

XXXXX

XXXXX¹ and XXXXX²

¹ XXXXX
XXXX,
² XXXXX
XXXX

Abstract. Keywords: ..

1 Introduction

2 Ideas

- sind alle constraints abgedeckt?
- kann man alle constraints in SPARQL definieren?
- sind alle constraints mit Logik ausdrückbar?
- vollständig mit Reasoning — OW
- vollständig ohne Reasoning — CW
- es gibt keinen query rewriting mechanismus für OWL 2, nur für OWL-QL
- constraints in einer anderen constraint language definieren wenn constraints nicht in OWL beschrieben werden können
- durch reasoning entstehen Probleme, auf die man nicht gekommen wäre –i sofort nachvollziehbar
- zeigen, dass OWL-QL und constraint language einer konkreten Domäne zusammen vollständig sind
- System entwickeln, das effizient ist / Experimente

Nehmen wir nun an, dass dein Framework welches entsprechende SPARQL Queries generiert diese auf einem SPARQL Endpoint evaluiert der zu der vorliegenden Ontologie bzw. des darin verwendeten OWL 2 Profils das entsprechende Entailment Regime realisiert, wären die zurückgegebenen Resultsets vollständig. Wie das Entailment Regime im Endpoint realisiert ist, also durch Query Rewriting oder durch Vervollständigung der ABox, ist dabei irrelevant.

Wie allerdings bspw. in https://www.uni-ulm.de/fileadmin/website_uni-ulm/iui.inst.090/Lehre/WS_2011-2012/SemWebGrundlagen/LectureNotes.pdf auf Seite 51 veranschaulicht, ist die Komplexität des Reasoning abhängig von der zugrunde gelegten Sprache und kann daher nur in bestimmten Fällen effizient durchgeführt werden. Wie in unserem letzten Paper beschrieben zielt unter anderem die Definition von DL-Lite gerade darauf ab Reasoning Aufgaben und Query Answering effizient zu ermöglichen und ist Grundlage des OWL 2 QL

Profils. Nun ist allgemein bekannt, dass die logische Konsistenz für diese Art von Sprachen effizient geprüft werden kann.

Allerdings wäre wie bspw. in http://www.aifb.kit.edu/images/d/d2/2005_925_Haase.Consistent.Evol.1.pdf beschrieben auch eine sogenannte 'User-defined Consistency' denkbar. Genau an dieser Stelle könnten wir ansetzen.

3 research questions

- for which RDF validation requirements the expressivity of DL-Lite_A respectively OWL 2 QL is sufficient?
- for which RDF validation requirements additional constraint languages are needed?
- which constraint languages are suitable to express remaining requirements?
- what are the effects of these constraints regarding complexity?

4 OWL 2 QL

OWL 2 profiles specification: [2]

- OWL 2 QL constructs
- Difference between OWL 2 DL and OWL 2 QL

Logical Underpinning for OWL 2 QL. OWL 2 QL is based on the DL-Lite family of description logics. Several variants of DL-Lite have been described in the literature, and DL-Lite_R provides the logical underpinning for OWL 2 QL. DL-Lite_R does not require the unique name assumption (UNA), since making this assumption would have no impact on the semantic consequences of a DL-Lite_R ontology. More expressive variants of DL-Lite, such as DL-Lite_A , extend DL-Lite_R with functional properties, and these can also be extended with keys; however, for query answering to remain in LOGSPACE, these extensions require UNA and need to impose certain global restrictions on the interaction between properties used in different types of axiom. Basing OWL 2 QL on DL-Lite_R avoids practical problems involved in the explicit axiomatization of UNA [2].

5 RDF Validation Requirements Not Covered By OWL 2 QL

5.1 Class-Specific Disjointness of Properties

requirements:

- R-11-DISJOINT-DATA-PROPERTIES-CLASS-SPECIFIC
- R-12-DISJOINT-OBJECT-PROPERTIES-CLASS-SPECIFIC
- R-13-DISJOINT-GROUP-OF-PROPERTIES-CLASS-SPECIFIC

5.1.1 Class-Specific Disjoint Data Properties R-11-DISJOINT-DATA-PROPERTIES-CLASS-SPECIFIC

- exclusive OR of data properties
- with OWL 2, inclusive OR of properties would be possible to express, but not exclusive OR of data properties

constraint (ShEx):

```
1 <Human> { (
2   foaf:name xsd:string | foaf:givenName xsd:string+ ,
3   foaf:familyName xsd:string ) }
```

Individuals matching the 'Human' data shape:

```
1 :Han
2   foaf:name "Han Solo" ;
3   foaf:familyName "Solo" .
4 :Anakin
5   foaf:givenName "Anakin" ;
6   foaf:givenName "Darth" ;
7   foaf:familyName "Skywalker" .
```

Individual not matching the 'Human' data shape:

```
1 :Anakin
2   foaf:name "Anakin Skywalker" ;
3   foaf:givenName "Anakin" ;
4   foaf:familyName "Skywalker" .
```

5.1.2 Class-Specific Disjoint Object Properties R-12-DISJOINT-OBJECT-PROPERTIES-CLASS-SPECIFIC

- see R-11-DISJOINT-DATA-PROPERTIES-CLASS-SPECIFIC

5.1.3 Class-Specific Disjoint Group of Properties R-13-DISJOINT-GROUP-OF-PROPERTIES-CLASS-SPECIFIC

- exclusive OR of property groups
- with OWL 2, inclusive OR of property groups would be possible to express, but not exclusive OR of property groups

constraint (ShEx):

A <Human> has either a name or at least 1 given name and 1 family name.

```
1 <Human> {
2   (
3     foaf:name xsd:string
4     |
5     foaf:givenName xsd:string+ ,
6     foaf:familyName xsd:string
7   )
8 }
```

Individuals matching the 'Human' data shape:

```
1 :Anakin
2   foaf:givenName "Anakin" ;
3   foaf:familyName "Skywalker" .
```

```
1 :Anakin
2   foaf:name "Anakin Skywalker" .
```

Individual not matching the 'Human' data shape:

```
1 :Anakin
2   foaf:givenName "Anakin" ;
3   foaf:familyName "Skywalker" ;
4   foaf:name "Anakin Skywalker" .
```

5.2 Default Values

requirements:

- R-31-DEFAULT-VALUES-OF-RDF-OBJECTS
- R-38-DEFAULT-VALUES-OF-RDF-LITERALS

5.2.1 R-31-DEFAULT-VALUES-OF-RDF-OBJECTS

- see R-38-DEFAULT-VALUES-OF-RDF-LITERALS

5.2.2 R-38-DEFAULT-VALUES-OF-RDF-LITERALS rule (SPIN):

Jedis have only 1 blue laser sword per default. Siths, in contrast, normally have 2 red laser swords.

```
1 owl:Thing
2   spin:rule [
3     a sp:Construct ;
4     sp:text ""
5       CONSTRUCT {
6         ?this :laserSwordColor "blue"^^xsd:string ;
7         ?this :numberLaserSwords "1"^^xsd:nonNegativeInteger .
8       }
9     WHERE {
10      ?this a :Jedi .
11    } "" ; ] .
12 owl:Thing
13   spin:rule [
14     a sp:Construct ;
15     sp:text ""
16       CONSTRUCT {
17         ?this :laserSwordColor "red"^^xsd:string ;
18         ?this :numberLaserSwords "2"^^xsd:nonNegativeInteger .
19       }
20     WHERE {
21      ?this a :Sith .
22    } "" ; ] .
```

data:

```
1 :Joda a :Jedi .
2 :DarthSidious a :Sith .
```

inferred triples:

```
1 :Joda
2   :laserSwordColor "blue"^^xsd:string ;
3   :numberLaserSwords "1"^^xsd:nonNegativeInteger .
4 :DarthSidious
5   :laserSwordColor "red"^^xsd:string ;
6   :numberLaserSwords "2"^^xsd:nonNegativeInteger .
```

5.3 Allowed and Not Allowed Values

requirements:

- R-30-ALLOWED-VALUES-FOR-RDF-OBJECTS
- R-37-ALLOWED-VALUES-FOR-RDF-LITERALS
- R-33-NEGATIVE-OBJECT-CONSTRAINTS
- R-200-NEGATIVE-LITERAL-CONSTRAINTS

5.3.1 R-30-ALLOWED-VALUES-FOR-RDF-OBJECTS

- covering approaches: OWL 2 DL (ObjectOneOf)

5.3.2 R-37-ALLOWED-VALUES-FOR-RDF-LITERAL

- covering approaches: OWL 2 DL (DataOneOf)

5.3.3 R-33-NEGATIVE-OBJECT-CONSTRAINTS

- covering approaches: ShEx, SPARQL, SPIN
- analogous to R-200-NEGATIVE-LITERAL-CONSTRAINTS

5.3.4 R-200-NEGATIVE-LITERAL-CONSTRAINTS

- definition: A matching triple has any literal except those explicitly excluded
- covering approaches: ShEx, SPARQL, SPIN

constraint (ShEx):

A matching triple has any literal except those excluded by the '-' operator.

```
1 <Jedi> {
2   :feelingForce 'true'^^xsd:boolean ,
3   :attitude 'good'^^xsd:string ,
4   :laserSwordColor 'blue'^^xsd:string ,
5   :numberLaserSwords '1'^^xsd:nonNegativeInteger }
6 <Sith> {
7   :feelingForce 'true'^^xsd:boolean ,
8   :attitude - 'good'^^xsd:string ,
9   :laserSwordColor - 'blue'^^xsd:string ,
10  :numberLaserSwords '2'^^xsd:nonNegativeInteger }
```

Individual matching the 'Jedi' data shape:

```
1 :Joda
2   :feelingForce 'true'^^xsd:boolean ;
3   :attitude 'good'^^xsd:string ;
4   :laserSwordColor 'blue'^^xsd:string ,
5   :numberLaserSwords '1'^^xsd:nonNegativeInteger .
```

Individual matching the 'Sith' data shape:

```
1 :DarthSidious
2   :feelingForce 'true'^^xsd:boolean ;
3   :attitude 'evil'^^xsd:string ;
4   :laserSwordColor 'red'^^xsd:string ,
5   :numberLaserSwords '2'^^xsd:nonNegativeInteger .
```

5.4 Membership in Controlled Vocabularies

requirements:

- R-32-MEMBERSHIP-OF-RDF-OBJECTS-IN-CONTROLLED-VOCABULARIES
- R-39-MEMBERSHIP-OF-RDF-LITERALS-IN-CONTROLLED-VOCABULARIES

constraint (DSP):

```
1 :bookDescriptionTemplate
2   a dsp:DescriptionTemplate ;
3   dsp:resourceClass swrc:Book ;
4   dsp:statementTemplate [
5     a dsp:NonLiteralStatementTemplate ;
6     dsp:property dterms:subject ;
7     dsp:nonLiteralConstraint [
8       a dsp:NonLiteralConstraint ;
9       dsp:valueClass skos:Concept ;
10      dsp:vocabularyEncodingScheme :BookSubjects, :BookTopics, :BookCategories ] ] .
```

A DSP consists of `dsp:DescriptionTemplates` that put constraints on instances of a certain class (`dsp:resourceClass`). `:bookDescriptionTemplate` describes resources of the type `swrc:Book`. The constraints can either be constraints on the description itself, e.g. a minimum occurrence of instances of this class. Additionally, constraints on single properties can be defined within a `dsp:StatementTemplate`. The `dsp:NonLiteralStatementTemplate` restricts books to have `dterms:subject` (`dsp:property`) relationships to RDF objects which are further described by the `dsp:NonLiteralConstraint`. These RDF objects have to be of the class `skos:Concept` (`dsp:ValueClass`). Controlled vocabularies (like `:BookSubjects`) are represented as `skos:ConceptSchemes` in RDF and as `dsp:VocabularyEncodingSchemes` in DSP. `dsp:VocabularyEncodingScheme` points to a list of controlled vocabularies the `skos:Concept` resources must be members of. The controlled vocabulary members (`skos:Concepts`) are related to the controlled vocabulary (`skos:ConceptScheme`) via the object properties `skos:inScheme` and `dcam:memberOf`.

valid data (DSP):

```

1 :ArtificialIntelligence
2   a swrc:Book ;
3   dcterms:subject :ComputerScience .
4 :ComputerScience
5   a skos:Concept ;
6   dcam:memberOf :BookSubjects ;
7   skos:inScheme :BookSubjects .
8 :BookSubjects
9   a skos:ConceptScheme .

```

invalid data (DSP):

```

1 :ArtificialIntelligence
2   a swrc:Book ;
3   dcterms:subject :ComputerScience .
4 :ComputerScience
5   a skos:Concept ;
6   dcam:memberOf :BooksAboutBirds ;
7   skos:inScheme :BooksAboutBirds ;
8   dcam:memberOf :BookSubjects ;
9   skos:inScheme :BookSubjects .
10 :BookSubjects
11   a skos:ConceptScheme .

```

The related subject (:ComputerScience) is a member of a controlled vocabulary (:BooksAboutBirds) which is not part of the list of allowed controlled vocabularies.

5.5 Pattern Matching

requirements:

- R-21-IRI-PATTERN-MATCHING-ON-RDF-SUBJECTS
- R-22-IRI-PATTERN-MATCHING-ON-RDF-OBJECTS
- R-23-IRI-PATTERN-MATCHING-ON-RDF-PROPERTIES
- R-44-PATTERN-MATCHING-ON-RDF-LITERALS
- R-141-NEGATIVE-PATTERN-MATCHING-ON-RDF-LITERALS

5.5.1 R-44-PATTERN-MATCHING-ON-RDF-LITERALS Covering approaches:

DQTP (MATCH Pattern), OWL 2 DL, RS, ShEx, SPARQL, SPIN constraints (OWL 2 DL) [description logics abstract syntax]:

```

1

```

constraints (OWL 2 DL) [functional-style syntax]:

```

1 Declaration( Datatype( :SSN ) )
2 DatatypeDefinition(
3   :SSN
4   DatatypeRestriction( xsd:string xsd:pattern "[0-9]{3}-[0-9]{2}-[0-9]{4}" ) )
5 DataPropertyRange( :hasSSN :SSN )

```

constraints (OWL 2 DL) [turtle syntax]:

```
1 :SSN
2   a rdfs:Datatype ;
3   owl:equivalentClass [
4     a rdfs:Datatype ;
5     owl:onDatatype xsd:string ;
6     owl:withRestrictions (
7       [ xsd:pattern "[0-9]{3}-[0-9]{2}-[0-9]{4}" ] ) ] .
```

– OWL 2 construct 'DatatypeRestriction' not allowed for OWL 2 QL

A social security number is a string that matches the given regular expression. The second axiom defines :SSN as an abbreviation for a datatype restriction on xsd:string. The first axiom explicitly declares :SSN to be a datatype. The datatype :SSN can be used just like any other datatype; for example, it is used in the third axiom to define the range of the :hasSSN property.

valid data (OWL 2 DL):

```
1 :ImBarnersLee
2   :hasSSN "123-45-6789"^^:SSN .
```

invalid data (OWL 2 DL):

```
1 :ImBarnersLee
2   :hasSSN "123456789"^^:SSN .
```

5.5.2 R-141-NEGATIVE-PATTERN-MATCHING-ON-RDF-LITERALS

Covering approaches: DQTP (MATCH Pattern), OWL 2 DL, SPARQL, SPIN

constraints (DQTP):

MATCH Pattern [1]

Application logic or real world constraints may put restrictions on the form of a literal value. P1 is the property we need to check against REGEX and NOP can be a not operator (!) or empty.

```
1 SELECT DISTINCT ?s WHERE { ?s %%P1%% ?value .
2   FILTER ( %%NOP%% regex(str(?value), %%REGEX%) ) }
```

example test bindings (DQTP):

```
1 1. dbo:isbn format is different '!' from '^[iIsSbBnN 0-9-])*$'
2 2. dbo:postCode format is different '!' from '[0-9]{5}$'
3 3. foaf:phone contains any letters ('[A-Za-z]')
```

test binding (DQTP):

```
1 dbo:isbn format is different '!' from '^[iIsSbBnN 0-9-])*$'
2
3 P1 => dbo:isbn
4 NOP => !
5 REGEX => '^[iIsSbBnN 0-9-])*$'
```


valid data (DQTP):

```
1 :FoundationsOfSWTechnologies
2   dbo:isbn 'ISBN-13 978-1420090505' .
```

invalid data (DQTP):

```
1 :HandbookOfSWTechnologies
2   dbo:isbn 'DOI 10.1007/978-3-540-92913-0' .
```

5.6 Calculations on and Comparisons of RDF Literals

requirements:

- R-41-STATISTICAL-COMPUTATIONS
- R-42-COMPUTATIONS-BASED-ON-DATATYPE
- R-43-COMPARISONS-BASED-ON-DATATYPE
- R-194-PROVIDE-STRING-FUNCTIONS-FOR-RDF-LITERALS

5.7 Constraining Facets on RDF Literals

XSD constraining facets: <http://www.w3.org/TR/2001/REC-xmlschema-2-20010502/#rf-facets>

requirements:

- R-44-PATTERN-MATCHING-ON-RDF-LITERALS
- R-45-RANGES-OF-RDF-LITERAL-VALUES
- R-46-CONSTRAINING-FACETS
- R-50-WHITESPACE-HANDLING-OF-RDF-LITERALS
- R-142-NEGATIVE-RANGES-OF-RDF-LITERAL-VALUES

5.7.1 R-44-PATTERN-MATCHING-ON-RDF-LITERALS

- see 'Pattern Matching'

5.7.2 R-45-RANGES-OF-RDF-LITERAL-VALUES constraints (OWL 2 DL) [description logics abstract syntax]:

```
1 TODO
```

constraints (OWL 2 DL) [functional-style syntax]:

```
1 Declaration( Datatype( :NumberPlayersPerWorldCupTeam ) )
2 DatatypeDefinition(
3   :NumberPlayersPerWorldCupTeam
4   DatatypeRestriction(
5     xsd:nonNegativeInteger
6     xsd:minInclusive "1"^^xsd:nonNegativeInteger
7     xsd:maxInclusive "23"^^xsd:nonNegativeInteger ) )
8 DataPropertyRange( :position :NumberPlayersPerWorldCupTeam )
```

constraints (OWL 2 DL) [turtle syntax]:

```
1 :NumberPlayersPerWorldCupTeam
2   a rdfs:Datatype ;
3   owl:equivalentClass [
4     a rdfs:Datatype ;
5     owl:onDatatype xsd:nonNegativeInteger ;
6     owl:withRestrictions (
7       [ xsd:minInclusive "1"^^xsd:nonNegativeInteger ]
8       [ xsd:maxInclusive "23"^^xsd:nonNegativeInteger ] ) ] .
```

The data range 'NumberPlayersPerWorldCupTeam' contains the non negative integers 1 to 23, as each world cup team can only have 23 football players at most.

valid data (OWL 2 DL):

```
1 :MarioGoetze
2   :position "19"^^:NumberPlayersPerWorldCupTeam .
```

invalid data (OWL 2 DL):

```
1 :MarioGoetze
2   :position "99"^^:NumberPlayersPerWorldCupTeam .
```

5.8 Language of RDF Literals

requirements:

- R-47-LANGUAGE-TAG-MATCHING
- R-48-MISSING-LANGUAGE-TAGS
- R-49-RDF-LITERALS-HAVING-AT-MOST-ONE-LANGUAGE-TAG

5.8.1 R-49-RDF-LITERALS-HAVING-AT-MOST-ONE-LANGUAGE-TAG constraints (DQTP):

ONELANGPattern [1]

A literal value should contain at most 1 literal for a language. P1 is the property containing the literal and V1 is the language we want to check.

```
1 SELECT DISTINCT ?s WHERE { ?s %%P1%% ?c
2   BIND ( lang(?c) AS ?l )
3   FILTER (isLiteral (?c) && lang(?c) = %%V1%%)}
4 GROUP BY ?s HAVING COUNT (?l) > 1
```

test binding (DQTP):

a single English ("en") foaf:name

```
1 P1 => foaf:name
2 V1 => en
```

valid data (DQTP):

```

1 :LeiaSkywalker
2   foaf:name 'Leia Skywalker'@en .

```

invalid data (DQTP):

```

1 :LeiaSkywalker
2   foaf:name 'Leia Skywalker'@en ;
3   foaf:name 'Leia'@en .

```

5.9 Property Occurrences

requirements:

- R-52-NEGATIVE-OBJECT-PROPERTY-CONSTRAINTS
- R-53-NEGATIVE-DATA-PROPERTY-CONSTRAINTS
- R-67-CLASSIFY-PROPERTIES-ACCORDING-TO-OCCURRENCE

5.9.1 R-52-NEGATIVE-OBJECT-PROPERTY-CONSTRAINTS

- instances of specific class must not have some object property
- OWL 2 DL: `ObjectComplementOf (ObjectSomeValuesFrom (ObjectPropertyExpression owl:Thing))`
- covering approaches: ShEx, SPIN

constraint (ShEx):

A matching triple has any predicate except those excluded by the '-' operator.

```

1 <FeelingForce> {
2   :feelingForce 'true'^^xsd:boolean ,
3   :attitude xsd:string }
4 <JediMentor> {
5   :feelingForce 'true'^^xsd:boolean ,
6   :attitude 'good'^^xsd:string ,
7   :laserSwordColor xsd:string ,
8   :numberLaserSwords xsd:nonNegativeInteger ,
9   :mentorOf @<JediStudent> ,
10  - :studentOf @<JediMentor> }
11 <JediStudent> {
12  :feelingForce 'true'^^xsd:boolean ,
13  :attitude 'good'^^xsd:string ,
14  :laserSwordColor xsd:string ,
15  :numberLaserSwords xsd:nonNegativeInteger ,
16  - :mentorOf @<JediStudent> ,
17  :studentOf @<JediMentor> }

```

individuals matching 'FeelingForce' and 'JediMentor' data shapes:

```

1 :Obi-Wan
2   :feelingForce 'true'^^xsd:boolean ;
3   :attitude 'good'^^xsd:string ;
4   :laserSwordColor 'blue'^^xsd:string ,
5   :numberLaserSwords '1'^^xsd:nonNegativeInteger ,
6   :mentorOf :Anakin .

```

individuals matching 'FeelingForce' and 'JediStudent' data shapes:

```
1 :Anakin
2   :feelingForce 'true'^xsd:boolean ;
3   :attitute 'good'^xsd:string ;
4   :laserSwordColor 'blue'^xsd:string ,
5   :numberLaserSwords '1'^xsd:nonNegativeInteger ,
6   :studentOf :Obi-Wan .
```

5.9.2 R-53-NEGATIVE-DATA-PROPERTY-CONSTRAINTS

- analogous to R-52-NEGATIVE-OBJECT-PROPERTY-CONSTRAINTS
- covering approaches: ShEx, SPIN

5.10 Property Groups

requirements:

- R-13-DISJOINT-GROUP-OF-PROPERTIES-CLASS-SPECIFIC
- R-66-PROPERTY-GROUPS

5.11 RDF-Specific Validation

requirements:

- R-120-HANDLE-RDF-COLLECTIONS

5.11.1 R-120-HANDLE-RDF-COLLECTIONS examples:

- size of collection
- first / last element of list must be a specific RDF literal
- compare elements of collection
- are collections identical?
- actions on RDF lists: <http://www.snee.com/bobdc.blog/2014/04/rdf-lists-and-sparql.html>
- 2. list element equals ”
- Does the list have more than 10 elements?

constraint (SPIN):

retrieves the 2. item from the list (2. student of Jedi mentor Jinn)

function call (SPIN):

```
1 BIND ( :getListitem( ?list, "1"xsd:nonNegativeInteger ) AS ?listItem ) .
```

function (SPIN):

```

1 :getListItem
2   a spin:Function ; rdfs:subClassOf spin:Functions ;
3   spin:constraint [
4     rdf:type spl:Argument ;
5     spl:predicate sp:arg1 ;
6     spl:valueType rdf:List ;
7     rdfs:comment "list" ; ] ;
8   spin:constraint [
9     rdf:type spl:Argument ;
10    spl:predicate sp:arg2 ;
11    spl:valueType xsd:nonNegativeInteger ;
12    rdfs:comment "item position (starting with 0)" ; ] ;
13   spin:body [
14     a sp:SELECT ;
15     sp:text ""
16       SELECT ?item
17       WHERE {
18         ?arg1 :contents/rdf:rest{?arg2}/rdf:first ?item } "" ; ] ;
19   spin:returnType rdfs:Resource .

```

data:

```

1 :Jinn :students
2   ( :Xanatos :Kenobi ) .

```

result:

```

1 :Kenobi

```

5.12 RDF Shapes

requirements:

- R-125-RDF-SHAPE-CHECKING

5.13 RDF Validation Results

requirements:

- R-150-RDF-REPRESENTATION-OF-VALIDATION-RESULTS
- R-151-USEFUL-MESSAGE-VALIDATION-RESULTS
- R-152-FIND-NOT-VALIDATED-TRIPLES
- R-153-RDF-REPRESENTATION-OF-CONSTRAINT-VIOLATIONS
- R-154-HANDLE-CONSTRAINT-VIOLATIONS
- R-155-GUIDANCE-HOW-TO-BECOME-VALID-DATA
- R-156-REFERENCES-TO-TRIPLES-CAUSING-THE-CONSTRAINT-VIOLATIONS
- R-157-REFERENCES-TO-VALIDATION-RULES-CAUSING-CONSTRAINT-VIOLATIONS
- R-158-SEVERITY-LEVELS-OF-CONSTRAINT-VIOLATIONS
- R-159-EXPLAIN-REASONS-OF-CONSTRAINT-VIOLATIONS

5.14 Requirements Covered by OWL 2 DL But Not by OWL 2 QL

6 Related Work

7 Evaluation

7.1 Evaluation Using Practical Data Set

7.2 RDF Validation Requirements Covered by OWL 2 QL

Table 2

7.3 RDF Validation Requirements Not Covered by OWL 2 QL

Table 3 Table 4 Table 5

7.3.1 RDF Validation Requirements Not Covered by OWL 2 QL But by OWL 2 DL

- OWL 2 DL as an instantiation of constraint languages which are high-level, human-friendly, and very expressive

Table 6

7.3.2 RDF Validation Requirements Not Covered by OWL 2 QL But by SPIN

- SPIN as an instantiation of constraint languages which are low-level and the most expressive

Table 7

7.3.3 RDF Validation Requirements Not Covered by OWL 2 QL But by ShEx

- ShEx as an instantiation of constraint languages which are high-level, human-friendly, intuitive, concise, and less expressive

Table 8

Table 1. RDF Validation Requirements Covered by OWL 2 QL

Requirements	Classification	Requirements
		R-1-UNIQUENESS-OF-URIS
		R-2-UNIQUE-INSTANCES
		R-3-EQUIVALENT-CLASSES (EquivalentClasses)
		R-4-EQUIVALENT-OBJECT-PROPERTIES (EquivalentObjectProperties)
		R-5-EQUIVALENT-DATA-PROPERTIES (EquivalentDataProperties)
		R-7-DISJOINT-CLASSES (DisjointClasses)
		R-9-DISJOINT-OBJECT-PROPERTIES (DisjointObjectProperties)
		R-10-DISJOINT-DATA-PROPERTIES (DisjointDataProperties)
		R-14-DISJOINT-INDIVIDUALS (DifferentIndividuals)
		R-25-OBJECT-PROPERTY-DOMAIN (ObjectPropertyDomain)
		R-26-DATA-PROPERTY-DOMAIN (DataPropertyDomain)
		R-27-CLASS-SPECIFIC-VALIDATION
		R-28-OBJECT-PROPERTY-RANGE (ObjectPropertyRange)
		R-35-DATA-PROPERTY-RANGE (DataPropertyRange)
		R-54-SUB-OBJECT-PROPERTIES (SubObjectPropertyOf)
		R-56-INVERSE-OBJECT-PROPERTIES (ObjectInverseOf)
		R-59-REFLEXIVE-OBJECT-PROPERTIES (ReflexiveObjectProperty)
		R-60-IRREFLEXIVE-OBJECT-PROPERTIES (IrreflexiveObjectProperty)
		R-61-SYMMETRIC-OBJECT-PROPERTIES (SymmetricObjectProperty)
		R-62-ASYMMETRIC-OBJECT-PROPERTIES (AsymmetricObjectProperty)
		R-64-SUB-DATA-PROPERTIES (SubDataPropertyOf)
		R-93-DIFFERENCE-BETWEEN-CONSTRAINTS-ON-OBJECT-AND-DATA-PROPERTIES
		R-94-POSITIVE-OBJECT-PROPERTY-ASSERTIONS (ObjectPropertyAssertion)
		R-95-POSITIVE-DATA-PROPERTY-ASSERTIONS (DataPropertyAssertion)
		R-99-STABLE-IDENTIFICATION-OF-CONSTRAINTS
		R-100-SUBSUMPTION (SubClassOf)
		R-101-DECLARATIVE-CONSTRAINT-LANGUAGE
		R-102-INTUITIVE-CONSTRAINT-LANGUAGE
		R-103-HIGH-LEVEL-CONSTRAINT-LANGUAGE
		R-104-CONSTRAINT-LANGUAGE-HAVING-IMPLEMENTATION-LANGUAGE
		R-105-CONSTRAINT-LANGUAGE-TRANSLATABLE-TO-IMPLEMENTATION-LANGUAGE
		R-107-TRANSFORMATIONS-BETWEEN-CONSTRAINT-LANGUAGE-AND-UML
		R-108-TRANSFORMATIONS-BETWEEN-CONSTRAINT-LANGUAGE-AND-XML-Schema
		R-109-TRANSFORMATIONS-BETWEEN-CONSTRAINT-LANGUAGE-AND-OCL
		R-110-TRANSFORMATIONS-BETWEEN-CONSTRAINT-LANGUAGE-AND-SPARQL

Table 2. RDF Validation Requirements Covered by OWL 2 QL

Requirements Classification	Requirements
	R-111-BASIC-USE-CASES-COVERED-BY-CONSTRAINT-LANGUAGE
	R-113-INTERACTION-OF-VALIDATION-WITH-REASONING
	R-115-CLOSED-WORLD-ASSUMPTION-CWA
	R-116-UNIQUE-NAME-ASSUMPTION-UNA
	R-117-CONTEXT-SENSITIVE-CONSTRAINTS
	R-118-NAMESPACE-SENSITIVE-CONSTRAINTS
	R-122-TRADE-OFF-BETWEEN-DIMENSIONS-EXPRESSIVITY-COMPLEXITY-PRE
	R-124-DESCRIBE-DATA
	R-126-CUSTOMIZABLE-VALIDATION-PROCESS
	R-128-HUMAN-UNDERSTANDABLE-CONCRETE-SYNTAXES-FORMULATING-CON
	R-129-MACHINE-UNDERSTANDABLE-CONCRETE-SYNTAXES-FORMULATION-CO
	R-130-CONCISE-CONCRETE-SYNTAXES-FORMULATING-CONSTRAINTS
	R-131-OWL-AS-CONCRETE-SYNTAX-FORMULATING-CONSTRAINTS
	R-132-MULTIPLE-CONCRETE-SYNTAXES-FORMULATING-CONSTRAINTS
	R-133-MULTIPLE-CONCRETE-SYNTAXES-FORMULATING-DATA
	R-136-MODULARITY-OF-CONSTRAINT-DEFINITIONS
	R-137-LEVERAGE-ON-EXISTING-TECHNOLOGIES
	R-138-CONSTRAINT-LANGUAGE-COMPATIBLE-WITH-SPARQL
	R-139-CONSTRAINT-LANGUAGE-DRIVES-USER-INTERFACE-FORM-GENERATIO
	R-140-SEPARATE-ONTOLOGIES-FROM-VALIDATION-SCHEMAS
	R-143-CONDITIONAL-TYPED-VALIDATION
	R-147-DISTRIBUTION-OF-CONSTRAINT-SCHEMAS
	R-148-DISTRIBUTED-VALIDATION-IN-COLLABORATIVE-ENVIRONMENTS
	R-149-MANAGEMENT-OF-CONSTRAINT-SCHEMA-EVOLUTION
	R-160-OPEN-SOURCE-CONSTRAINT-VALIDATION
	R-161-ACCEPTABLE-PERFORMANCE-OF-VALIDATION-ALGORITHM
	R-162-SPECIFICATION-PUBLICLY-AVAILABLE
	R-163-IMPLEMENTATION-EXISTS
	R-164-IMPLEMENTATION-PUBLICLY-AVAILABLE
	R-165-EXECUTABLE-DEMOS-EXAMPLES-USE-CASES
	R-168-PERFORM-BIG-DATASETS
	R-169-RDF-REPRESENTATION-OF-CONSTRAINT-LANGUAGE
	R-173-SEPARATE-CONSTRAINTS-FROM-VOCABULARIES-AND-ONTOLOGIES
	R-174-REUSE-CONSTRAINTS
	R-175-DISCOVER-CONSTRAINTS
	R-177-DEFINE-SEMANTICS-FOR-CONSTRAINTS
	R-178-ASSOCIATE-CONSTRAINTS-WITH-VOCABULARIES
	R-182-USE-KNOWN-CONCRETE-SYNTAX
	R-184-COMPACT-CONCRETE-SYNTAX
	R-187-DEFINE-SEMANTICS-OF-CONSTRAINTS-IN-TERMS-OF-SPARQL
	R-190-SPECIFY-EXPECTED-BEHAVIOR-UNDER-ALL-POSSIBLE-ENTAILMENT-RI
	R-192-DEFINE-ANNOTATIONS-FOR-CONSTRAINTS
	R-195-CONSTRAINT-LANGUAGE-EASY-TO-CONSUME-BY-TOOLS
	R-197-ATTACH-CONSTRAINTS-TO-CLASSES
	R-198-RDF-VALIDATION-AFTER-INFERENCING
	R-199-RDF-VALIDATION-MUST-COMPILE-DOWN-TO-SPARQL

Table 3. RDF Validation Requirements Not Covered by OWL 2 QL

Requirements	Covering Constraint La
R-6-EQUIVALENT-INDIVIDUALS (SameIndividual)	OWL 2 DL
R-8-DISJOINT-UNION-OF-CLASS-EXPRESSIONS (DisjointUnion)	OWL 2 DL
R-11-DISJOINT-DATA-PROPERTIES-CLASS-SPECIFIC	ShEx
R-12-DISJOINT-OBJECT-PROPERTIES-CLASS-SPECIFIC	ShEx
R-13-DISJOINT-GROUP-OF-PROPERTIES-CLASS-SPECIFIC	ShEx
R-15-CONJUNCTION-OF-CLASS-EXPRESSIONS (ObjectIntersectionOf)	OWL 2 DL
R-16-CONJUNCTION-OF-DATA-RANGES (DataIntersectionOf)	OWL 2 DL
R-17-DISJUNCTION-OF-CLASS-EXPRESSIONS (DisjointUnionOf)	OWL 2 DL
R-18-DISJUNCTION-OF-DATA-RANGES (DataUnionOf)	OWL 2 DL
R-19-NEGATION-OF-CLASS-EXPRESSIONS (ObjectComplementOf)	OWL 2 DL
R-20-NEGATION-OF-DATA-RANGES (DataComplementOf)	OWL 2 DL
R-21-IRI-PATTERN-MATCHING-ON-RDF-SUBJECTS	SPIN
R-22-IRI-PATTERN-MATCHING-ON-RDF-OBJECTS	SPIN, ShEx
R-23-IRI-PATTERN-MATCHING-ON-RDF-PROPERTIES	SPIN, ShEx
R-24-PROVENANCE-CONSTRAINTS	
R-29-CLASS-SPECIFIC-RANGE-OF-RDF-OBJECTS	SPIN, RS
R-30-ALLOWED-VALUES-FOR-RDF-OBJECTS (ObjectOneOf)	OWL 2 DL
R-31-DEFAULT-VALUES-OF-RDF-OBJECTS	SPIN, BF, RS
R-32-MEMBERSHIP-OF-RDF-OBJECTS-IN-CONTROLLED-VOCABULARIES	DSP, SPIN
R-33-NEGATIVE-OBJECT-CONSTRAINTS	ShEx, SPIN
R-34-AVAILABLE-CLASS-DEFINITION	ShEx, SPIN
R-36-CLASS-SPECIFIC-RANGE-OF-RDF-LITERALS	ShEx, BF, SPIN
R-37-ALLOWED-VALUES-FOR-RDF-LITERALS (DataOneOf)	OWL 2 DL
R-38-DEFAULT-VALUES-OF-RDF-LITERALS	SPIN, BF, RS
R-39-MEMBERSHIP-OF-RDF-LITERALS-IN-CONTROLLED-VOCABULARIES	DSP, SPIN
R-44-PATTERN-MATCHING-ON-RDF-LITERALS	DQTP, OWL 2 DL, ShEx
R-41-STATISTICAL-COMPUTATIONS	SPIN
R-42-COMPUTATIONS-BASED-ON-DATATYPE	
R-43-COMPARISONS-BASED-ON-DATATYPE	DQTP, ShEx, SPIN
R-45-RANGES-OF-RDF-LITERAL-VALUES	DQTP, SPIN
R-46-CONSTRAINING-FACETS	Stardog, SPIN
R-47-LANGUAGE-TAG-MATCHING	SPIN
R-48-MISSING-LANGUAGE-TAGS	SPIN
R-49-RDF-LITERALS-HAVING-AT-MOST-ONE-LANGUAGE-TAG	DQTP, SPIN
R-50-WHITESPACE-HANDLING-OF-RDF-LITERALS	SPIN
R-51-HTML-HANDLING-OF-RDF-LITERALS	SPIN
R-52-NEGATIVE-OBJECT-PROPERTY-CONSTRAINTS	ShEx, SPIN
R-53-NEGATIVE-DATA-PROPERTY-CONSTRAINTS	ShEx, SPIN
R-55-OBJECT-PROPERTY-PATHS (SubObjectPropertyOf)	OWL 2 DL
R-57-FUNCTIONAL-OBJECT-PROPERTIES (FunctionalObjectProperty)	OWL 2 DL
R-58-INVERSE-FUNCTIONAL-OBJECT-PROPERTIES (InverseFunctionalObjectProperty)	OWL 2 DL
R-63-TRANSITIVE-OBJECT-PROPERTIES (TransitiveObjectProperty)	OWL 2 DL
R-65-FUNCTIONAL-DATA-PROPERTIES (FunctionalDataProperty)	OWL 2 DL
R-66-PROPERTY-GROUPS	ShEx, SPIN
R-67-CLASSIFY-PROPERTIES-ACCORDING-TO-OCCURRENCE	
R-68-REQUIRED-PROPERTIES (ObjectMinCardinality, DataMinCardinality)	OWL 2 DL
R-69-OPTIONAL-PROPERTIES (ObjectMinCardinality, DataMinCardinality)	OWL 2 DL
R-70-REPEATABLE-PROPERTIES (ObjectMinCardinality, DataMinCardinality)	OWL 2 DL
R-71-CONDITIONAL-PROPERTIES	
R-72-RECOMMENDED-PROPERTIES	

Table 4. RDF Validation Requirements Not Covered by OWL 2 QL

Requirements
R-74-EXACT-QUALIFIED-CARDINALITY-RESTRICTIONS-ON-OBJECT-PROPERTIES (ObjectExactCardinality)
R-75-MINIMUM-QUALIFIED-CARDINALITY-RESTRICTIONS-ON-OBJECT-PROPERTIES (ObjectMinCardinality)
R-76-MAXIMUM-QUALIFIED-CARDINALITY-RESTRICTIONS-ON-OBJECT-PROPERTIES (ObjectMaxCardinality)
R-77-EXACT-QUALIFIED-CARDINALITY-RESTRICTIONS-ON-DATA-PROPERTIES (DataExactCardinality)
R-78-MINIMUM-QUALIFIED-CARDINALITY-RESTRICTIONS-ON-DATA-PROPERTIES (DataMinCardinality)
R-79-MAXIMUM-QUALIFIED-CARDINALITY-RESTRICTIONS-ON-DATA-PROPERTIES (DataMaxCardinality)
R-80-EXACT-UNQUALIFIED-CARDINALITY-RESTRICTIONS-ON-OBJECT-PROPERTIES (ObjectExactCardinality)
R-81-MINIMUM-UNQUALIFIED-CARDINALITY-RESTRICTIONS-ON-OBJECT-PROPERTIES (ObjectMinCardinality)
R-82-MAXIMUM-UNQUALIFIED-CARDINALITY-RESTRICTIONS-ON-OBJECT-PROPERTIES (ObjectMaxCardinality)
R-83-EXACT-UNQUALIFIED-CARDINALITY-RESTRICTIONS-ON-DATA-PROPERTIES (DataExactCardinality)
R-84-MINIMUM-UNQUALIFIED-CARDINALITY-RESTRICTIONS-ON-DATA-PROPERTIES (DataMinCardinality)
R-85-MAXIMUM-UNQUALIFIED-CARDINALITY-RESTRICTIONS-ON-DATA-PROPERTIES (DataMaxCardinality)

8 Conclusion and Future Work

9 Appendix

9.1 Allowed Usage of Constructs in Class Expressions in OWL 2 QL

Subclass Expressions

```

1 subClassExpression :=
2   Class |
3   subObjectSomeValuesFrom | DataSomeValuesFrom
4 subObjectSomeValuesFrom := 'ObjectSomeValuesFrom' '(' ObjectPropertyExpression owl:Thing ')'
```

Superclass Expressions

```

1 superClassExpression :=
2   Class |
3   superObjectIntersectionOf | superObjectComplementOf |
4   superObjectSomeValuesFrom | DataSomeValuesFrom
```

9.2 Supported Constructs in OWL 2 QL

- subclass axioms (SubClassOf)
- class expression equivalence (EquivalentClasses)
- class expression disjointness (DisjointClasses)
- inverse object properties (InverseObjectProperties)
- property inclusion (SubObjectPropertyOf not involving property chains and SubDataPropertyOf)
- property equivalence (EquivalentObjectProperties and EquivalentDataProperties)
- property domain (ObjectPropertyDomain and DataPropertyDomain)
- property range (ObjectPropertyRange and DataPropertyRange)
- disjoint properties (DisjointObjectProperties and DisjointDataProperties)

Table 5. RDF Validation Requirements Not Covered by OWL 2 QL

Requirements	Coveri
R-86-EXISTENTIAL-QUANTIFICATION-ON-OBJECT-PROPERTIES (ObjectSomeValuesFrom)	OWL 2
R-87-UNIVERSAL-QUANTIFICATION-ON-OBJECT-PROPERTIES (ObjectAllValuesFrom)	OWL 2
R-88-INDIVIDUAL-VALUE-RESTRICTION-ON-OBJECT-PROPERTIES (ObjectHasValue)	OWL 2
R-89-SELF-RESTRICTION (ObjectHasSelf)	OWL 2
R-90-EXISTENTIAL-QUANTIFICATION-ON-DATA-PROPERTIES (DataSomeValuesFrom)	OWL 2
R-91-UNIVERSAL-QUANTIFICATION-ON-DATA-PROPERTIES (DataAllValuesFrom)	OWL 2
R-92-LITERAL-VALUE-RESTRICTION (DataHasValue)	OWL 2
R-96-NEGATIVE-OBJECT-PROPERTY-ASSERTIONS (NegativeObjectPropertyAssertion)	OWL 2
R-97-NEGATIVE-DATA-PROPERTY-ASSERTIONS (NegativeDataPropertyAssertion)	OWL 2
R-98-CHECK-VALIDITY-OF-URIS	
R-106-EXTENSIBLE-CONSTRAINT-LANGUAGE	
R-112-EXTENSIBLE-CONSTRAINTS	
R-114-PROVIDE-RDF-REST-SERVICES-FOR-RDF-VALIDATION	
R-119-VALIDATION-ON-NAMED-GRAPHS	
R-120-HANDLE-RDF-COLLECTIONS	ShEx,
R-121-SPECIFY-ORDER-OF-RDF-RESOURCES	
R-123-STATE	
R-125-RDF-SHAPE-CHECKING	ShEx
R-126-CUSTOMIZABLE-VALIDATION-PROCESS	
R-134-SPECIFY-USAGE-OF-TERMS	
R-135-CONSTRAINT-LEVELS	
R-141-NEGATIVE-PATTERN-MATCHING-ON-RDF-LITERALS	DQTP
R-142-NEGATIVE-RANGES-OF-RDF-LITERAL-VALUES	DQTP
R-146-CONSTRAINT-VALIDATION-OF-RDF-INPUT-WITH-RESPECT-TO-EXISTING-RDF	
R-150-RDF-REPRESENTATION-OF-VALIDATION-RESULTS	SPIN,
R-151-USEFUL-MESSAGE-VALIDATION-RESULTS	SPIN,
R-152-FIND-NOT-VALIDATED-TRIPLES	ShEx
R-153-RDF-REPRESENTATION-OF-CONSTRAINT-VIOLATIONS	SPIN
R-154-HANDLE-CONSTRAINT-VIOLATIONS	ShEx,
R-155-GUIDANCE-HOW-TO-BECOME-VALID-DATA	ShEx,
R-156-REFERENCES-TO-TRIPLES-CAUSING-THE-CONSTRAINT-VIOLATIONS	SPIN
R-157-REFERENCES-TO-VALIDATION-RULES-CAUSING-CONSTRAINT-VIOLATIONS	ShEx,
R-158-SEVERITY-LEVELS-OF-CONSTRAINT-VIOLATIONS	SPIN
R-159-EXPLAIN-REASONS-OF-CONSTRAINT-VIOLATIONS	SPIN,
R-166-RDF-STREAMING-VALIDATION	
R-167-VALIDATE-RDF-IN-AN-HTML-DOCUMENT-CONSTAINING-RDFA-MARKUP	
R-170-VALIDATION-OF-SPARQL-ENDPOINTS	
R-171-VALIDATION-OF-URIS-BY-DEREFERENCING	
R-172-GENERATE-HUMAN-READABLE-DOCUMENTATION	
R-176-PROVIDE-HIGH-LEVEL-VOCABULARY-FOR-THE-MOST-COMMON-TYPES-OF-CONSTRAINTS	
R-179-ASSOCIATE-CONSTRAINTS-WITH-RDF-DOCUMENTS	
R-180-ASSOCIATE-CONSTRAINTS-WITH-RDF-DATASETS	
R-181-ASSOCIATE-CONSTRAINTS-WITH-RDF-REST-APIS	
R-183-CONSTRAINTS-ABOUT-CONSTRAINTS	
R-185-FEDERALIZED-RDF-VALIDATION	
R-186-EXTEND-EXPRESSIVITY-WITH-SPARQL	
R-188-EXPRESSIVITY-OF-CONSTRAINT-LANGUAGE-EQUIVALENT-TO-SPARQL	
R-189-ADD-ANNOTATIONS-TO-CONSTRAINT-VIOLATION-OBJECTS	
R-191-SHAPES-RELATED-TO-TYPES	
R-193-MULTIPLE-CONSTRAINT-VALIDATION-EXECUTION-LEVELS	
R-194-PROVIDE-STRING-FUNCTIONS-FOR-RDF-LITERALS	SPIN
R-200-NEGATIVE-LITERAL-CONSTRAINTS	ShEx,

Table 6. RDF Validation Requirements Not Covered by OWL 2 QL But by OWL 2 DL

Requirements	Classification	Requirements
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Table 7. RDF Validation Requirements Not Covered by OWL 2 QL But by SPIN

Requirements	Classification	Requirements
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- symmetric properties (SymmetricObjectProperty)
- reflexive properties (ReflexiveObjectProperty)
- irreflexive properties (IrreflexiveObjectProperty)
- asymmetric properties (AsymmetricObjectProperty)
- assertions: DifferentIndividuals, ClassAssertion, ObjectPropertyAssertion, and DataPropertyAssertion

9.3 Not Supported Constructs in OWL 2 QL

- existential quantification to a class expression or a data range (ObjectSomeValuesFrom and DataSomeValuesFrom) in the subclass position
- self-restriction (ObjectHasSelf)
- existential quantification to an individual or a literal (ObjectHasValue, DataHasValue)
- enumeration of individuals and literals (ObjectOneOf, DataOneOf)
- universal quantification to a class expression or a data range (ObjectAllValuesFrom, DataAllValuesFrom)
- cardinality restrictions (ObjectMaxCardinality, ObjectMinCardinality, ObjectExactCardinality, DataMaxCardinality, DataMinCardinality, DataExactCardinality)
- disjunction (ObjectUnionOf, DisjointUnion, and DataUnionOf)
- property inclusions (SubObjectPropertyOf) involving property chains
- functional and inverse-functional properties (FunctionalObjectProperty, InverseFunctionalObjectProperty, and FunctionalDataProperty)
- transitive properties (TransitiveObjectProperty)
- keys (HasKey)
- individual equality assertions and negative property assertions (SameIndividual, NegativeObjectPropertyAssertion, NegativeDataPropertyAssertion)

References

1. Dimitris Kontokostas, Patrick Westphal, Sören Auer, Sebastian Hellmann, Jens Lehmann, Roland Cornelissen, and Amrapali Zaveri. Test-driven evaluation of

Table 8. RDF Validation Requirements Not Covered by OWL 2 QL But by ShEx

Requirements	Classification	Requirements
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- linked data quality. In *Proceedings of the 23rd International Conference on World Wide Web*, WWW '14, pages 747–758, Republic and Canton of Geneva, Switzerland, 2014. International World Wide Web Conferences Steering Committee.
2. Boris Motik, Bernardo Cuenca Grau, Ian Horrocks, Zhe Wu, Achille Fokoue, and Carsten Lutz. Owl 2 web ontology language: Profiles. Technical report, December 2008.