triples (given in Turtle serialization):<sup>81</sup>

Note(81)

```
_:class rdf:type      rdfs:Class ;
        rdfs:comment "documentation" .
```

Table A.1.: Classes of the RDF vocabulary for describing OMS languages

Class	<i>documentation</i>
OMSLanguage	<i>an OMS language</i>
Logic	<i>a logic that defines the semantics of an OMS language</i>
Serialization	<i>a serialization of an OMS language</i>

Table A.2 lists the properties of the RDF vocabulary for describing OMS languages. Each row of the table translates into the following RDF triples (given in Turtle serialization):

```
_:property rdf:type      rdf:Property ;
           rdfs:domain   _:domain ;
           rdfs:range     _:range ;
           rdfs:comment   "documentation" .
```

82

Note(82)

<sup>80</sup>NOTE: FYI: given its light weight I think that makes sense. It doesn't rule out extensions to OWL (or even DOL) anyway.

<sup>81</sup>NOTE: TODO: also cover rdfs:subClassOf (once we have such cases)

<sup>82</sup>NOTE: Q-AUT: we need to define "sublogic" as a term – how? I guess that would include the notion of an "OWL profile"

A. Annex (normative): *RDF* vocabulary for describing *OMS* languages conforming with *DOL*

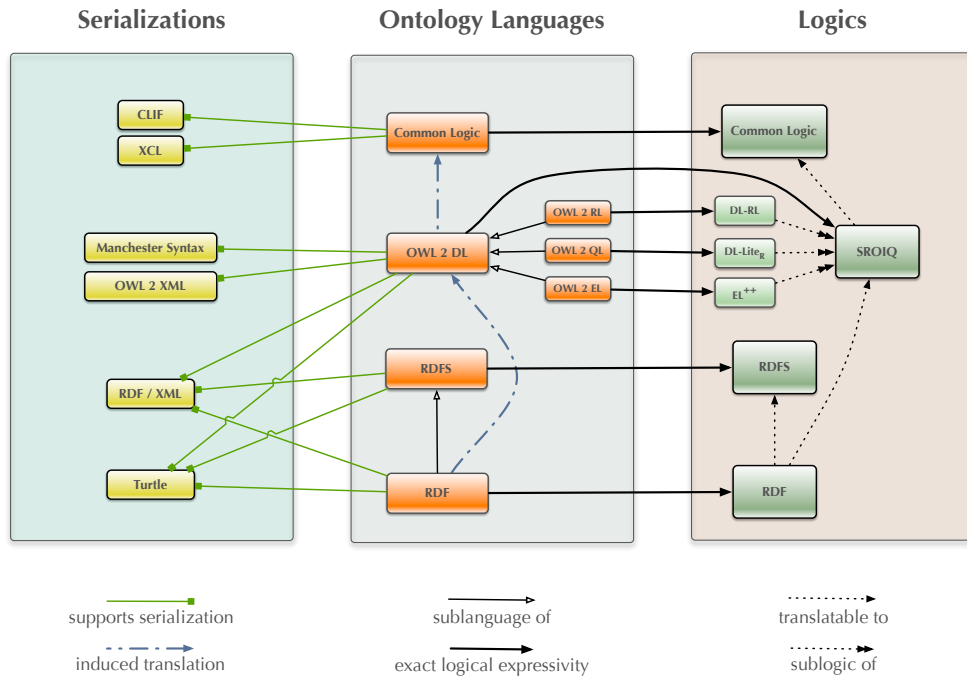


Figure A.1.: Subset of the OntoIop registry, shown as an RDF graph



A. Annex (normative): RDF vocabulary for describing OMS languages conforming with DOL

Table A.2.: Properties of the RDF vocabulary for describing OMS languages

Property	domain	range
<i>documentation</i>		
subLogicOf	Logic	Logic
<i>The subject is a sublogic of the object</i>		
supportsLogic	OMSLanguage	Logic
<i>The subject OMS language has a semantics specified in terms of the object logic.</i>		
specifiesSemanticsOf	Logic	OMSLanguage
<i>The subject logic is used to specify the semantics of the object OMS language; inverse of supportsLogic.</i>		
supportsSerialization	OMSLanguage	Serialization
<i>OMS in the subject OMS language can be serialized in the object serialization. Note that the serialization should be as specific as possible, i.e. one should not say that "OWL can be serialized in XML" and "Common Logic can be serialized in XML", but instead "OWL can be serialized in OWL/XML" and "Common Logic can be serialized in XCL", taking into account that OWL/XML and XCL are two different XML languages.</i>		
serializes	Serialization	OMSLanguage
<i>The subject logic is used to specify the semantics of the object OMS language; inverse of supportsSerialization.</i>		

## B. Annex (normative): Conformance of OWL 2 with DOL

The semantic conformance of OWL 2 (as specified in W3C/TR REC-owl2-syntax:2009) with DOL is established in [34].

The OWL/XML serialization satisfies the criteria for XML conformance. The mapping of OWL 2 to RDF graphs satisfies the criteria for RDF conformance<sup>83</sup>. The OWL 2 Manchester syntax satisfies the criteria for text conformance.<sup>84</sup>

Note(83)

Note(84)

OWL can be formalized as an institute as follows:

**Definition 7** *OWL 2 DL*. OWL 2 DL is the description logic (DL) based fragment of the web ontology language OWL 2. We start with the simple description logic  $\mathcal{ALC}$ , and then proceed to the more complex description logic  $\mathcal{SROIQ}$  which is underlying OWL 2 DL. Signatures of the description logic  $\mathcal{ALC}$  consist of a set  $\mathcal{A}$  of atomic concepts, a set  $\mathcal{R}$  of roles and a set  $\mathcal{I}$  of individual constants. The partial order on signatures is defined as component wise inclusion. Models are first-order structures  $I = (\Delta^I, \cdot^I)$  with universe  $\Delta^I$  that interpret concepts as unary and roles as binary predicates (using  $\cdot^I$ ).  $I_1 \leq I_2$  if  $\Delta^{I_1} = \Delta^{I_2}$  and all concepts and roles of  $I_1$  are subconcepts and subroles of those in  $I_2$ . Sentences are subsumption relations  $C_1 \sqsubseteq C_2$  between concepts, where concepts follow the grammar<sup>85</sup>

Note(85)

$$C ::= \mathcal{A} \mid \top \mid \perp \mid C_1 \sqcup C_2 \mid C_1 \sqcap C_2 \mid \neg C \mid \forall R.C \mid \exists R.C$$

These kind of sentences are also called TBox sentences. Sentences can also be ABox sentences, which are membership assertions of individuals in concepts (written  $a : C$  for  $a \in \mathcal{I}$ ) or pairs of individuals in roles (written  $R(a, b)$  for  $a, b \in \mathcal{I}, R \in \mathcal{R}$ ). Satisfaction is the standard satisfaction of description logics.

The logic  $\mathcal{SROIQ}$  [23], which is the logical core of the Web Ontology Language OWL 2 DL<sup>1</sup>, extends  $\mathcal{ALC}$  with the following constructs: (i) complex role inclusions such as  $R \circ S \sqsubseteq S$  as well as simple role hierarchies such as  $R \sqsubseteq S$ , assertions for symmetric, transitive, reflexive, asymmetric and disjoint roles (called RBox sentences, denoted by  $\mathcal{SR}$ ), as well as the construct  $\exists R.\text{Self}$  (collecting the set of 'R-reflexive points'); (ii) nominals, i.e. concepts of the form  $\{a\}$ , where  $a \in \mathcal{I}$  (denoted by  $\mathcal{O}$ ); (iii) inverse roles (denoted by  $\mathcal{I}$ ); qualified and unqualified number restrictions ( $\mathcal{Q}$ ). For details on the rather complex grammatical restrictions for  $\mathcal{SROIQ}$  (e.g. regular role inclusions, simple roles) compare [23].

OWL profiles are syntactic restrictions of OWL 2 DL that support specific modeling and reasoning tasks, and which are accordingly based on DLs with appropriate computational properties. Specifically, OWL 2 EL is designed for ontologies containing large numbers of concepts or relations, OWL 2 QL to support query answering over large amounts of data, and OWL 2 RL to support scalable reasoning using rule languages (EL, QL, and RL for short).

<sup>83</sup>NOTE: This is not exactly true, as some things, e.g. imports, can't be identified.

<sup>84</sup>NOTE: also need conformance propositional logic; use PL "profile" of the CASL "IFIP standard"

<sup>85</sup>NOTE: Q-AUT: This grammar should also be adapted to ISO EBNF.

<sup>1</sup>See also <http://www.w3.org/TR/owl2-overview/>

*B. Annex (normative): Conformance of OWL 2 with DOL*

*We sketch the logic  $\mathcal{EL}$  which is underlying the EL profile.<sup>2</sup>  $\mathcal{EL}$  is a syntactic restriction of  $\mathcal{ALC}$  to existential restriction, concept intersection, and the top concept:*

$$C ::= \mathcal{A} \mid \top \mid C_1 \sqcap C_2 \mid \exists R.C$$

*Note that  $\mathcal{EL}$  does not have disjunction or negation, and is therefore a sub-Boolean logic.*

---

<sup>2</sup>To be exact, **EL** adds various 'harmless' expressive means and syntactic sugar to  $\mathcal{EL}$  resulting in the DL  $\mathcal{EL}^{++}$ .

## C. Annex (normative): Conformance of Common Logic with DOL

The semantic conformance of Common Logic (as specified in ISO/IEC 24707:2007) with DOL is established in [34].

The XCF dialect of Common Logic has a serialization that satisfies the criteria for XML conformance. The CLIF dialect of Common Logic has a serialization that satisfies the criteria for text conformance.

Common Logic can be defined as an institute as follows:

**Definition 8 Common Logic.** A common logic signature  $\Sigma$  (called vocabulary in Common Logic terminology) consists of a set of names, with a subset called the set of discourse names, and a set of sequence markers. An inclusion of signatures needs to fulfill the requirement that a name is a discourse name in the smaller signature if and only if it is one in the larger signature. A  $\Sigma$ -model  $I = (UR, UD, rel, fun, int)$  consists of a set  $UR$ , the universe of reference, with a non-empty subset  $UD \subseteq UR$ , the universe of discourse, and four mappings:

- $rel$  from  $UR$  to subsets of  $UD^* = \{ \langle x_1, \dots, x_n \rangle \mid x_1, \dots, x_n \in UD \}$  (i.e., the set of finite sequences of elements of  $UD$ );
- $fun$  from  $UR$  to total functions from  $UD^*$  into  $UD$ ;
- $int$  from names in  $\Sigma$  to  $UR$ , such that  $int(v)$  is in  $UD$  if and only if  $v$  is a discourse name;
- $seq$  from sequence markers in  $\Sigma$  to  $UD^*$ .

A  $\Sigma$ -sentence is a first-order sentence, where predications and function applications are written in a higher-order like syntax:  $t(s)$ . Here,  $t$  is an arbitrary term, and  $s$  is a sequence term, which can be a sequence of terms  $t_1 \dots t_n$ , or a sequence marker. A predication  $t(s)$  is interpreted by evaluating the term  $t$ , mapping it to a relation using  $rel$ , and then asking whether the sequence given by the interpretation  $s$  is in this relation. Similarly, a function application  $t(s)$  is interpreted using  $fun$ . Otherwise, interpretation of terms and formulae is as in first-order logic. A further difference is the presence of sequence terms (namely sequence markers and juxtapositions of terms), which denote sequences in  $UD^*$ , with term juxtaposition interpreted by sequence concatenation. Note that sequences are essentially a non-first-order feature that can be expressed in second-order logic.

Model reducts are defined in the following way: Given a signature inclusion  $\Sigma' \leq \Sigma$  and a  $\Sigma$ -model  $I = (UR, UD, rel, fun, int)$ ,  $I|_{\Sigma'} = (UR', UD, rel', fun', int')$  is defined by

- $UR'$  is the restriction of  $UR$  to those elements satisfying the following conditions:
  1. they are not in the universe of discourse  $UD$ ;
  2. they are the interpretation (according to  $int$ ) of a non-discourse name in  $\Sigma$ ;
  3. they are not the interpretation (according to  $int$ ) of a non-discourse name in  $\Sigma'$ .
- $rel'$  is  $rel$  restricted to  $UR'$ ;
- $fun'$  is  $fun$  restricted to  $UR'$ ;

C. Annex (normative): Conformance of Common Logic with DOL

- $int'$  is  $int$  restricted to  $\Sigma'$ .

Note that with this notion of reduct, extensions commonly understood as definitions in segregated dialects of Common Logic are indeed both definitional and conservative extensions.

<sup>86</sup>

Note(86)

We call the restriction of CL to sentence without sequence markers  $CL^-$ .

---

<sup>86</sup>NOTE: Ordering on models! Universes agree,  $fun_1(x) = fun_2(x)$ ,  $rel_1(x) \subseteq rel_2(x)$ ,  $int_1(n) = int_2(n)$

## D. Annex (normative): Conformance of RDF and RDFS with DOL

The semantic conformance of RDFS (as specified in W3C/TR REC-rdf-schema:2004) with DOL is established in [34].

The way of representing RDFS ontologies as RDF graphs satisfies the criteria for RDF conformance.

**Definition 9 (RDF and RDFS)** *Following [30], we define the institutions for the Resource Description Framework (RDF) and RDF-Schema (RDFS), respectively. These are based on a logic called bare RDF (SimpleRDF), which consists of triples only (without any predefined resources).*

*A signature  $\mathbf{R}_s$  in SimpleRDF is a set of resource references. For  $sub, pred, obj \in \mathbf{R}_s$ , a triple of the form  $(sub, pred, obj)$  is a sentence in SimpleRDF, where  $sub, pred, obj$  represent subject name, predicate name, object name, respectively. An  $\mathbf{R}_s$ -model  $M = \langle R_m, P_m, S_m, EXT_m \rangle$  consists of a set  $R_m$  of resources, a set  $P_m \subseteq R_m$  of predicates, a mapping function  $S_m : \mathbf{R}_s \rightarrow R_m$ , and an extension function  $EXT_m : P_m \rightarrow \mathcal{P}(R_m \times R_m)$  mapping every predicate to a set of pairs of resources. Satisfaction is defined as follows:*

$$\mathfrak{M} \models_{\mathbf{R}_s} (sub, pred, obj) \Leftrightarrow (S_m(sub), (S_m(obj)) \in EXT_m(S_m(pred))).$$

*Both RDF and RDFS are built on top of SimpleRDF by fixing a certain standard vocabulary both as part of each signature and in the models.<sup>87</sup> Actually, the standard vocabulary is given by a certain theory. In case of RDF, it contains e.g. resources `rdf:type` and `rdf:Property` and `rdf:subject`, and sentences like, e.g.  $(rdf:type, rdf:type, rdf:Property)$ , and  $(rdf:subject, rdf:type, rdf:Property)$ .*

Note(87)

*In the models, the standard vocabulary is interpreted with a fixed model. Moreover, for each RDF-model  $M = \langle R_m, P_m, S_m, EXT_m \rangle$ , if  $p \in P_m$ , then it must hold  $(p, S_m(rdf:Property)) \in EXT_m(rdf:type)$ . For RDFS, similar conditions are formulated (here, for example also the subclass relation is fixed).*

*In the case of RDFS, the standard vocabulary contains more elements, like `rdf:domain`, `rdf:range`, `rdf:Resource`, `rdf:Literal`, `rdf:Datatype`, `rdf:Class`, `rdf:subClassOf`, `rdf:subPropertyOf`, `rdf:member`, `rdf:Container`, `rdf:ContainerMembershipProperty`.*

*There is also OWL full, an extension of RDFS with resources like `owl:Thing` and `owl:oneOf`, tailored towards the representation of OWL.*

<sup>87</sup>NOTE: Refer to the RDF standard here.

## E. Annex (normative): A Core Logic Graph

This annex provides a core graph of logics and translations, covering those OMS languages whose conformance with DOL is established in the preceding, normative annexes (OWL 2 in annex B, Common Logic in annex C, and RDFS in annex D). The graph is shown in Figure E.1. Its nodes refer to the following OMS languages and profiles:

- RDF W3C/TR REC-rdf-concepts:2004
- RDFS W3C/TR REC-rdf-schema:2004
- EL, QL, RL (all being profiles of OWL) W3C/TR REC-owl2-profiles:2009
- OWL W3C/TR REC-owl2-syntax:2009
- CL (Common Logic) ISO/IEC 24707:2007

The translations are specified in [34].<sup>88</sup>

<sup>89</sup>

Note(88)

Note(89)

### E.1. $EL \rightarrow OWL$ and $\mathcal{EL}++ \rightarrow \mathcal{SROIQ}(D)$

$EL \rightarrow OWL$  is the sublanguage inclusion obtained by the syntactic restriction according to the definition of EL, see W3C/TR REC-owl2-profiles:2009. Since by definition,  $\mathcal{EL}++$  is a syntactic restriction of  $\mathcal{SROIQ}(D)$ ,  $\mathcal{EL}++ \rightarrow \mathcal{SROIQ}(D)$  is the corresponding sublogic inclusion.

### E.2. $QL \rightarrow OWL$ and $DL\text{-}Lite_R \rightarrow \mathcal{SROIQ}(D)$

$QL \rightarrow OWL$  is the sublanguage inclusion obtained by the syntactic restriction according to the definition of QL, see W3C/TR REC-owl2-profiles:2009. Since by definition,  $DL\text{-}Lite_R$  is a syntactic restriction of  $\mathcal{SROIQ}(D)$ ,  $DL\text{-}Lite_R \rightarrow \mathcal{SROIQ}(D)$  is the corresponding sublogic inclusion.

### E.3. $RL \rightarrow OWL$ and $RL \rightarrow \mathcal{SROIQ}(D)$

$RL \rightarrow OWL$  is the sublanguage inclusion obtained by the syntactic restriction according to the definition of RL, see W3C/TR REC-owl2-profiles:2009. Since by definition, RL is a syntactic restriction of  $\mathcal{SROIQ}(D)$ ,  $RL \rightarrow \mathcal{SROIQ}(D)$  is the corresponding sublogic inclusion.

<sup>88</sup>NOTE: TODO: Provide linear syntax here (as in the paper)

<sup>89</sup>NOTE: FYI: We need this in order to be able to say something about default translations, and about establishing conformance by translation to a language that already conforms.

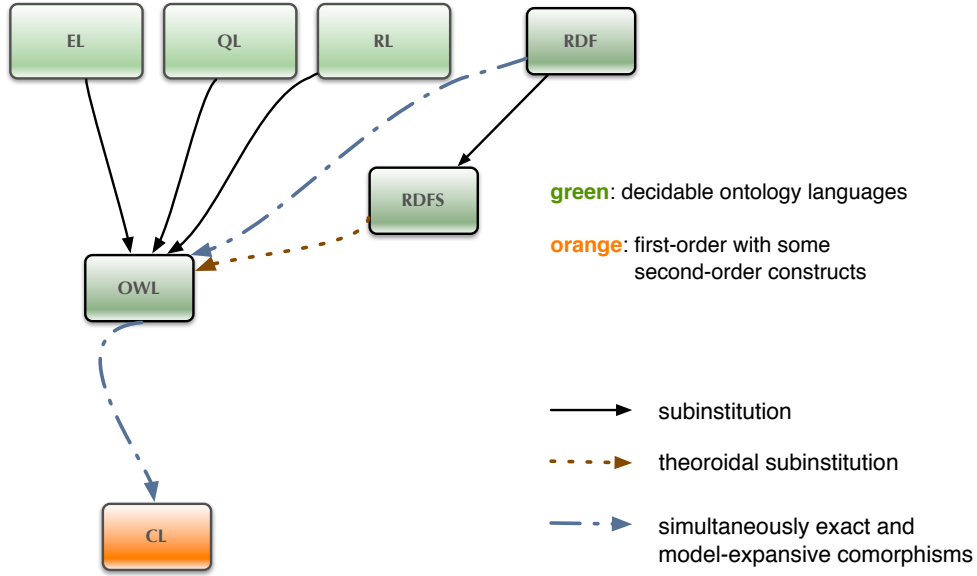


Figure E.1.: Translations between conforming OMS languages (normative)

#### E.4. SimpleRDF $\rightarrow$ RDF

SimpleRDF  $\rightarrow$  RDF is an obvious inclusion, except that SimpleRDF resources need to be re-named if they happen to have a predefined meaning in RDF. The model translation needs to forget the fixed parts of RDF models, since this part can always reconstructed in a unique way, we get an isomorphic model translation.

#### E.5. RDF $\rightarrow$ RDFS

This is entirely analogous to SimpleRDF  $\rightarrow$  RDF.

#### E.6. SimpleRDF $\rightarrow$ $\mathcal{SROIQ}(D)$

<sup>90</sup>

Note(90)

A SimpleRDF signature is translated to  $\mathcal{SROIQ}(D)$  by providing a class  $P$  and three roles  $sub$ ,  $pred$  and  $obj$  (these reify the extension relation), and one individual per SimpleRDF resource. A SimpleRDF triple  $(s, p, o)$  is translated to the  $\mathcal{SROIQ}(D)$  sentence

$$\top \sqsubseteq \exists U. (\exists sub. \{s\} \sqcap \exists pred. \{p\} \sqcap \exists obj. \{o\}).$$

<sup>90</sup>NOTE: This translation is not really useful. Consider the RDF-OWL-reduct construction instead.



## E. Annex (normative): A Core Logic Graph

From an  $\mathcal{SROIQ}$  (D) model  $\mathcal{I}$ , obtain a SimpleRDF model by inheriting the universe and the interpretation of individuals (then turned into resources). The interpretation  $P^{\mathcal{I}}$  of  $P$  gives  $P_m$ , and  $EXT_m$  is obtained by de-reifying, i.e.

$$EXT_m(x) := \{(y, z) | \exists u. (u, x) \in pred^{\mathcal{I}}, (u, y) \in sub^{\mathcal{I}}, (u, z) \in obj^{\mathcal{I}}\}.$$

$RDF \rightarrow \mathcal{SROIQ}(D)$  is defined similarly. The theory of RDF built-ins is (after translation to  $\mathcal{SROIQ}(D)$ ) added to any signature translation. This ensures that the model translation can add the built-ins.

## E.7. OWL $\rightarrow$ FOL

### E.7.1. Translation of Signatures

$\Phi((\mathbf{C}, \mathbf{R}, \mathbf{I})) = (F, P)$  with

- function symbols:  $F = \{a^{(1)} | a \in \mathbf{I}\}$
- predicate symbols  $P = \{A^{(1)} | A \in \mathbf{C}\} \cup \{R^{(2)} | R \in \mathbf{R}\}$

### E.7.2. Translation of Sentences

Concepts are translated as follows:

- $\alpha_x(A) = A(x)$
- $\alpha_x(\neg C) = \neg \alpha_x(C)$
- $\alpha_x(C \sqcap D) = \alpha_x(C) \wedge \alpha_x(D)$
- $\alpha_x(C \sqcup D) = \alpha_x(C) \vee \alpha_x(D)$
- $\alpha_x(\exists R.C) = \exists y. (R(x, y) \wedge \alpha_y(C))$
- $\alpha_x(\exists U.C) = \exists y. \alpha_y(C)$
- $\alpha_x(\forall R.C) = \forall y. (R(x, y) \rightarrow \alpha_y(C))$
- $\alpha_x(\forall U.C) = \forall y. \alpha_y(C)$
- $\alpha_x(\exists R.\text{Self}) = R(x, x)$
- $\alpha_x(\leq nR.C) = \forall y_1, \dots, y_{n+1}. \bigwedge_{i=1, \dots, n+1} (R(x, y_i) \wedge \alpha_{y_i}(C)) \rightarrow \bigvee_{1 \leq i < j \leq n+1} y_i = y_j$
- $\alpha_x(\geq nR.C) = \exists y_1, \dots, y_n. \bigwedge_{i=1, \dots, n} (R(x, y_i) \wedge \alpha_{y_i}(C)) \wedge \bigwedge_{1 \leq i < j \leq n} y_i \neq y_j$
- $\alpha_x(\{a_1, \dots, a_n\}) = (x = a_1 \vee \dots \vee x = a_n)$

For inverse roles  $R^-$ ,  $R^-(x, y)$  has to be replaced by  $R(y, x)$ , e.g.

$$\alpha_x(\exists R^-.C) = \exists y. (R(y, x) \wedge \alpha_y(C))$$

This rule also applies below.

Sentences are translated as follows:

- $\alpha_{\Sigma}(C \sqsubseteq D) = \forall x. (\alpha_x(C) \rightarrow \alpha_x(D))$
- $\alpha_{\Sigma}(a : C) = \alpha_x(C)[a/x]^1$

---

<sup>1</sup>Replace  $x$  by  $a$ .

## E. Annex (normative): A Core Logic Graph

- $\alpha_\Sigma(R(a, b)) = R(a, b)$
- $\alpha_\Sigma(R \sqsubseteq S) = \forall x, y. R(x, y) \rightarrow S(x, y)$
- $\alpha_\Sigma(R_1; \dots; R_n \sqsubseteq R) = \forall x, y. (\exists z_1, \dots, z_{n-1}. R_1(x, z_1) \wedge R_2(z_1, z_2) \wedge \dots \wedge R_n(z_{n-1}, y)) \rightarrow R(x, y)$
- $\alpha_\Sigma(\text{Dis}(R_1, R_2)) = \neg \exists x, y. R_1(x, y) \wedge R_2(x, y)$
- $\alpha_\Sigma(\text{Ref}(R)) = \forall x. R(x, x)$
- $\alpha_\Sigma(\text{Irr}(R)) = \forall x. \neg R(x, x)$
- $\alpha_\Sigma(\text{Asy}(R)) = \forall x, y. R(x, y) \rightarrow \neg R(y, x)$
- $\alpha_\Sigma(\text{Tra}(R)) = \forall x, y, z. R(x, y) \wedge R(y, z) \rightarrow R(x, z)$

### E.7.3. Translation of Models

- For  $M' \in \text{Mod}^{FOL}(\Phi\Sigma)$  define  $\beta_\Sigma(M') := (\Delta, \cdot^I)$  with  $\Delta = |M'|$  and  $A^I = M'_A, a^I = M'_a, R^I = M'_R$ .

**Proposition 10**  $C^\mathcal{I} = \{m \in M'_{Thing} | M' + \{x \mapsto m\} \models \alpha_x(C)\}$

**Proof.** By Induction over the structure of  $C$ .

- $A^\mathcal{I} = M'_A = \{m \in M'_{Thing} | M' + \{x \mapsto m\} \models A(x)\}$
- $(\neg C)^\mathcal{I} = \Delta \setminus C^\mathcal{I} \stackrel{I.H.}{=} \Delta \setminus \{m \in M'_{Thing} | M' + \{x \mapsto m\} \models \alpha_x(C)\} = \{m \in M'_{Thing} | M' + \{x \mapsto m\} \models \neg \alpha_x(C)\}$

□

The satisfaction condition holds as well.

### E.8. OWL $\rightarrow$ CL

## F. Annex (informative): Extended Logic Graph

This annex extends the graph of logics and translations given in annex E by a list of OMS language whose conformance with DOL will be established through the registry. The graph is shown in Figure F.1. Its nodes are included in the following list of OMS languages and profiles (in addition to those mentioned in annex E):

- PL (propositional logic)
- SimpleRDF (RDF triples without a reserved vocabulary)
- OBO<sup>OWL</sup> and OBO1.4
- RIF (Rule Interchange Format)
- EER (Enhanced Entity-Relationship Diagrams)
- Datalog
- ORM (object role modeling)
- the meta model of schema.org
- UML (Unified Modeling Language), with possibly different logics according to different UML semantics
- SKOS (Simple Knowledge Organization System )
- FOL<sup>=</sup> (untyped first-order logic, as used for the TPTP format)
- F-logic
- CASL (Common Algebraic Specification Language)

The actual translations are specified in [34].

<sup>91</sup>

Note(91)

---

<sup>91</sup>NOTE: TODO: Provide linear syntax here (as in the paper). TM: what do you mean by this?

*F. Annex (informative): Extended Logic Graph*

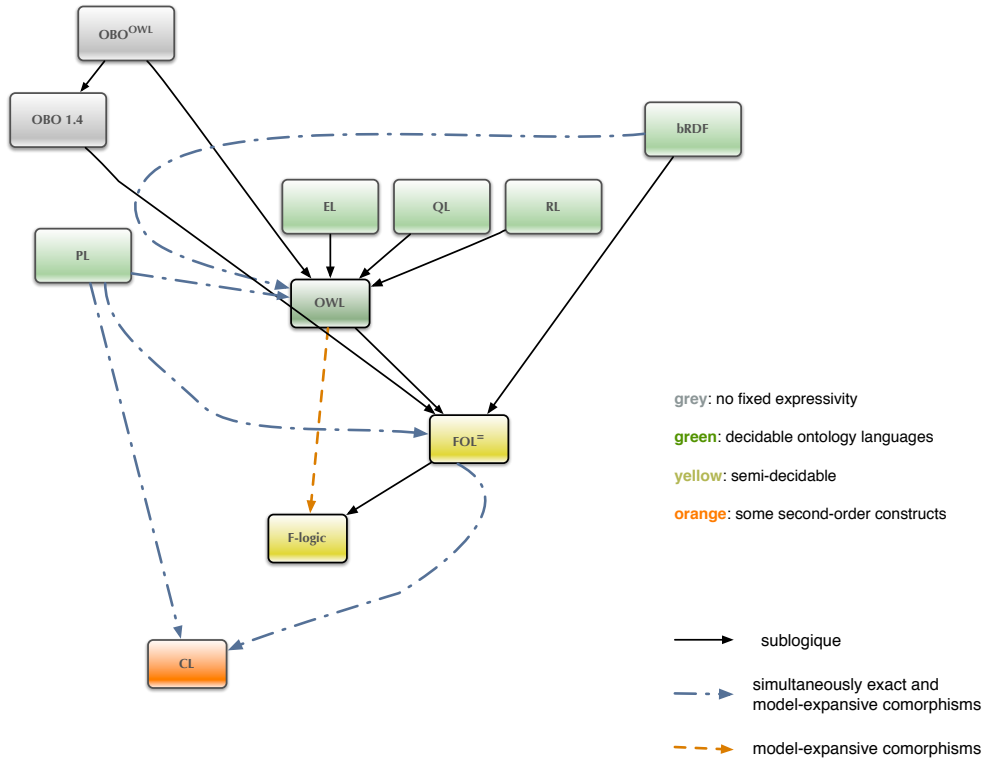


Figure F.1.: Translations between conforming OMS languages (extended)

## G. Annex (informative): Example Uses of all DOL Constructs

92

Note(92)

Top-level declarations in libraries	
Top-level declaration	Examples
language IRI	Alignments, Publications
logic IRI	Alignments, Mereology
serialization IRI	Alignments, Mereology
PrefixMap	Mereology
ontology IRI = OMS end	Alignments, Mereology
ontology IRI = %mcons OMS end	Mereology
interpretation IRI : OMS to OMS = Symbol  -> Symbol ...	Mereology
93 interpretation IRI : OMS to OMS = %cons Symbol  -> Symbol ...	Note(93)
interpretation IRI : OMS to OMS = translation IRI	
equivalence IRI : OMS <-> OMS = OMS end	Algebra
module IRI : OMS of OMS for Symbols	
module IRI %ccons : OMS of OMS for Symbols	
alignment IRI : OMS to OMS end	
alignment IRI 1 : OMS to OMS end	
alignment IRI ? : OMS to OMS end	
alignment IRI + : OMS to OMS end	
alignment IRI * : OMS to OMS end	
alignment IRI : OMS to OMS = Correspondences	Alignments

<sup>92</sup>NOTE: the uses cases in the RFP should be reused and worked into DOL examples

<sup>93</sup>NOTE: Q-AUT: Should we have another column here that refers to the *abstract* syntax?

G. Annex (informative): Example Uses of all DOL Constructs

OMS	
OMS notation	Examples
BasicOMS	Alignments, Mereology
IRI	Alignments, Mereology
IRI %( IRI )%	
minimize { OMS }	BlocksWithCircumscription
OMS minimize Symbols var Symbols	BlocksWithCircumscription
OMS with Symbol  -> Symbol ...	Alignments
OMS with translation IRI	Mereology
OMS with translation IRI : IRI → IRI	
OMS with translation IRI → IRI	
OMS with translation → IRI	
OMS hide SymbolItems	Algebra
OMS reveal Symbols	
OMS reveal Symbol  -> Symbol ...	
OMS hide along IRI	
OMS hide along IRI : IRI → IRI	
OMS hide along IRI → IRI	
OMS hide along → IRI	
OMS approximate with IRI	
OMS approximate in IRI with IRI	
OMS approximate in IRI	
OMS and OMS	
OMS then OMS	Mereology
OMS then %ccons OMS	
OMS then %ccons %( IRI )% OMS	
OMS then %mcons OMS	
OMS then %mono OMS	
OMS then %wdef OMS	
OMS then %def OMS	
OMS then %implied OMS	BlocksWithCircumscription
logic IRI : OMS	
language IRI : OMS	
serialization IRI : OMS	
OMS bridge Translation OMS	Publications
combine NetworkElements	Alignments, Publications
combine NetworkElements excluding IRIs	

## G.1. Mereology: Distributed and Heterogeneous Ontologies

94

Note(94)

<sup>94</sup>NOTE: Q-AUT: In the TKE paper we made the name of the propositional logic ontology syntax explicit. The propositional logic listing now leaves us with a problem: neither is propositional logic specified as DOL-conformant, nor is Hets' CASL-like syntax, nor is anything of this intended to ever be normative. TM: hence either leave it out, or make propositional logic normative. What about the examples in

## G. Annex (informative): Example Uses of all DOL Constructs

```

%prefix( :      <http://www.example.org/mereology#>
          owl: <http://www.w3.org/2002/07/owl#>
          log:   <http://purl.net/dol/logic/>      %% descriptions of logics ...
          trans: <http://purl.net/dol/translations/> )% %% ... and translations

library Mereology

logic log:Propositional syntax ser:Prop/Hets      %% non-standard serialization built into
ontology Taxonomy = %mcons      %% basic taxonomic information about mereology reused from
  props PT, T, S, AR, PD
  . S  $\vee$  T  $\vee$  AR  $\vee$  PD  $\longrightarrow$  PT
  %% PT is the top concept
  . S  $\wedge$  T  $\longrightarrow \perp$                                 %% PD, S, T, AR are pairwise disjoint
  . T  $\wedge$  AR  $\longrightarrow \perp$ 
  %% and so on
end

language lang:OWL2 logic log:SROIQ syntax ser:OWL2/Manchester
%% OWL Manchester syntax
ontology BasicParthood =                                %% Parthood in SROIQ, as far as easily expressible
  Class: ParticularCategory SubClassOf: Particular
  %% omitted similar declarations of the other categories
  DisjointUnionOf: SpaceRegion, TimeInterval, AbstractRegion, Perdurant
  %% pairwise disjointness more compact thanks to an OWL built-in
  ObjectProperty: isPartOf Characteristics: Transitive
  ObjectProperty: isProperPartOf Characteristics: Asymmetric SubPropertyOf: isPartOf
  Class: Atom EquivalentTo: inverse isProperPartOf only owl:Nothing
end                                %% an atom has no proper parts

interpretation TaxonomyToParthood : Taxonomy to BasicParthood =
  translation trans:PropositionalToSROIQ,      %% translate the logic, then rename the entities
  PT  $\mapsto$  Particular, S  $\mapsto$  SpaceRegion, T  $\mapsto$  TimeInterval, A  $\mapsto$  AbstractRegion, %[ and so on

logic log:CommonLogic syntax ser:CommonLogic/CLIF
  %% syntax: the Lisp-like CLIF dialect of Common Logic
ontology ClassicalExtensionalParthood =
  BasicParthood with translation trans:SROIQtoCL
  %% import the OWL ontology from above, translate it to Common Logic, then extend it
then
  . (forall (X) (if (or (= X S) (= X T) (= X AR) (= X PD))
    (forall (x y z) (if (and (X x) (X y) (X z))
      (and
        %% now list all the axioms
        (if (and (isPartOf x y) (isPartOf y x)) (= x y))
        %% antisymmetry
        (if (and (isProperPartOf x y) (isProperPartOf y z)) (isProperPartOf x z))
        %% transitivity; can't be expressed in OWL together with asymmetry

```

---

OWL+CL develop during the Ontology Summit Hackathon?

## G. Annex (informative): Example Uses of all DOL Constructs

```

    (iff (overlaps x y) (exists (pt) (and (isPartOf pt x) (isPartOf pt y))))
    (iff (isAtomicPartOf x y) (and (isPartOf x y) (Atom x)))
    (iff (sum z x y)
        (forall (w) (iff (overlaps w z) (and (overlaps w x) (overlaps w y)))))
    (exists (s) (sum s x y))
%% existence of the sum
    ))))
. (forall (Set a) (iff (fusion Set a)
%% definition of fusion
    (forall (b) (iff (overlaps b a)
        (exists (c) (and (Set c) (overlaps c a)))))))
}

```

## G.2. Blocks World: Minimization

95

Note(95)

```

library BlocksWithCircumscription
logic log:OWL

ontology Blocks =
    %% FIXED PART
    Class: Block
    Individual: B1 Types: Block
    Individual: B2 Types: Block DifferentFrom: B1
    %% B1 and B2 are different blocks
then
    %% CIRCUMSCRIBED PART
    minimize {
        Class: Abnormal
        Individual: B1 Types: Abnormal
        %% B1 is abnormal
    }
then
    %% VARYING PART
    Class: Ontable
    Class: BlockNotAbnormal EquivalentTo: Block and not Abnormal SubClassOf: Ontable
    %% Normally, a block is on the table
then %implied
    Individual: B2 Types: Ontable
    %% B2 is on the table
end

```

ToDo

<sup>95</sup>NOTE: Q-AUT: Here we need the prefixes for registry entries (e.g. logics) once more; they should be reused across examples. Or we need to specify a mechanism that gets rid of *these* prefixes altogether. @TM, could you please comment on my specification enhancement request <http://trac.informatik.uni-bremen.de:8080/hets/ticket/1020#comment:33?>



## G. Annex (informative): Example Uses of all DOL Constructs

To Do: Instead of Blocks World, perhaps we could specify an ontology that uses inheritance networks with exceptions, and then use circumscription to axiomatize that ontology.

```
ontology Blocks_Alternative =
  Class: Block
  Class: Abnormal
  Individual: B1 Types: Block, Abnormal
  Individual: B2 Types: Block DifferentFrom: B1
    %% B1 and B2 are different blocks
    %% B1 is abnormal
  Class: Ontable
  Class: BlockNotAbnormal EquivalentTo: Block and not Abnormal SubClassOf: Ontable
    %% Normally, a block is on the table
  minimize Abnormal var Ontable, BlockNotAbnormal
then %implied
  Individual: B2 Types: Ontable
    %% B2 is on the table
end
```

### G.2.1. Alignments

```
%prefix( :      <http://www.example.org/alignment#>
          owl  <http://www.w3.org/2002/07/owl#>
          log    <http://purl.net/dol/logic/> %% descriptions of logics ...
          trans  <http://purl.net/dol/translations/> )% %% ... and translations

library Alignments

language lang:OWL2 logic log:SROIQ syntax ser:OWL2/Manchester

alignment Alignment1 : { Class: Woman } to { Class: Person } =
  Woman < Person
end

ontology AlignedOntology1 =
  combine Alignment1
end

ontology Onto1 =
  Class: Person
  Class: Woman SubClassOf: Person
  Class: Bank
end

ontology Onto2 =
  Class: HumanBeing
  Class: Woman SubClassOf: HumanBeing
```

### G. Annex (informative): Example Uses of all DOL Constructs

```
Class: Bank
end

alignment VAlignment : Onto1 to Onto2 =
  Person = HumanBeing,
  Woman = Woman
end

ontology VAlignedOntology =
  combine 1 : Onto1, 2 : Onto2, VAlignment
  %% 1:Person is identified with 2:HumanBeing
  %% 1:Woman is identified with 2:Woman
  %% 1:Bank and 2:Bank are kept distinct
end

ontology VAlignedOntologyRenamed =
  VAlignedOntology with 1:Bank |-> RiverBank, 2:Bank |-> FinancialBank
end
```

## G.3. Distributed Description Logics

```
%prefix( :      <http://www.example.org/mereology#>
          owl  <http://www.w3.org/2002/07/owl#>
          log    <http://purl.net/dol/logic/> %% descriptions of logics ...
          trans  <http://purl.net/dol/translations/> )% %% ... and translations

library Publications

language lang:OWL2 logic log:SROIQ syntax ser:OWL2/Manchester

ontology Publications1 =
  Class: Publication
  Class: Article SubClassOf: Publication
  Class: InBook SubClassOf: Publication
  Class: Thesis SubClassOf: Publication
  Class: MasterThesis SubClassOf: Thesis
  Class: PhDThesis SubClassOf: Thesis
end

ontology Publications2 =
  Class: Thing
  Class: Article SubClassOf: Thing
  Class: BookArticle SubClassOf: Thing
  Class: Publication SubClassOf: Thing
  Class: Thesis SubClassOf: Thing
end

ontology Publications_Combined =
```

## G. Annex (informative): Example Uses of all DOL Constructs

```

combine
  1 : Publications1 with translation OWL2MS-OWL,
  2 : Publications2 with translation OWL2MS-OWL
  %% implicitly: Article  $\mapsto$  1:Article ...
  %%               Article  $\mapsto$  2:Article ...
bridge with translation MS-OWL2DDL
  %% implicitly added my translation MS-OWL2DDL: binary relation providing the bridge
  1:Publication  $\xrightarrow{\sqsubseteq}$  2:Publication
  1:PhdThesis  $\xrightarrow{\sqsubseteq}$  2:Thesis
  1:InBook  $\xrightarrow{\sqsubseteq}$  2:BookArticle
  1:Article  $\xrightarrow{\sqsubseteq}$  2:Article
  1:Article  $\xrightarrow{\supseteq}$  2:Article
end

ontology Publications_Extended =
Publications
then
bridge with translation DDL2-ECO
  %% turns implicit domain-relation into default relation 'D'
  %% add E-connection style bridge rules on top
end

%% Note: unfinished...
%% add second spec following example from AI journal paper on E-connections,
%% page 22: three different bridge relations between two ontologies; first DDL
%% modelling, translation to ECO with default relation, renaming and extension
%% in ECO style.

library Market

language lang:OWL2 logic log:SROIQ syntax ser:OWL2/Manchester
ontology Purchases =
combine
  1 : { Class: PurchaseOrder },
  2 : { ObjectProperty: Buyer
      ObjectProperty: Good
      ObjectProperty: BoughtBy }
bridge with translation OWL2DDLwithRoles
  1:PurchaseOrder -into-> 2:BoughtBy
  %% means in FOL: forall x 1PurchaseOrder(x) -> forall yz CR12(x,y,z) -> 2BoughtBy(y,z)
end

```

### G.3.1. Algebra

96

Note(96)

```
%prefix( :      <http://www.example.org/alignment#>
            owl <http://www.w3.org/2002/07/owl#>
            log   <http://purl.net/dol/logic/> %% descriptions of logics ...
            trans <http://purl.net/dol/translations/> )% %% ... and translations

library Algebra

logic log:CommonLogic syntax ser:CommonLogic/CLIF

ontology implicit_group =
(forall (x y z)
  (= (op x (op y z)) (op (op x y) z)))
(exists (e)
  (forall (x)
    (and
      (= x (op e x))
      (= x (op x e))))
(forall (x)
  (exists (y)
    (and
      (= x (op x (op x y)))
      (= x (op x (op y x))))))
end

ontology explicit_group =
(forall (x y z)
  (= (op x (op y z)) (op (op x y) z)))
(forall (x)
  (and
    (= x (op e x))
    (= x (op x e))))
(forall (x)
  (and
    (= x (op x (op x (inv x))))
    (= x (op x (op (inv x) x)))))
end

equivalence groups_equiv : implicit_group <-> { explicit_group hide e, inv }
end
```

---

<sup>96</sup>NOTE: use “spec” here???

## H. Annex (informative): Use cases

This annex sketches scenarios that outline how DOL is intended to be applied. For each scenario, we list its status of implementation, the DOL features it makes use of, and provide a brief description.

### H.1. Generating multilingual labels for menus in a user interface

**Status** exists (but not yet DOL-based)

**Features** Aligning (multiple OWL ontologies), Annotation

DO-ROAM (**D**ata and **O**ntology driven **R**oute-finding **O**f **A**ctivity-oriented **M**obility<sup>1</sup>) is a web service with an interactive frontend that extends OpenStreetMap by an ontology-based search for located activities and opening hours [8]. The service is driven by a set of different OWL ontologies that have been aligned to each other using the Falcon matching tool [24]. The user interface of the DO-ROAM web frontend offers multilingual labels, which are maintained in close connection to the underlying ontologies.

Porting DO-ROAM to DOL would enable the coherent representation of the aligned ontologies as one OMS network, and it would enable the maintenance of the user interface labels as annotations inside the ontology.

### H.2. Connecting devices of differing complexity in an Ambient Assisted Living setting

**Status** core ontology (not DOL-based) and service environment exists – the DOL-based extensions not yet

**Features** Logical OMS mappings across different logics, connection to linked open datasets

Consider the following ambient assisted living (AAL) scenario:

Clara instructs her **wheelchair** to get her to the **kitchen** (next door to the **living room**). For **dinner**, she would like to take a *pizza* from the **freezer** and bake it in the **oven**. (Her diet is *vegetarian*.) Afterwards she needs to rest in **bed**.

Existing ontologies for ambient assisted living (e.g. the OpenAAL<sup>2</sup> OWL ontology) cover the *core* of these concepts; they provide at least classes (or generic superclasses) corresponding to the concepts highlighted in **bold**. However, that does not cover the scenario completely:

---

<sup>1</sup><http://www.do-roam.org>

<sup>2</sup><http://openaal.org>

## H. Annex (informative): Use cases

- Some concepts (here: food and its properties, *italicized*) are not covered. There are separate ontologies for that (such as the Pizza ontology<sup>3</sup>), whereas information about concrete products (here: information about the concrete pizza in Clara's oven) would rather come from Linked Open Datasets than from formal ontologies.
- Not all concepts (here: space and time, underlined) are covered at the required level of complexity. OpenAAL says that appointments have a date and that rooms can be connected to each other, but not what exactly that means. Foundational ontologies and spatial calculi, often formalized in first-order logic, cover space and time at the level of complexity required by a central controller of an apartment and by an autonomously navigating wheelchair.
- Thirdly, even description logic might be too complex for very simple devices involved into the scenario, such as the kitchen light switch, for which propositional logic may be sufficient.

Thus, an adequate formalization of this scenario has to be heterogeneous. For example, one could imagine the following axioms:

**light switch** “light is switched on if and only if someone is in the room and it is dark outside” – this could be formalized in propositional logic as  $\text{light\_on} \equiv \text{person\_in\_room} \wedge \text{dark\_outside}$ .

**freezer** “a vegetarian pizza is a pizza whose toppings are all vegetarian” – this could be formalized in description logic as  $\text{VegetarianPizza} \equiv \text{Pizza} \sqcap \forall \text{hasTopping}.\text{Vegetarian}$

**wheelchair** “two areas in a house (e.g. a working area in a room) are either the same, or intersecting, or bordering, or separated, or one is part of the other” – this could be formalized as an RCC-style spatial calculus in first-order logic as

$$\forall a_1, a_2. \quad \text{equal}(a_1, a_2) \vee \text{overlapping}(a_1, a_2) \vee \text{bordering}(a_1, a_2) \vee \text{disconnected}(a_1, a_2) \vee \text{part\_of}(a_1, a_2) \vee \text{part\_of}(a_2, a_1).$$

DOL would be capable of expressing all that within one library of heterogeneous ontologies arranged around an OWL core (here: the OpenAAL ontology), including logical OMS mappings from OpenAAL to the other ontologies, as well as a re-declaration of a concrete pizza product from a product dataset as an instance of the Pizza OWL class.

### H.3. Interpreting the OWL formalization of the DOLCE foundational ontology in First-order logic

**Status** potential use case

**Features** Logical OMS mappings

DOLCE is a foundational ontology that has primarily been formalized in the first-order logic ontology language KIF (a predecessor of Common Logic), but also in OWL (“DOLCE Lite”) [32]. This ‘OWLized’ version was targeting use in semantic web services and domain ontology interoperability, and to provide the generic categories and relationships to aid domain ontology development. DOLCE has been used also for semantic middleware, and in OWL-formalised

<sup>3</sup>This is not a fully comprehensive food ontology, but rather a well-known sample OWL ontology; cf. <http://owl.cs.manchester.ac.uk/tutorials/protegeowltutorial/>

ontologies of neuroimaging, computing, ecology, and data mining and optimization. Given the differences in expressivity, DOLCE Lite had to simplify certain notions. For example, the DOLCE Lite formalization of “temporary parthood” (something is part of something else at a certain point or interval in time) omits any information about the time, as OWL only supports binary predicates (a.k.a. “properties”). That leaves ambiguities for modeling a view from DOLCE Lite to the first-order DOLCE, as such a view would have to reintroduce the third (temporal) component of such predicates:

- Should a relation asserted in terms of DOLCE Lite be assumed to hold for *all* possible points/intervals in time, i.e. should it be universally quantified?
- Or should such a relation be assumed to hold for *some* points/intervals in time, i.e. should it be existentially quantified?
- Or should a concrete value for the temporal component be assumed, e.g. “0” or “now”?

DOL would support the formalization of all of these views and, given suitable consistency checking tools, the analyzation of whether any such view would satisfy all further axioms that the first-order DOLCE states about temporal parthood.

## H.4. Extending the OWL Time ontology to a more comprehensive coverage of time

**Status** potential use case

**Features** Logical OMS mappings

The OWL Time ontology<sup>4</sup> covers temporal concepts such as instants and intervals and has been designed for describing the temporal content of Web pages and the temporal properties of Web services. While OWL is suitable for these intended applications, only a first-order axiomatization is capable of faithfully capturing all relevant notions, such as the trichotomy of the “before” relation: One instant is either before another one, or at the same time, or after. Moreover, a relationship between facts expressed in terms of instants and facts expressed in terms of intervals (both of which is, independently, possible in OWL), can only be established via first-order logic, e.g. by declaring an interval of length zero equivalent to an instant.

A separate first-order axiomatization of OWL Time exists [[22],[37]]. DOL would instead provide the mechanism of modeling OWL Time as one coherent heterogeneous ontology, using OWL and, e.g., Common Logic.<sup>97</sup> For the temporal description logic  $\mathcal{DLR}_{US}$  for knowledge bases and logic-based temporal conceptual data modeling [[1],[2]];  $\mathcal{DLR}_{US}$  combines the propositional temporal logic with the *Since* and *Until* operators and the (non-temporal) description logic  $\mathcal{DLR}$  and can be regarded as an expressive fragment of the first-order temporal logic  $L^{since,until}$ . Within DOL, this would enable one to have ‘lightweight’ time aspects with OWL Time, which are then properly formalized with  $\mathcal{DLR}_{US}$  or a leaner variant TDL-Lite [[4]], where notions such as (some time) “before” are given a formal semantics of the intended meaning that the plain OWL Times human-readable object property does not have. The latter, then, would enable the modeller to represent the meaning—hence, restrict the possible models—and check the consistency of the temporal constraints and so-called ‘evolution constraints’ in the ontology (evolution constraints constrain membership of an object or an individual relation

Note(97)

<sup>4</sup><http://www.w3.org/TR/2006/WD-owl-time-20060927/>

<sup>97</sup>NOTE: This is also a use case for multiple namespaces: OWL supports namespaces, CL doesn't.

to a concept or relationship over time). For instance, that each divorcee must have been a participant in a marriage before, that boarding only may occur after checking in, and that any employee must obtain a salary increase after two years of employment. It also can be used to differentiate between essential and immutable parthood, therewith being precise in the ontology about, e.g., the distinction how a human brain is part of a human (humans cannot live without it), versus how a hand is part of a human (humans can live without it), versus how the hand is part of, say, a boxer, which is essential to the boxer but only for as long as he is a boxer [[3]].

## H.5. Metadata in COLORE (Common Logic Repository)

**Status** exists (but not yet DOL-based)

**Features** Annotation, Metadata vocabularies

COLORE, the Common Logic Repository<sup>5</sup> is an open repository of more than 150 ontologies as of December 2011, all formalized in Common Logic. COLORE stores metadata about its ontologies, which are represented using a custom XML schema that covers the following aspects<sup>6</sup>, without specifying a formal semantics for them:

**module provenance** author, date, version, description, keyword, parent ontology<sup>7</sup>

**axiom source provenance** name, author, year<sup>8</sup>

**direct relations** maps (signature morphisms), definitional extension, conservative extension, inconsistency between ontologies, imports, relative interpretation, faithful interpretation, definable equivalence

DOL provides built-in support for a subset of the “direct relations” and specifies a formal semantics for them. In addition, it supports the implementation of the remainder of the COLORE metadata vocabulary as an ontology, reusing suitable existing metadata vocabularies such as OMV (cf. annex I), and it supports the implementation of one or multiple Common Logic ontologies plus their annotations as one coherent library.

## H.6. Extending OWL with datatypes defined in CASL

**Status** potential use case

**Features** ...

- OWL datatypes are in practice restricted to the XML Schema datatypes
- XML Schema can only specify the *syntax* of datatypes
- CASL can specify syntax (but not quite in the same way as XML Schema) *and* semantics of datatypes

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<sup>5</sup><http://stl.mie.utoronto.ca/colore/>

<sup>6</sup><http://stl.mie.utoronto.ca/colore/metadata.html>

<sup>7</sup>Note that this use of the term “module” in COLORE corresponds to the term *structured OMS* in this OMG Specification

<sup>8</sup>Note that this may cover any *sentences* in the sense of this OMG Specification



## *H. Annex (informative): Use cases*

98 99

Note(98)

Note(99)

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<sup>98</sup>NOTE: TODO: ModuleRelDefn combined with approximation and RDF-based querying of annotation/metadata dimensions

<sup>99</sup>NOTE: TODO: Maybe have an(other?) appendix that refers to the usage of DOL within ontology engineering methodologies, or at least to some good practices of using DOL

# I. Annex (informative): Annotation Vocabularies

100

Note(100)

Table I.1.: Vocabularies recommended for annotating DOL OMS		
Vocabulary name	Purpose	ref.
DCMI Metadata Terms	general-purpose and biographical metadata	[6]
Ontology Metadata Vocabulary (OMV)	ontology engineering metadata	[21]

101

Note(101)

<sup>100</sup>NOTE: Q-ALL: Or should this rather be normative?  
<sup>101</sup>NOTE: TODO: maybe mention: How do we use the ISO 12620 DCR for our extension of the OMV?

## **J. Annex (informative): Bibliography**

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