RDF Validation Requirements - Evaluation and Logical Underpinning

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Abstract. There are many case studies for which the formulation of RDF constraints and the validation of RDF data conforming to these constraint is very important. As a part of the collaboration with the W3C and the DCMI working groups on RDF validation, we identified major RDF validation requirements and initiated an RDF validation requirements database which is available to contribute at http://purl.org/net/rdf-validation. The purpose of this database is to collaboratively collect case studies, use cases, requirements, and solutions regarding RDF validation. Although, there are multiple constraint languages which can be used to formulate RDF constraints (associated with these requirements), there is no standard way to formulate them. This paper serves to evaluate to which extend each requirement is satisfied by each of these constraint languages. We take reasoning into account as an important pre-validation step and therefore map constraints to DL in order to show that each constraint can be mapped to an ontology describing RDF constraints generically.

Keywords: RDF Validation, RDF Validation Requirements, RDF Constraints, Constraint Languages, Evaluation, Linked Data, Semantic Web

1 Introduction

The W3C organized the RDF Validation Workshop\textsuperscript{4}, where experts from industry, government, and academia discussed first use cases for RDF constraint formulation and validation. In 2014, two working groups on RDF validation have been established: the W3C RDF Data Shapes\textsuperscript{5} and the DCMI RDF Application Profiles working groups\textsuperscript{6}. Bosch and Eckert \textsuperscript{1} collected the findings of these working groups and initiated a database of requirements to formulate and validate RDF constraints. The database is available for contribution at http://purl.org/net/rdf-validation. The intention associated with this database

\footnotesize{\textsuperscript{4} http://www.w3.org/2012/12/rdf-val/\textsuperscript{5} http://www.w3.org/2014/rds.charter\textsuperscript{6} http://wiki.dublincore.org/index.php/RDF-Application-Profiles}
is to collaboratively collect case studies, use cases, requirements, and solutions regarding RDF validation in a comprehensive and structured way. The requirements are classified to better evaluate existing solutions. We mapped each requirement to formulate RDF constraints directly to an RDF constraint type.

A constraint language is a language which is used to formulate constraints. The W3C Data Shapes working group defines constraint as a component of a schema what needs to be satisfied. There is no constraint language which can be seen as the standalone standard. However, there are multiple constraint languages (each having its own syntax and semantics) which can be used to express RDF constraints, such as existential and universal quantification, cardinality restrictions, and exclusive-or of properties. The five most popular constraint languages are Description Set Profiles (DSP), Resource Shapes (ReSh), Shape Expressions (ShEx), the SPARQL Inferencing Notation (SPIN), and the Web Ontology Language (OWL 2).

In this paper, we describe each requirement within the RDF validation requirements database in detail (sections 2-75). Additional descriptions can be found directly in the database. Each requirement corresponds to an RDF constraint type which may be expressible by multiple constraint languages. For each requirement, we represent some examples in different constraint languages.

We evaluated to which extent the most promising five constraint languages fulfill each of the overall 74 requirements to formulate RDF constraints (section 76.1). We distinguished if a constraint is fulfilled by OWL 2 QL or if the more expressive OWL 2 DL is needed. We also take reasoning into account, as reasoning may be performed prior to validating constraints.

In order to define an ontology to describe RDF constraints generically, it is needed to define the terminology for the formulation of RDF constraints and to classify them. We identified four dimensions to classify constraints:

- **Universality**: specific constraints vs. generic constraints
- **Complexity**: simple constraints vs. complex constraints
- **Context**: property constraints vs. class constraints
- **DL Expressivity**: constraints expressible in DL vs. constraints not expressible in DL

As there are already five promising constraint languages, our purpose is not to invent a new constraint language. We rather developed a very simple ontology (only three classes, three object properties, and three data properties) which is universal enough to describe any RDF constraint expressible by any RDF constraint language. We call this ontology the RDF constraints ontology (RDF-CO).

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7 [https://www.w3.org/2014/data-shapes/wiki/Glossary](https://www.w3.org/2014/data-shapes/wiki/Glossary)
8 [http://dublincore.org/documents/2008/03/31/dc-dsp/](http://dublincore.org/documents/2008/03/31/dc-dsp/)
9 [http://www.w3.org/Submission/shapes/](http://www.w3.org/Submission/shapes/)
10 [http://www.w3.org/Submission/shex-primer/](http://www.w3.org/Submission/shex-primer/)
11 [http://spinrdf.org/](http://spinrdf.org/)
12 [http://www.w3.org/TR/ow2-syntax/](http://www.w3.org/TR/ow2-syntax/)
13 Available at: [https://github.com/boschthomas/RDF-CO](https://github.com/boschthomas/RDF-CO)
Specific constraints are expressed by specific constraint languages like DSP, OWL 2, ReSh, ShEx, and SPIN. Generic constraints are expressed by the RDF-CO. As RDF-CO describes constraints generically, it does not distinguish constraints according to the dimension universality. The majority of constraints can be expressed in DL. In contrast, there are constraints which cannot be expressed in DL, but are also expressible in the RDF-CO. Complex constraints are built by combining simple constraints or complex constraints. DL statements which represent complex constraints are created out of DL statements representing composed constraints (if expressible in DL). Simple constraints may be applied to either properties (properties constraints) or classes (class constraints). There are no terms representing simple and complex constraints in the RDF-CO, since context classes (associated simple constraints hold for individuals of these classes) of simple constraints may just be reused by further constraints. As a consequence, the distinction of property and class constraints is sufficient to describe all possible RDF constraints.

In this paper, we investigate which constraints can be expressed in DL and which not. If a constraint can be expressed in DL, we added the mapping to DL and to the generic constraint in order to logically underpin associated requirements. If a constraint cannot be expressed in DL, we only added the mapping to the generic constraint. Therefore, we show that each constraint can be mapped to a generic constraint. In section 76.2 we classify the constraints according to the dimensions to classify constraints.

2 Subsumption

Subsumption (DL terminology: concept inclusion) corresponds to the requirement R-100-SUBSUMPTION. A subclass axiom SubClassOf( CE1 CE2 ) states that the class expression CE1 is a subclass of the class expression CE2. Roughly speaking, this states that CE1 is more specific than CE2.

2.1 Simple Example

All mothers are parents. The concept Mother is subsumed by the concept Parent:

\[
\mathtt{Mother} \subseteq \mathtt{Parent}
\]

Mapping to RDF-CO:

| c. type | context class | left p. list | right p. list | classes | c. element | c. value |
|---------|---------------|--------------|---------------|---------|------------|---------|
| class   | Mother        | .            | .             | Parent  | \(\subseteq\) |         |

2.2 Simple Example

Jedis feel the force:

\[
\mathtt{Jedi} \subseteq \mathtt{FeelingForce}
\]
Expressed by multiple constraint languages:

```
# OWL2:
Jedi rdfs:subClassOf FeelingForce .
```

```
# ReSh:
the extension ext:extendsShape may be used
```

```
# ShEx:
FeelingForce {
  feelingForce (true )
} Jedi {
  & FeelingForce ,
  attitude ('good')
}
```

Data matching the shapes FeelingForce and Jedi:

```
Yoda
  feelingForce true ;
  attitude 'good' .
```

Mapping to RDF-CO:

| c. type | context class | left p. list | right p. list | classes   | c. element | c. value |
|---------|---------------|--------------|---------------|-----------|------------|---------|
| class   | Jedi          | -            | -             | FeelingForce |            | ⊑       |

2.3 Complex Example

If an individual is rich, then this individual is not poor:

Rich ⊑ ¬ Poor

Mapping to RDF-CO:

| c. type | context class | left p. list | right p. list | classes   | c. element | c. value |
|---------|---------------|--------------|---------------|-----------|------------|---------|
| class   | Rich          | -            | -             | Poor      |            | ⊑ ¬ Poor |

3 Class Equivalence

Class Equivalence corresponds to the requirement R-3-EQUIVALENT-CLASSES. Concept equivalence asserts that two concepts have the same instances [4]. While synonyms are an obvious example of equivalent concepts, in practice one more often uses concept equivalence to give a name to complex expressions [4]. Concept equivalence is indeed subsumption from left and right (A ⊑ B and B ⊑ A implies A ≡ B ).
3.1 Simple Example

Person ⊑ Human

Mapping to RDF-CO:

| c. type | context class | left p. list | right p. list | classes | c. element | c. value |
|---------|---------------|--------------|---------------|---------|------------|----------|
| Class   | Person        | -            | -             | Human   | ⊑          | Person   |
| Class   | Human         | -            | -             | Person  | ⊑          | -        |

4 Sub Properties

Sub Properties (DL terminology: role inclusion) correspond to the requirements R-54-SUB-OBJECT-PROPERTIES and R-54-SUB-DATA-PROPERTIES. Sub-property axioms are analogous to subclass axioms. These axioms state that the property expression PE1 is a subproperty of the property expression PE2 — that is, if an individual x is connected by PE1 to an individual or a literal y, then x is also connected by PE2 to y.

4.1 Simple Example

parentOf ⊑ ancestorOf

States that parentOf is a sub-role of ancestorOf, i.e., every pair of individuals related by parentOf is also related by ancestorOf.

Mapping to RDF-CO:

| c. type | context class | left p. list | right p. list | classes | c. element | c. value |
|---------|---------------|--------------|---------------|---------|------------|----------|
| property| parentOf      | -            | ancestorOf    | ⊑       | -          | ⊑        |

4.2 Simple Example

hasDog ⊑ hasPet

4.3 Complex Example

$Person \sqcap \forall hasAge. \leq_{10} Person \sqcap \forall hasEvenAge. \leq_{10}$

5 Object Property Paths

Object Property Paths (or Object Property Chains and in DL terminology complex role inclusion axiom or role composition) corresponds to the requirement R-55-OBJECT-PROPERTY-PATHS. The more complex form of sub properties. This axiom states that, if an individual x is connected by a sequence of object property expressions OPE1, ..., OPEn with an individual y, then x is also connected with y by the object property expression OPE. Role composition can only appear on the left-hand side of complex role inclusions [4].
5.1 Simple Example

\[ \text{brotherOf} \circ \text{parentOf} \subseteq \text{uncleOf} \]

`# OWL2:

uncleOf owl:propertyChainAxiom ( brotherOf parentOf ) .`

Mapping to RDF-CO:

| c. type | context class | left p. list | right p. list | classes | c. element | c. value |
|---------|---------------|--------------|---------------|---------|------------|----------|
| property |               | brotherOf, parentOf | uncleOf |         |            |          |

6 Disjoint Properties

Disjoint Properties corresponds to the requirement R-9-DISJOINT-PROPERTIES. A disjoint properties axiom states that all of the properties are pairwise disjoint; that is, no individual \( x \) can be connected to an individual \( y \) by these properties.

6.1 Simple Example

The object properties \( \text{parentOf} \) and \( \text{childOf} \) are disjoint:

\[ \text{Disjoint(\text{parentOf}, \text{childOf})} \]

or alternatively:

\[ \text{parentOf} \subseteq \neg \text{childOf} \]

Mapping to RDF-CO:

| c. type | context class | left p. list | right p. list | classes | c. element | c. value |
|---------|---------------|--------------|---------------|---------|------------|----------|
| property |               | parentOf, childOf | t |         |            |          |

syntactic sugar:

Mapping to RDF-CO:

| c. type | context class | left p. list | right p. list | classes | c. element | c. value |
|---------|---------------|--------------|---------------|---------|------------|----------|
| property |               | parentOf, childOf | t |         |            |          |

7 Intersection

Intersection (composition, conjunction) corresponds to the requirements R-15-CONJUNCTION-OF-CLASS-EXPRESSIONS and R-16-CONJUNCTION-OF-DATA-RANGES. DLs allow new concepts and roles to be built using a variety of different constructors. We distinguish concept and role constructors depending on whether concept or role expressions are constructed. In the case of concepts, one can further separate basic Boolean constructors, role restrictions and nominals/enumerations [4]. Boolean concept constructors provide basic boolean operations that are closely related to the familiar operations of intersection, union and complement of sets, or to conjunction, disjunction and negation of logical expressions [4].
Mother ≡ Female ⊓ Parent

Concept inclusions allow us to state that all mothers are female and that all mothers are parents, but what we really mean is that mothers are exactly the female parents. DLs support such statements by allowing us to form complex concepts such as the intersection (also called conjunction) which denotes the set of individuals that are both female and parents. A complex concept can be used in axioms in exactly the same way as an atomic concept, e.g., in the equivalence Mother ≡ Female ⊓ Parent.

7.1 Simple Example

Female ⊓ Parent

Complex concept of all individuals which are of the concept Female and of the concept Parent.

Mapping to RDF-CO:

| c. type | context class | left p. list | right p. list | classes   | c. element | c. value |
|---------|---------------|--------------|--------------|-----------|------------|----------|
| class   | Female ⊓ Parent |              |              | Female, Parent |           | ⊓        |

7.2 Simple Example

Mother ≡ Female ⊓ Parent

Mapping to RDF-CO:

| c. type | context class | left p. list | right p. list | classes   | c. element | c. value |
|---------|---------------|--------------|--------------|-----------|------------|----------|
| class   | Mother        |              |              | Female, Parent |           | ⊓        |

8 Disjunction

Disjunction of classes or data ranges corresponds to the requirements R-17-DISJUNCTION-OF-CLASS-EXPRESSIONS and R-18-DISJUNCTION-OF-DATA-RANGES. Synonyms are union and inclusive or.

8.1 Simple Example

Father ⊔ Mother ⊔ Child

Mapping to RDF-CO:

| c. type | context class | left p. list | right p. list | classes   | c. element | c. value |
|---------|---------------|--------------|--------------|-----------|------------|----------|
| class   | Father ⊔ Mother ⊔ Child |              |              | Father, Mother, Child |           | ⊔        |
8.2 Simple Example

\[ \text{Parent} \equiv \text{Father} \sqcup \text{Mother} \]

Mapping to RDF-CO:

| c. type | context class | left p. list | right p. list | classes | c. element | c. value |
|---------|---------------|--------------|---------------|---------|------------|----------|
| class   | Parent        |              |              | Father, Mother |           |          |

9 Negation

Negation (complement) corresponds to the requirements R-19-NEGATION-OF-CLASS-EXPRESSIONS and R-20-NEGATION-OF-DATA-RANGES.

9.1 Simple Example

\[ \neg \text{Married} \]

Set of all individuals that are not married.

Mapping to RDF-CO:

| c. type | context class | left p. list | right p. list | classes | c. element | c. value |
|---------|---------------|--------------|---------------|---------|------------|----------|
| class   | Married       |              |              | Married | \neg       |          |

9.2 Complex Example

\[ \text{Female} \sqcap \neg \text{Married} \]

All female individuals that are not married.

Mapping to RDF-CO:

| c. type | context class | left p. list | right p. list | classes | c. element | c. value |
|---------|---------------|--------------|---------------|---------|------------|----------|
| class   | \neg Married  |              |              | Married | \neg       |          |
| class   | Female, \neg Married |          |              | Female, \neg Married | \neg |          |

10 Disjoint Classes

Disjoint Classes corresponds to the requirement R-7-DISJOINT-CLASSES. A disjoint classes axiom states that all of the classes are pairwise disjoint; that is, no individual can be at the same time an instance of these classes.
10.1 Simple Example

Individuals cannot be male and female at the same time:

\[ \text{Male} \sqcap \text{Female} \subseteq \bot \]

or alternatively:

\[ \text{Male} \subseteq \neg \text{Female} \]

Mapping to RDF-CO:

| c. type | context class | left p. list | right p. list | classes  | c. element | c. value |
|---------|---------------|--------------|---------------|----------|------------|----------|
| class   | Male \sqcap Female |              |               | Male, Female, Male \sqcap Female | \sqcap | \bot     |

syntactic sugar:

| c. type | context class | left p. list | right p. list | classes  | c. element | c. value |
|---------|---------------|--------------|---------------|----------|------------|----------|
| class   | Male \sqcap Female |              |               | Male \sqcap Female | \neq |           |

10.2 Simple Example

One can either be a hologram or a human, but not both:

\[ \text{Hologram} \sqcap \text{Human} \subseteq \bot \]

or alternatively:

\[ \text{Hologram} \subseteq \neg \text{Human} \]

Mapping to RDF-CO:

| c. type | context class | left p. list | right p. list | classes  | c. element | c. value |
|---------|---------------|--------------|---------------|----------|------------|----------|
| class   | Hologram \sqcap Human |              |               | Hologram, Human | \sqcap | \bot     |

syntactic sugar:

| c. type | context class | left p. list | right p. list | classes  | c. element | c. value |
|---------|---------------|--------------|---------------|----------|------------|----------|
| class   | Hologram \sqcap Human |              |               | Hologram \sqcap Human | \neq |           |

| c. type | context class | left p. list | right p. list | classes  | c. element | c. value |
|---------|---------------|--------------|---------------|----------|------------|----------|
| class   | Hologram \sqcap Human |              |               | Hologram \sqcap Human | \neq |           |
11 Existential Quantification on Properties

Existential Quantification on Properties conforms to the requirement R-86-EXISTENTIAL-QUANTIFICATION-ON-PROPERTIES. In DL terminology the existential quantification is also called existential restriction. An existential class expression consists of a property expression and a class expression or a data range, and it contains all those individuals that are connected by the property expression to an individual that is an instance of the class expression or to literals that are in the data range.

11.1 Simple Example

\[ \exists \text{parentOf}. \top \]

Complex concept that describes the set of individuals that are parents of at least one individual (instance of \( \top \)).

Mapping to RDF-CO:

| c. type | context class | left p. list | right p. list | classes | c. element | c. value |
|---------|---------------|--------------|---------------|---------|------------|---------|
| property | \exists \text{parentOf} | | | | parentOf | \top |

11.2 Simple Example

\[ \exists \text{parentOf}. \text{Female} \]

The complex concept describes those individuals that are parents of at least one female individual, i.e., those that have a daughter.

Mapping to RDF-CO:

| c. type | context class | left p. list | right p. list | classes | c. element | c. value |
|---------|---------------|--------------|---------------|---------|------------|---------|
| property | \exists \text{parentOf}. \text{Female} | | | | parentOf | \text{Female} |

11.3 Simple Example

\[ \text{Parent} \equiv \exists \text{parentOf}. \top \]

Mapping to RDF-CO:

| c. type | context class | left p. list | right p. list | classes | c. element | c. value |
|---------|---------------|--------------|---------------|---------|------------|---------|
| property | Parent | parentOf | | | \top | \exists |

11.4 Simple Example

\[ \text{ParentOfSon} \equiv \exists \text{parentOf}. \text{Male} \]

Mapping to RDF-CO:

| c. type | context class | left p. list | right p. list | classes | c. element | c. value |
|---------|---------------|--------------|---------------|---------|------------|---------|
| property | ParentOfSon | parentOf | | | Male | \exists |
12 Universal Quantification on Properties

Universal Quantification on Properties corresponds to the requirement R-91-UNIVERSAL-QUANTIFICATION-ON-PROPERTIES, which is also called value restriction in DL terminology.

\[(\forall R.C)^\mathcal{I} = \{a \in \Delta^\mathcal{I} \mid (a, b) \in R^\mathcal{I} \rightarrow b \in C^\mathcal{I}\}\]  where $\mathcal{I}$ is an interpretation function, $\Delta^\mathcal{I}$ is the domain, $a, b \in \Delta^\mathcal{I}$ are individuals $C$ is a concept, $R$ is a role.

12.1 Simple Example

\[\forall \text{parentOf.Female}\]

The set of individuals all of whose children are female also includes those that have no children at all.

Mapping to RDF-CO:

| c. type | context class | left p. list | right p. list | classes | c. element | c. value |
|---------|---------------|--------------|--------------|---------|------------|---------|
| property | parentOf. Female | parentOf | Female | | | |

13 Property Domain

Property Domain corresponds to the requirements R-25-OBJECT-PROPERTY-DOMAIN and R-26-DATA-PROPERTY-DOMAIN. The constraint restricts the domain of object and data properties. In DL terminology this constraint is also called domain restrictions on roles. The purpose is to declare that a given property is associated with a class, e.g. to populate input forms with appropriate widgets but also constraint checking. In OO terms this is the declaration of a member, field, attribute or association.  \[\exists R. \top \sqsubseteq C\]  is the object property restriction where $R$ is the object property (role) whose domain is restricted to concept $C$.

13.1 Simple Example

\[\exists \text{sonOf. Male}\]

Restricts the domain of sonOf to male individual. syntactic sugar:

Mapping to RDF-CO:

| c. type | context class | left p. list | right p. list | classes | c. element | c. value |
|---------|---------------|--------------|--------------|---------|------------|---------|
| property | sonOf | | Male | domain | | |
14 Property Range

Property Range corresponds to the requirements R-28-OBJECT-PROPERTY-RANGE and R-35-DATA-PROPERTY-RANGE. This constraint restricts the range of object and data properties. In DL terminology it is also called range restrictions on roles. $T \subseteq \forall RC$ is the range restriction to the object property $R$ (restricted by the concept $C$).

14.1 Simple Example

$T \subseteq \forall \text{sonOf . Parent}$

equivalent to:

$\exists \text{sonOf} . T \subseteq \text{Person}$

Restricts the range of sonOf to parents.

```python
# OWL 2:
sonOf rdfs:range Parent .
```

```python
# DSP:
:hasDogRange
  a dsp:DescriptionTemplate ;
  dsp:resourceClass owl:Thing ;
  dsp:statementTemplate [ a dsp:NonLiteralStatementTemplate ;
    dsp:property sonOf ;
    dsp:nonLiteralConstraint [ a dsp:NonLiteralConstraint ;
      dsp:valueClass Parent ] ] .
```

syntactic sugar:

Mapping to RDF-CO:

| C. type | context class | left p. list | right p. list | classes | c. element | c. value |
|---------|---------------|--------------|---------------|---------|------------|---------|
| property | sonOf         | Parent       | range         |         |            |         |

15 Class-Specific Property Range

Class-Specific Property Range corresponds to the requirements R-29-CLASS-SPECIFIC-RANGE-OF-RDF-OBJECTS and R-36-CLASS-SPECIFIC-RANGE-OF-RDF-LITERALS. The constraint restricts the range of object and data properties for individuals within a specific context (e.g. class, application profile). The values of each member property of a class may be limited by their value type, such as xsd:string or Person.

15.1 Simple Example

Only men can have sonOf relationships to parents:

$\neg \text{Man} \subseteq \neg \exists \text{sonOf. Parent}$
15.2 Simple Example

Only vulcans can have friendship relationships to cardassians

\[ \neg \text{Vulcan} \subseteq \neg \exists \text{friendOf.Carsassian} \]

16 Minimum Unqualified Cardinality Restrictions on Properties

Minimum Unqualified Cardinality Restrictions on Properties corresponds to the requirements R-81-MINIMUM-UNQUALIFIED-CARDINALITY-ON-PROPERTIES and R-211-CARDINALITY-CONSTRAINTS. \( \leq nR \top \) is the minimum unqualified cardinality restriction where \( n \in \mathbb{N} \) (written \( \leq nR \) in short). A minimum cardinality restrictions contains all those individuals that are connected by a property to at least \( n \) different individuals/literals that are instances of a particular class or data range. If the class is missing, it is taken to be owl:Thing. If the data range is missing, it is taken to be rdfs:Literal. For unqualified cardinality restrictions, classes respective data ranges are not stated.

16.1 Simple Example

```shex
# ShEx:
:Jedi {
  :attitude ('good') }
:JediStudent {
  & :Jedi ,
  :studentOf {}{1} }
:JediMaster {
  & :Jedi ,
  :mentorOf {}{1,2} }
:SuperJediMaster {
  & :Jedi ,
  :mentorOf {}{3,} }

– Jedis have the attitude 'good'
– Jedi students are students of exactly 1 resource
– Jedi masters are mentoring at least 1 and at most 2 resources
– Super Jedi masters are mentoring at least 3 resources
```

```data
# data:
:Yoda :attitude 'good' ;
  :mentorOf :MaceWindu , :Obi-Wan , :Luke .
:MaceWindu :attitude 'good' ;
  :studentOf :Yoda .
:Obi-Wan :attitude 'good' ;
  :studentOf :Yoda ;
  :mentorOf :Anakin .
:Anakin :attitude 'good' ;
  :studentOf :Obi-Wan .
:Luke :attitude 'good' ;
  :studentOf :Yoda .
```
Individuals matching the ':SuperJediMaster' data shape:

Yoda

\( \text{Jedi} \sqsubseteq \exists \text{attitude} \{\text{good}\} \)
\( \text{JediStudent} \sqsubseteq \text{Jedi} \sqcap \geq 1 \text{studentOf}. \top \sqsubseteq \leq 1 \text{studentOf}. \top \)
\( \text{JediMasters} \sqsubseteq \text{Jedi} \sqcap \geq 1 \text{mentorOf}. \top \sqsubseteq \leq 2 \text{mentorOf}. \top \)
\( \text{SuperJediMaster} \sqsubseteq \text{Jedi} \sqcap \geq 3 \text{mentorOf}. \top \)

### 16.2 Simple Example

\( \text{Captain} \sqsubseteq \geq 1 \text{commandsVessel}. \top \)

Captains command at least one vessel.

**Mapping to RDF-CO:**

| c. type | context class | left p. list | right p. list | classes | c. element | c. value |
|---------|---------------|--------------|---------------|---------|------------|---------|
| property | Captain       | commandsVessel | | | | 1 |

### 17 Minimum Qualified Cardinality Restrictions on Properties

Minimum Qualified Cardinality Restrictions on Properties corresponds to the requirements R-75-MINIMUM-QUALIFIED-CARDINALITY-ON-PROPERTIES and R-211-CARDINALITY-CONSTRAINTS. A minimum cardinality restriction contains all those individuals that are connected by a property to at least \( n \) different individuals/literals that are instances of a particular class or data range. If the class is missing, it is taken to be owl:Thing. If the data range is missing, it is taken to be rdfs:Literal. For qualified cardinality restrictions, classes respective data ranges are stated. \( \geq n \cdot R.C \) is a minimum qualified cardinality restriction where \( n \in \mathbb{N} \).

#### 17.1 Simple Example

\( \geq 2 \text{childOf} . \text{Parent} \)

Set of individuals that are children of at least two parents.

**Mapping to RDF-CO:**

| c. type | context class | left p. list | right p. list | classes | c. element | c. value |
|---------|---------------|--------------|---------------|---------|------------|---------|
| property | \( \geq 2 \text{childOf} . \text{Parent} \) | Parent | childOf | Parent | \( \geq \) | 2 |
17.2 Simple Example

foaf:Person \( \geq 2 \) hasName xsd:string

Mapping to RDF-CO:

| c. type | context class | left p. list | right p. list | classes | c. element | c. value |
|---------|----------------|--------------|---------------|---------|------------|---------|
| property | foaf:Person   | hasName      | xsd:string    | \( \geq 2 \) |             |         |

17.3 Simple Example

```shex
# ShEx:
:Jedi {  
  :attitude ('good') }  
:JediStudent {  
  & :Jedi ,  
  :studentOf $:Jedi(1) }  
:JediMaster {  
  & :Jedi ,  
  :mentorOf $:Jedi(1,2) }  
:SuperJediMaster {  
  & :Jedi ,  
  :mentorOf $:Jedi(3,1) }
```

- Jedis have the attitude 'good'
- Jedi students are students of exactly 1 Jedi
- Jedi masters are mentoring at least 1 and at most 2 Jedis
- Super Jedi masters are mentoring at least 3 Jedis

```data
# data:  
:Yoda  
  :attitude 'good' ;  
  :mentorOf :MaceWindu , :Obi-Wan , :Luke .  
:MaceWindu  
  :attitude 'good' ;  
  :studentOf :Yoda .  
:Obi-Wan  
  :attitude 'good' ;  
  :studentOf :Yoda ;  
  :mentorOf :Anakin .  
:Anakin  
  :attitude 'good' ;  
  :studentOf :Obi-Wan .  
:Luke  
  :attitude 'good' ;  
  :studentOf :Yoda .
```

```data
# Individuals matching the ':SuperJediMaster' data shape:  
:Yoda  

# Individuals matching the ':JediMaster' data shape:  
:Obi-Wan
```

mentorOf and studentOf are taken to be inverse properties:

\[
\text{Jedi} \subseteq \exists \text{attitude.\{good\}}  
\text{JediStudent} \subseteq \text{Jedi} \cap \exists \text{studentOf.\{Jedi\}}  
\text{JediMasters} \subseteq \text{Jedi} \cap \exists \text{mentorOf.\{Jedi\}}  
\text{SuperJediMaster} \subseteq \text{Jedi} \cap \exists \text{mentorOf.\{Jedi\}}
\]
17.4 Complex Example

Father2Daughters \equiv \text{Man} \sqsubseteq (\geq 2 \text{hasChild.Woman})

Mapping to RDF-CO:

| c. type | context class | left p. list | right p. list | classes | c. element | c. value |
|---------|---------------|--------------|---------------|---------|------------|---------|
| property | Father2Daughters | \geq 2 hasChild.Woman | hasChild.Woman | Woman | Man, \geq 2 hasChild.Woman | \sqsubseteq | 2 |

17.5 Simple Example

\text{Captain} \sqsubseteq \geq 1 \text{commandsVessel.Vessel}

Mapping to RDF-CO:

| c. type | context class | left p. list | right p. list | classes | c. element | c. value |
|---------|---------------|--------------|---------------|---------|------------|---------|
| property | Captain | commandsVessel | Vessel | \geq 1 | |

17.6 Complex Example

\text{FederationCaptain} \sqsubseteq \text{Federation} \sqsubseteq \geq 1 \text{commandsVessel.Vessel}

Mapping to RDF-CO:

| c. type | context class | left p. list | right p. list | classes | c. element | c. value |
|---------|---------------|--------------|---------------|---------|------------|---------|
| property | FederationCaptain | \geq 1 commandsVessel.Vessel | commandsVessel | Vessel | Federation, \geq 1 commandsVessel.Vessel | \sqsubseteq | 1 |

18 Maximum Unqualified Cardinality Restrictions on Properties

Maximum Unqualified Cardinality Restrictions on Properties corresponds to the requirements R-82-MAXIMUM-UNQUALIFIED-CARDINALITY-ON-PROPERTIES and R-211-CARDINALITY-CONSTRAINTS. A maximum cardinality restriction contains all those individuals that are connected by a property to at most n different individuals/literals that are instances of a particular class or data range. If the class is missing, it is taken to be owl:Thing. If the data range is not present, it is taken to be rdfs:Literal. Unqualified means that the class respective the data range is not stated. \geq nR. \top is a maximum unqualified cardinality restriction where n \in \mathbb{N} (written \geq nR in short).
18.1 Simple Example

```shex
# ShEx:
-Jedi { :attitude ('good') }  
-JediStudent { & :Jedi , :studentOf {}{1} }  
-JediMaster { & :Jedi , :mentorOf {}{1,2} }  
-SuperJediMaster { & :Jedi , :mentorOf {}{3,} }
```

- Jedis have the attitude 'good'
- Jedi students are students of exactly 1 resource
- Jedi masters are mentoring at least 1 and at most 2 resources
- Super Jedi masters are mentoring at least 3 resources

```data
# data:
-Yoda :attitude 'good' ; :mentorOf :MaceWindu , :Obi-Wan , :Luke .  
-MaceWindu :attitude 'good' ; :studentOf :Yoda .  
-Obi-Wan :attitude 'good' ; :studentOf :Yoda ; :mentorOf :Anakin .  
-Anakin :attitude 'good' ; :studentOf :Obi-Wan .  
-Luke :attitude 'good' ; :studentOf :Yoda .
```

```subj
# Individuals matching the ':JediMaster' data shape:
-Obi-Wan
```

\[
\begin{align*}
\text{Jedi} & \in \exists \text{attitude.}\{\text{good}\} \\
\text{JediStudent} & \subseteq \text{Jedi} \ni 1\text{studentOf.}\top \subseteq 1\text{studentOf.}\top \\
\text{JediMasters} & \subseteq \text{Jedi} \ni 1\text{mentorOf.}\top \subseteq 2\text{mentorOf.}\top \\
\text{SuperJediMaster} & \subseteq \text{Jedi} \ni 3\text{mentorOf.}\top \\
\end{align*}
\]

19 Maximum Qualified Cardinality Restrictions on Properties

Maximum Qualified Cardinality Restrictions on Properties corresponds to the requirements R-76-MAXIMUM-QUALIFIED-CARDINALITY-ON-PROPERTIES and R-211-CARDINALITY-CONSTRAINTS. A maximum cardinality restriction contains all those individuals that are connected by a property to at most \(n\) different individuals/literals that are instances of a particular class or data range. If the class is missing, it is taken to be owl:Thing. If the data range is not present, it is taken to be rdfs:Literal. Qualified means that the class respective the data range is stated. \(\leq nR.C\) is a maximum qualified cardinality restriction where \(n \in \mathbb{N}\).
19.1 Simple Example

\[ \leq 2 \text{childOf . Parent} \]

Set of individuals that are children of at most two parents.

Mapping to RDF-CO:

| c. type   | context class | left p. list | right p. list | classes | c. element | c. value |
|-----------|---------------|--------------|---------------|---------|------------|----------|
| property  | \leq 2 \text{childOf . Parent} | childOf      | Parent        | Parent  | \leq       | 2        |

19.2 Simple Example

```shex
# ShEx:
:Jedi {
  :attitude ('good')
  :JediStudent {
    &: :Jedi,
    :studentOf @:Jedi{1}
  }
  :JediMaster {
    &: :Jedi,
    :mentorOf @:Jedi{1,2}
  }
  :SuperJediMaster {
    &: :Jedi,
    :mentorOf @:Jedi(3)
  }
}
```

- Jedis have the attitude 'good'
- Jedi students are students of exactly 1 Jedi
- Jedi masters are mentoring at least 1 and at most 2 Jedis
- Super Jedi masters are mentoring at least 3 Jedis

```data
# data:
:Yoda
  :attitude 'good';
  :mentorOf :MaceWindu , :Obi-Wan , :Luke.
:MaceWindu
  :attitude 'good';
  :studentOf :Yoda .
:Obi-Wan
  :attitude 'good';
  :studentOf :Yoda ;
  :mentorOf :Anakin .
:Anakin
  :attitude 'good';
  :studentOf :Obi-Wan .
:Luke
  :attitude 'good';
  :studentOf :Yoda .
```

```data
# Individuals matching the ':JediMaster' data shape:
:Obi-Wan
```

\[ \text{Jedi} \subset \exists \text{attitude.\{good\}} \]

\[ \text{JediStudent} \subset \text{Jedi} \cap \geq 1 \text{studentOf.Jedi} \]

\[ \text{JediMasters} \subset \text{Jedi} \cap \geq 1 \text{mentorOf.Jedi} \]

\[ \text{SuperJediMaster} \subset \text{Jedi} \cap \geq 3 \text{mentorOf.Jedi} \]
20 Exact Unqualified Cardinality Restrictions on Properties

Exact Unqualified Cardinality Restrictions on Properties corresponds to the requirements R-80-EXACT-UNQUALIFIED-CARDINALITY-ON-PROPERTIES and R-211-CARDINALITY-CONSTRAINTS. An exact cardinality restriction contains all those individuals that are connected by a property to exactly n different individuals that are instances of a particular class or data range. If the class is missing, it is taken to be owl:Thing. If the data range is not present, it is taken to be rdfs:Literal. Unqualified means that the class respective data range is not stated. \( \geq nR.\top \cap \leq nR.\top \) is an exact unqualified cardinality restriction where \( n \in \mathbb{N} \).

20.1 Simple Example

```shex
# ShEx:
:JediStudent { 
  :studentOf {}{1} } 
```

```reSh:
# ReSh: 
:JediStudent a rs:ResourceShape ; 
  rs:property [ 
    rs:name "studentOf" ; 
    rs:propertyDefinition :studentOf ; 
    rs:valueShape [ a rs:ResourceShape] ; 
    rs:occurs rs:Exactly-one ; ] . 
```

– Jedis have the attitude 'good'
– Jedi students are students of exactly 1 resource

```data:
# data: 
:Yoda 
  :attitude 'good' ; 
  :mentorOf :MaceWindu , :Obi-Wan , :Luke . 
:MaceWindu 
  :attitude 'good' ; 
  :studentOf :Yoda . 
:Obi-Wan 
  :attitude 'good' ; 
  :studentOf :Yoda ; 
  :mentorOf :Anakin . 
:Anakin 
  :attitude 'good' ; 
  :studentOf :Obi-Wan . 
:Luke 
  :attitude 'good' ; 
  :studentOf :Yoda . 
```

```individuals:
# Individuals matching the ':JediStudent' data shape: 
:MaceWindu :Obi-Wan :Anakin :Luke 
```

\( \text{JediStudent} \subseteq \text{Jedi} \cap \geq 1\text{studentOf.}\top \cap \leq 1\text{studentOf.}\top \)
21 Exact Qualified Cardinality Restrictions on Properties

Exact Qualified Cardinality Restrictions on Properties corresponds to the requirements R-74-EXACT-QUALIFIED-CARDINALITY-ON-PROPERTIES and R-211-CARDINALITY-CONSTRAINTS. An exact cardinality restriction contains all those individuals that are connected by a property to exactly n different individuals that are instances of a particular class or data range. If the class is missing, it is taken to be owl:Thing. If the data range is not present, it is taken to be rdfs:Literal. Qualified means that the class respective data range is stated. \( nR.C \cap nR.C \) is an exact qualified cardinality restriction where \( n \in \mathbb{N} \).

21.1 Simple Example

```shex
# ShEx:
:Jedi { :attitude ('good') } :JediStudent { :studentOf @:Jedi(1) }
```

```reasoner
# ReSh:
:Jedi a rs:ResourceShape ;
   rs:property [   
   rs:name "attitude" ;
   rs:propertyDefinition :attitude ;
   rs:allowedValue "good" ;
   rs:occurs rs:Exactly-one ;
   ] .

:JediStudent a rs:ResourceShape ;
   rs:property [   
   rs:name "studentOf" ;
   rs:propertyDefinition :studentOf ;
   rs:valueShape :Jedi ;
   rs:occurs rs:Exactly-one ;
   ] .
```

- Jedis have the attitude 'good'
- Jedi students are students of exactly 1 Jedi

```reasoner
# data:
:Yoda :attitude 'good' ;
   :mentorOf :MaceWindu , :Obi-Wan , :Luke .

:MaceWindu :attitude 'good' ;
   :studentOf :Yoda .

:Obi-Wan :attitude 'good' ;
   :studentOf :Yoda ;
   :mentorOf :Anakin .

:Anakin :attitude 'good' ;
   :studentOf :Obi-Wan .

:Luke :attitude 'good' ;
   :studentOf :Yoda .
```

```reasoner
# Individuals matching the ':JediStudent' data shape:
:MaceWindu :Obi-Wan :Anakin :Luke
```

- Jedis have the attitude 'good'
- Jedi students are students of exactly 1 Jedi
21.2 Complex Example

Person $\sqsubseteq 2$ childOf . Parent $\sqcap 2$ childOf . Parent

Every person is a child of exactly two parents.

Mapping to RDF-CO:

| c. type | context class | left p. list | right p. list | classes | c. element | c. value |
|---------|---------------|--------------|---------------|---------|------------|----------|
| property | $\geq 2$ childOf . Parent | childOf | - | Parent | $\geq$ | 2 |
| property | $< 3$ childOf . Parent | childOf | - | Parent | < | 2 |
| class | Person | - | - | $\geq 2$ childOf . Parent, $\leq 2$ childOf . Parent | - | - |

syntactic sugar:

Mapping to RDF-CO:

| c. type | context class | left p. list | right p. list | classes | c. element | c. value |
|---------|---------------|--------------|---------------|---------|------------|----------|
| property | Person | childOf | - | Parent | = | 2 |

22 Inverse Object Properties

Inverse Object Properties corresponds to the requirement R-56-INVERSE-OBJECT-PROPERTIES. In many cases properties are used bi-directionally and then accessed in the inverse direction, e.g. parent $\equiv$ child$^-$. There should be a way to declare value type, cardinality etc of those inverse relations without having to declare a new property URI. The object property OP1 is an inverse of the object property OP2. Thus, if an individual x is connected by OP1 to an individual y, then y is also connected by OP2 to x, and vice versa.

22.1 Simple Example

$parentOf \equiv childOf^-$

Mapping to RDF-CO:

| c. type | context class | left p. list | right p. list | classes | c. element | c. value |
|---------|---------------|--------------|---------------|---------|------------|----------|
| property | parentOf | childOf | - | childOf | inverse | |

22.2 Simple Example

$captainOf \equiv hasCaptain^-$

Mapping to RDF-CO:

| c. type | context class | left p. list | right p. list | classes | c. element | c. value |
|---------|---------------|--------------|---------------|---------|------------|----------|
| property | captainOf | hasCaptain | - | hasCaptain | inverse | |
23  Transitive Object Properties

Transitive Object Properties corresponds to the requirement R-63-TRANSITIVE-OBJECT-PROPERTIES. Transitivity is a special form of complex role inclusion. An object property transitivity axiom states that the object property is transitive — that is, if an individual x is connected by the object property to an individual y that is connected by the object property to an individual z, then x is also connected by the object property to z.

23.1 Simple Example

\[ \text{ancestorOf} \circ \text{ancestorOf} \subseteq \text{ancestorOf} \]

\[
\begin{array}{|c|c|c|c|c|c|c|c|}
\hline
\text{c. type} & \text{context class} & \text{left p. list} & \text{right p. list} & \text{classes} & \text{c. element} & \text{c. value} \\
\hline
\text{property} & \text{ancestorOf}, \text{ancestorOf} & \text{ancestorOf} & \text{ancestorOf} & \subseteq \\
\hline
\end{array}
\]

syntactic sugar:

\[
\begin{array}{|c|c|c|c|c|c|c|c|}
\hline
\text{c. type} & \text{context class} & \text{left p. list} & \text{right p. list} & \text{classes} & \text{c. element} & \text{c. value} \\
\hline
\text{property} & \text{ancestorOf} & \text{ancestorOf} & \text{inverse} & \subseteq \\
\hline
\end{array}
\]

24  Symmetric Object Properties

Symmetric Object Properties corresponds to the requirement R-61-SYMMETRIC-OBJECT-PROPERTIES. A role is symmetric if it is equivalent to its own inverse. An object property symmetry axiom states that the object property expression OPE is symmetric — that is, if an individual x is connected by OPE to an individual y, then y is also connected by OPE to x.

24.1 Simple Example

The property \textit{marriedTo} is symmetric:

\[ \text{marriedTo} \equiv \text{marriedTo}^- \]

\[
\begin{array}{|c|c|c|c|c|c|c|c|}
\hline
\text{c. type} & \text{context class} & \text{left p. list} & \text{right p. list} & \text{classes} & \text{c. element} & \text{c. value} \\
\hline
\text{property} & \text{marriedTo} & \text{marriedTo} & \text{inverse} & \\
\hline
\end{array}
\]

syntactic sugar:

\[
\begin{array}{|c|c|c|c|c|c|c|c|}
\hline
\text{c. type} & \text{context class} & \text{left p. list} & \text{right p. list} & \text{classes} & \text{c. element} & \text{c. value} \\
\hline
\text{property} & \text{marriedTo} & \text{marriedTo} & \text{symmetric} & \\
\hline
\end{array}
\]
25 Asymmetric Object Properties

Asymmetric Object Properties corresponds to the requirement R-62-ASYMMETRIC-OBJECT-PROPERTIES. A role is asymmetric if it is disjoint from its own inverse \[^4\]. An object property asymmetry axiom AsymmetricObjectProperty( OPE ) states that the object property expression OPE is asymmetric - that is, if an individual x is connected by OPE to an individual y, then y cannot be connected by OPE to x.

25.1 Simple Example

The property parentOf is asymmetric:

\[
\text{parentOf} \subseteq \neg \text{parentOf}^-
\]

alternatively:

\[
\text{parentOf} \cap \text{parentOf}^- \subseteq \bot
\]

alternatively:

\[
\text{disjoint(parentOf, parentOf^-)}
\]

Mapping to RDF-CO:

\[
\begin{array}{|c|c|c|c|c|c|}
\hline
\text{c. type} & \text{context class} & \text{left p. list} & \text{right p. list} & \text{classes} & \text{c. element} & \text{c. value} \\
\hline
\text{property} & \text{property} & \text{parentOf}^- & \text{parentOf} & \text{parentOf}^- & \text{inverse} & \# \\
\hline
\end{array}
\]

syntactic sugar:

Mapping to RDF-CO:

\[
\begin{array}{|c|c|c|c|c|c|}
\hline
\text{c. type} & \text{context class} & \text{left p. list} & \text{right p. list} & \text{classes} & \text{c. element} & \text{c. value} \\
\hline
\text{property} & \text{property} & \text{parentOf} & \text{parentOf} & \text{asymmetric} & \text{asymmetric} & \text{asymmetric} \\
\hline
\end{array}
\]

25.2 Simple Example

Child parent relations (dbo:child) cannot be symmetric.

25.3 Simple Example

Person birth place relations (dbo:birthPlace) cannot be symmetric.

26 Class-Specific Reflexive Object Properties

Using DL terminology Class-Specific Reflexive Object Properties is called local reflexivity - a set of individuals (of a specific class) that are related to themselves via a given role \[^4\].
26.1 Simple Example

TalkingToThemselves $\subseteq \exists$ talksTo .Self.

Set of individuals that are talking to themselves.

**Mapping to RDF-CO:**

| c. type | context class | left p. list | right p. list | classes | c. element | c. value |
|---------|---------------|--------------|---------------|---------|------------|----------|
| property | TalkingToThemselves | talksTo | Self | - | - | - |

syntactic sugar:

**Mapping to RDF-CO:**

| c. type | context class | left p. list | right p. list | classes | c. element | c. value |
|---------|---------------|--------------|---------------|---------|------------|----------|
| property | talksTo .Self | talksTo | - | - | reflexive | - |

27 Reflexive Object Properties

**Reflexive Object Properties** (reflexive roles, global reflexivity in DL) corresponds to the requirement R-59-REFLEXIVE-OBJECT-PROPERTIES. Global reflexivity can be expressed by imposing local reflexivity on the top concept \[4\].

27.1 Simple Example

Each individual knows itself:

$\top \subseteq \exists$ knows . Self

**Mapping to RDF-CO:**

| c. type | context class | left p. list | right p. list | classes | c. element | c. value |
|---------|---------------|--------------|---------------|---------|------------|----------|
| property | $\top$ knows . Self | knows | Self | - | - | - |
| class | $\top$ | - | $\top$, $\exists$ knows . Self | - | - | $\subseteq$ |

syntactic sugar:

**Mapping to RDF-CO:**

| c. type | context class | left p. list | right p. list | classes | c. element | c. value |
|---------|---------------|--------------|---------------|---------|------------|----------|
| property | $\top$ knows | - | - | reflexive | - | - |

28 Irreflexive Object Properties

**Irreflexive Object Properties** (irreflexive roles in DL) corresponds to the requirement R-60-IRREFLEXIVE-OBJECT-PROPERTIES. A role is irreflexive if it is never locally reflexive \[4\]. An object property irreflexivity axiom IrreflexiveObjectProperty( OPE ) states that the object property expression OPE is irreflexive - that is, no individual is connected by OPE to itself.
28.1 Simple Example

\[ T \equiv \neg \exists marriedTo.Self \]

Alternatively:

\[ \exists marriedTo.Self \equiv \bot \]

Alternatively:

\[ marriedTo \cap marriedTo^\sim \equiv \bot \] (without special self-concept Self)

Mapping to RDF-CO:

| c. type | context class | left p. list | right p. list | classes   | c. element | c. value |
|---------|---------------|--------------|---------------|-----------|------------|----------|
| property | knows . Self  | T            | T             | Self      | T          | T        |
| class    | ~ \exists knows . Self | T            | T             | Self      | T          | T        |

Syntactic sugar:

Mapping to RDF-CO:

| c. type | context class | left p. list | right p. list | classes   | c. element | c. value |
|---------|---------------|--------------|---------------|-----------|------------|----------|
| property | marriedTo     |              |               | irreflexive |            |          |

28.2 Simple Example

A resource cannot be its own parent (dbo:parent).

28.3 Simple Example

A resource cannot be its own child (dbo:child).

29 Context-Specific Property Groups

Context-Specific Property Groups corresponds to the requirement R-66-PROPERTY-GROUPS to group data and object properties.

29.1 Simple Example

```shex
# ShEx:
<Human> {  
  (    
    foaf:name xsd:string ,    
    foaf:givenName xsd:string  
  ) ,    
  (    
    foaf:mbox IRI ,    
    foaf:homepage foaf:Document  
  ) }
```
1. group: 1 foaf:name (range: xsd:string) and 1 foaf:givenName (range: xsd:string)
and (,)
2. group: 1 foaf:mbox (range: IRI) and 1 foaf:homepage (range: foaf:Document)

\[
\text{Human} \equiv M \cap N \\
M \equiv C \cap F \\
C \sqsubseteq 1 \text{name . string} \cap \equiv 1 \text{name . string} \\
F \sqsubseteq 1 \text{givenName . string} \cap \equiv 1 \text{givenName . string} \\
N \equiv I \cap L \\
I \sqsubseteq 1 \text{mbox . string} \cap \equiv 1 \text{mbox . string} \\
L \sqsubseteq 1 \text{homepage . Document} \cap \equiv 1 \text{homepage . Document}
\]

Mapping to RDF-CO:

| c. type  | context class | left p. list | right p. list | classes    | c. element | c. value |
|----------|---------------|--------------|---------------|------------|------------|----------|
| class    | Human         | -            | -             | M, N       | -          | -        |
| class    | M             | -            | C, F          | -          | -          | -        |
| class    | C             | A, B         | -             | -          | -          | -        |
| property | A             | foaf:name    | -             | string     | -          | 1        |
| property | B             | foaf:name    | -             | string     | -          | 1        |
| class    | F             | D, E         | -             | -          | -          | -        |
| property | D             | foaf:givenName | -             | string     | -          | 1        |
| property | E             | foaf:givenName | -             | string     | -          | 1        |
| class    | N             | I, L         | -             | -          | -          | -        |
| class    | I             | G, H         | -             | -          | -          | -        |
| property | G             | foaf:mbox    | -             | string     | -          | 1        |
| property | H             | foaf:mbox    | -             | string     | -          | 1        |
| class    | L             | J, K         | -             | -          | -          | -        |
| property | J             | foaf:homepage | -             | foaf:Document | -          | 1        |
| property | K             | foaf:homepage | -             | foaf:Document | -          | 1        |

30 Context-Specific Exclusive OR of Properties

Context-Specific Exclusive OR of Properties corresponds to the requirement R-11-CONTEXT-SPECIFIC-EXCLUSIVE-OR-OF-PROPERTIES. Exclusive or is a logical operation that outputs true whenever both inputs differ (one is true, the other is false). This constraint is generally expressed in DL as follows:

\[
C \sqsubseteq (\neg A \cap B) \cup (A \cap \neg B)
\]

and alternatively:

\[
C \sqsubseteq (A \cup B) \cap \neg (A \cap B)
\]

30.1 Simple Example

```shex
# ShEx:
<Human> { ( 
  foaf:name xsd:string | 
  foaf:givenName xsd:string ) }
```
# OWL 2:

```owl
Human owl:disjointUnionOf ( :CC1 :CC2 ) .
CC1 rdfs:subClassOf [ a owl:Restriction ;
  owl:onProperty foaf:name ;
  owl:someValuesFrom xsd:string ] .
CC2 rdfs:subClassOf [ a owl:Restriction ;
  owl:onProperty foaf:givenName ;
  owl:someValuesFrom xsd:string ] .
```

1

foaf:name (range xsd:string) XOR 1 foaf:givenName (range xsd:string)

\[
\text{Human} \sqsubseteq (\neg A \sqcap B) \sqcup (A \sqcap \neg B) \\
A \sqsupseteq 1 \text{name} . \text{string} \sqsubseteq 1 \text{name} . \text{string} \\
B \sqsupseteq 1 \text{givenName} . \text{string} \sqsubseteq 1 \text{givenName} . \text{string}
\]

Mapping to RDF-CO:

| c. type | context class | left p. list | right p. list | classes | c. element | c. value |
|---------|---------------|--------------|---------------|---------|------------|----------|
| class   | Human         | -            | -             | A \sqcap B, A \sqcap B | -         | -        |
| class   | \neg A \sqcap B | -            | -             | A, \neg B | -         | -        |
| class   | A             | -            | -             | A        | -         | -        |
| property| \geq 1 name.string | name | -             | \geq 1 name.string, \leq 1 name.string | -        | -        |
| property| \leq 1 name.string | name | -             | \leq 1 name.string | -        | -        |
| class   | B             | -            | -             | B        | -         | -        |
| property| \geq 1 givenName.string | givenName | -             | \geq 1 givenName.string, \leq 1 givenName.string | -        | -        |
| property| \leq 1 givenName.string | givenName | -             | \leq 1 givenName.string | -        | -        |

syntactic sugar:

Mapping to RDF-CO:

| c. type | context class | left p. list | right p. list | classes | c. element | c. value |
|---------|---------------|--------------|---------------|---------|------------|----------|
| property| \geq 1 name.string | name | -             | = \geq 1 name.string | -        | 1        |
| property| \leq 1 givenName.string | givenName | -             | = \leq 1 givenName.string | -        | 1        |
| class   | Human         | -            | -             | = \geq 1 name.string, = \leq 1 givenName.string, XOR | -        | -        |

### 30.2 Simple Example

```shex
<FeelingForce> { ( attackingBySword xsd:boolean | attackingByForce xsd:boolean ) }
```

```owl
FeelingForce owl:disjointUnionOf ( CC1 CC2 ) .
CC1 rdfs:subClassOf [ a owl:Restriction ;
  owl:onProperty attackingBySword ;
  owl:someValuesFrom xsd:boolean ] .
CC2 rdfs:subClassOf [ a owl:Restriction ;
  owl:onProperty attackingByForce ;
  owl:someValuesFrom xsd:boolean ] .
```
This means that **FeelingForce** individuals are individuals having one **attackingBySword** relationship (range xsd:boolean) or one **attackingByForce** relationship (range xsd:boolean) but not both.

\[
A \equiv \exists \text{attackingBySword}.xsd:boolean \\
B \equiv \exists \text{attackingByForce}.xsd:boolean \\
\text{FeelingForce} \subseteq (\neg A \land B) \sqcup (A \land \neg B)
\]

### 30.3 Simple Example

\[\text{Person} \subseteq ((\text{Male} \land \neg \text{Female}) \sqcup (\neg \text{Male} \land \text{Female}))\]

### 30.4 Complex Example

```shex
# ShEx:
<Human> { 
  foaf:name xsd:string | foaf:givenName xsd:string* ,
  foaf:familyName xsd:string ) }
```

- 1 foaf:name (range xsd:string) XOR 1-n foaf:givenName (range xsd:string)
- and
- 1 foaf:familyName (range xsd:string)

Individuals matching the 'Human' data shape:

```shex
:Han
  foaf:name "Han Solo" ;
  foaf:familyName "Solo" .
:Anakin
  foaf:givenName "Anakin" ;
  foaf:givenName "Darth" ;
  foaf:familyName "Skywalker" .
```

Individual not matching the 'Human' data shape:

```shex
:Anakin
  foaf:name "Anakin Skywalker" ;
  foaf:givenName "Anakin" ;
  foaf:familyName "Skywalker" .
```

### 31 Context-Specific Inclusive OR of Properties

**Context-Specific Inclusive OR of Properties** corresponds to the requirement R-202-CONTEXT-SPECIFIC-INCLUSIVE-OR-OF-PROPERTIES. Inclusive or is a logical connective joining two or more predicates that yields the logical value "true" when at least one of the predicates is true. The context can be a class, i.e., the constraint applies for individuals of this specific class.
31.1 Simple Example

- 1 foaf:name (range: xsd:string) OR 1 foaf:givenName (range: xsd:string)
- it is also possible that both 1 foaf:name and 1 foaf:givenName are stated
- context: class Human

\[ \text{Human} \subseteq \text{A} \cup \text{B} \]
\[ \text{A} \subseteq 1 \text{name . string} \cap 1 \text{name . string} \]
\[ \text{B} \subseteq 1 \text{givenName . string} \cap 1 \text{givenName . string} \]

syntactic sugar:

Mapping to RDF-CO:

| c. type | context class | left p. list | right p. list | classes | c. element | c. value |
|---------|---------------|--------------|--------------|---------|------------|---------|
| property | = 1 name . string | name | - | string | = 1 | |
| property | = 1 givenName . string | givenName | - | string | = 1 | |
| class | Human | - | - | 1 name . string, = 1 givenName . string | | |

32 Context-Specific Exclusive OR of Property Groups

Context-Specific Exclusive OR of Property Groups corresponds to the requirement: R-13-DISJOINT-GROUP-OF-PROPERTIES-CLASS-SPECIFIC. Exclusive or is a logical operation that outputs true whenever both inputs differ (one is true, the other is false). Only one of multiple property groups leads to valid data.

32.1 Simple Example

```shex
# ShEx:
<Human> {
  ( foaf:name xsd:string , foaf:givenName xsd:string ) |
  ( foaf:mbox IRI , foaf:homepage foaf:Document ) }
```

- 1. group XOR 2. group
- 1. group: 1 foaf:name (range: xsd:string) and 1 foaf:givenName (range: xsd:string)
- 2. group: 1 foaf:mbox (range: IRI) and 1 foaf:homepage (range: foaf:Document)
- context: class Human

```shex
# valid data:
Thomas
a Human ;
foaf:mbox <thomas.bosch@gesis.org> ;
foaf:homepage <\protect\url{http://purl.org/net/thomasbosch}> .
```

```shex
# invalid data:
Thomas
a Human ;
foaf:name ‘Thomas Bosch’ ;
foaf:givenName ‘Thomas’ ;
foaf:mbox <thomas.bosch@gesis.org> ;
foaf:homepage <\protect\url{http://purl.org/net/thomasbosch}> .
```
syntactic sugar:

### Mapping to RDF-CO:

| c. type | context class | left p. list | right p. list | classes | c. element | c. value |
|---------|---------------|--------------|---------------|---------|------------|---------|
| class   | Human         | -            | -             | E, F    | XOR        |         |
| class   | E             | -            | -             | = 1 name.string, = 1 givenName.string | = |         |
| class   | F             | -            | -             | = 1 mbox.IRI, = 1 homepage.Document | = |         |
| property| name         | -            | -             | string  | = | 1        |
| property| givenName    | -            | -             | string  | = | 1        |
| property| mbox         | -            | -             | IRI     | = | 1        |
| property| homepage     | -            | -             | Document | = | 1        |

33. **Context-Specific Inclusive OR of Property Groups**

At least one property group must match for individuals of a specific context. Context may be a class, a shape, or an application profile.

#### 33.1 Simple Example

- 1. group OR 2. group
- 1. group: 1 foaf:firstName (range: xsd:string) and 1 foaf:lastName (range: xsd:string)
- 2. group: 1 foaf:givenName (range: xsd:string) and 1 foaf:familyName (range: xsd:string)
- context: class Person

```r
# valid data:
:Anakin
  a :Person ;
  foaf:firstName 'Anakin' ;
  foaf:lastName 'Skywalker' ;
  foaf:givenName 'Anakin' ;
  foaf:familyName 'Skywalker' .
```

```r
# invalid data:
:Anakin
  a :Person .
```

Human ⊆ (¬ E ∨ F) ⊆ (E ∨ ¬ F)

E ⊆ A ⊃ B

F ⊆ C ⊃ D

A ⊆ 1 name . string ∨ 1 name . string

B ⊆ 1 givenName . string ∨ 1 givenName . string

C ⊆ 1 mbox . IRI ∨ 1 mbox . IRI

D ⊆ 1 homepage . Document ∨ 1 homepage . Document
syntactic sugar:

Mapping to RDF-CO:

| c. type | context class | left p. list | right p. list | classes | c. element | c. value |
|---------|---------------|-------------|--------------|---------|------------|---------|
| class   | Human         |             | -            | E, F    | = 1        | -       |
| class   | E             |             | -            | = 1     | name.string, givenName.string | -       |
| property| = 1           | name        | string       | = 1     | mbox.IRI   | homepage.Document |
| property| = 1           | givenName   | string       | = 1     | mbox       | -       |
| property| = 1           | mbox.IRI    | IRI          | = 1     | homepage.Document | -       |
| property| = 1           | homepage.Document | Document | = 1     | -         | -       |

34 Allowed Values

Allowed Values corresponds to the requirements: R-30-ALLOWED-VALUES-FOR-RDF-OBJECTS and R-37-ALLOWED-VALUES-FOR-RDF-LITERALS. It is a common requirement to narrow down the value space of a property by an exhaustive enumeration of the valid values (both literals or resource). This is often rendered in drop down boxes or radio buttons in user interfaces. Allowed values for properties

- must be these IRIs,
- must be IRIs matching specific patterns,
- must be IRIs matching one of multiple patterns,
- must be (any) literals,
- must be literals of a list of allowed literals (e.g. “red” “blue” “green”),
- must be typed literals of this type (e.g. XML dataType).

34.1 Example

```plaintext
# DSP:
descriptionTemplate
  a dsp:DescriptionTemplate ;
dsp:minOccur "0"^^xsd:nonNegativeInteger ;
dsp:maxOccur "infinity"^^xsd:string ;
dsp:resourceClass swrc:Book ;
dsp:statementTemplate [a
dsp:NonLiteralStatementTemplate ;
dsp:minOccur "0"^^xsd:nonNegativeInteger ;
dsp:maxOccur "infinity"^^xsd:string ;
dsp:property dcterms:subject ;
dsp:nonLiteralConstraint [a
dsp:NonLiteralConstraint ;
dsp:valueClass skos:Concept ;
dsp:valueURI ComputerScience, SocialScience, Librarianship ] ] .

# OWL2:
dcterms:subject rdfs:range ObjectOneOf .
ObjectOneOf owl:equivalentClass [ObjectOneOf( ComputerScience SocialScience Librarianship )
  a owl:Class ;
  owl:oneOf( ComputerScience SocialScience Librarianship ) ] .
```
The range of the object property dcterms:subject must consist of the individuals ComputerScience SocialScience Librarianship which are of the class skos:Concept:

\[ T \subseteq \forall \text{dcterms:subject} . \text{skos:Concept} \cap \\
( \{ \text{ComputerScience} \} \sqcup \{ \text{SocialScience} \} \sqcup \{ \text{Librarianship} \} ) \]

### 34.2 Simple Example

Beatle \( \equiv \{ \text{john} \} \sqcup \{ \text{paul} \} \sqcup \{ \text{george} \} \sqcup \{ \text{ringo} \} \)

Mapping to RDF-CO:

| c. type | context class | left p. list | right p. list | classes | c. element | c. value |
|---------|---------------|--------------|---------------|---------|------------|----------|
| class   | Beatle        |              |               |         |            |          |
| classes | \{john\}, \{paul\}, \{george\}, \{ringo\} |              |               |         |            |          |

### 34.3 Simple Example

\{ \text{ComputerScience} \} \sqcup \{ \text{SocialScience} \} \sqcup \{ \text{Librarianship} \}

Mapping to RDF-CO:

| c. type | context class | left p. list | right p. list | classes | c. element | c. value |
|---------|---------------|--------------|---------------|---------|------------|----------|
| class   | complex concept |              |               |         |            |          |
| classes | \{ComputerScience\}, \{SocialScience\}, \{Librarianship\} |              |               |         |            |          |

### 34.4 Simple Example

Jedis have blue, green, or white laser swords.

```ruby
1 # DSP:
2 personDescriptionTemplate
3 a dsp:DescriptionTemplate ;
4 dsp:resourceClass Jedi ;
5 dsp:statementTemplate [
6   a dsp:LiteralStatementTemplate ;
7   dsp:property laserSwordColor ;
8   dsp:literalConstraint [
9     a dsp:LiteralConstraint ;
10    dsp:literal "blue" ;
11    dsp:literal "green" ;
12    dsp:literal "white" ] ] .
```

```ruby
1 # OWL2:
2 laserSwordColor rdfs:range laserSwordColors .
3 laserSwordColors
4 a rdfs:Datatype .
5 rdfs:oneOf ("blue" "green" "white") .
```

```ruby
1 # ReSh:
2 Jedi a rs:ResourceShape ;
3 rs:property [ 
4   rs:name "laserSwordColor" ;
5   rs:propertyDefinition laserSwordColor ;
6   rs:allowedValue "blue", "green", "white" ;
7   rs:occurs rs:Exactly-one ; ] .
```
# ShEx:
Jedi {
  laserSwordColor ('blue' 'green' 'white') }

# Jedi individuals:
Yoda
  laserSwordColor 'blue' .

Jedi \( \equiv \exists \) laserSwordColor.\{blue, green, white\}

## Mapping to RDF-CO:

| c. type | context class | left p. list | right p. list | classes | c. element | c. value |
|---------|---------------|--------------|---------------|---------|------------|----------|
| property | Jedi          | laserSwordColor |       | LaserSwordColor \{blue, green, white\} | \( \equiv \) | \( - \) |

35  **Not Allowed Values**

Not Allowed Values corresponds to the requirements R-33-NEGATIVE-OBJECT-CONSTRAINTS and R-200-NEGATIVE-LITERAL-CONSTRAINTS. A matching triple has any literal / object except those explicitly excluded.

### 35.1 Simple Example

Siths do not have blue, green, or white laser swords.

# OWL2:
laserSwordColor rdfs:range negativeLaserSwordColors .
NegativeLaserSwordColors a rdfs:Datatype .
  owl:complementOf laserSwordColors .
laserSwordColors a rdfs:Datatype .
  owl:oneOf ("blue" "green" "white") .

# ShEx:
Sith {
  ! laserSwordColor ('blue' 'green' 'white') }

# Sith individuals:
DarthSidious
  laserSwordColor 'red' .

Sith \( \equiv \neg \exists \) laserSwordColor.\{blue, green, white\}

## Mapping to RDF-CO:

| c. type | context class | left p. list | right p. list | classes | c. element | c. value |
|---------|---------------|--------------|---------------|---------|------------|----------|
| property | laserSwordColor . LaserSwordColor |       | laserSwordColor |       | LaserSwordColor \{blue, green, white\} | \( \neg \) | \( - \) |
36 Membership in Controlled Vocabularies

Membership in Controlled Vocabularies corresponds to the requirements R-32-MEMBERSHIP-OF-RDF-OBJECTS-IN-CONTROLLED-VOCABULARIES and R-39-MEMBERSHIP-OF-RDF-LITERALS-IN-CONTROLLED-VOCABULARIES. Resources can only be members of listed controlled vocabularies.

### 36.1 Simple Example

```plaintext
# DSP:
bookDescriptionTemplate
  a dsp:DescriptionTemplate ;
dsp:resourceClass src:Book ;
dsp:statementTemplate [ 
  a dsp:NonLiteralStatementTemplate ;
dsp:property dcterms:subject ;
dsp:nonLiteralConstraint [ 
  a dsp:NonLiteralConstraint ;
dsp:valueClass skos:Concept ;
dsp:vocabularyEncodingScheme BookSubjects, BookTopics, BookCategories ] ] .

skos:Concept resources can only be members of the listed controlled vocabularies.

A ≡ Concept ∩ B
B ≡ ∀inScheme.C
C ≡ ConceptScheme ∩ (\{BookSubjects\} ∪ \{BookTopics\} ∪ \{BookCategories\})
```

Mapping to RDF-CO:

| c. type | context class | left p. list | right p. list | classes | c. element | c. value |
|---------|---------------|--------------|---------------|---------|------------|----------|
| property | subject       | A            |               | Concept, B | range | - |
| class    | A             | Concept, B   |               | range | - |
| property | inScheme      | C            |               | v      | - |
| class    | C             | ConceptScheme, D |               | range | - |
| class    | D             | [BookSubjects], [BookTopics], [BookCategories] |               | - | - |

# valid data:
ArtificialIntelligence
  a src:Book ;
  dcterms:subject ComputerScience .
ComputerScience
  a skos:Concept ;
dcam:memberOf BookSubjects ;
skos:inScheme BookSubjects .
BookSubjects
  a skos:ConceptScheme .

# invalid data:
ArtificialIntelligence
  a src:Book ;
  dcterms:subject ComputerScience .
ComputerScience
  a skos:Concept ;
dcam:memberOf BooksAboutBirds ;
```
The related subject (ComputerScience) is a member of a controlled vocabulary (BooksAboutBirds) which is not part of the list of allowed controlled vocabularies.

37 IRI Pattern Matching

IRI Pattern Matching corresponds to the requirements

- R-21-IRI-PATTERN-MATCHING-ON-RDF-SUBJECTS,
- R-22-IRI-PATTERN-MATCHING-ON-RDF-OBJECTS and
- R-23-IRI-PATTERN-MATCHING-ON-RDF-PROPERTIES

indicating IRI pattern matching on subjects, properties, and objects.

38 Literal Pattern Matching

Literal Pattern Matching corresponds to the requirement

R-44-PATTERN-MATCHING-ON-RDF-LITERALS. indicating pattern matching on literals.

38.1 Simple Example

```owl
# OWL 2 DL (functional-style syntax):
Declaration( Datatype( SSN ) )
DatatypeDefinition(
  SSN
  DatatypeRestriction( xsd:string xsd:pattern "[0-9]{3}-[0-9]{2}-[0-9]{4}" )
  hasSSN SSN )

# OWL 2 DL (turtle syntax):
SSN
  a rdfs:Datatype ;
  owl:equivalentClass [ a rdfs:Datatype ;
    owl:onDatatype xsd:string ;
    owl:withRestrictions ( [ xsd:pattern "[0-9]{3}-[0-9]{2}-[0-9]{4}" ] ]  .
hasSSN rdfs:range SSN .
```

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

# invalid data:
1. TimBernersLee
2. hasSSN "123456789"^^SSN.

Not expressible in DL!

Mapping to RDF-CO:

| c. type | context class | left p. list | right p. list | classes | c. element | c. value |
|---------|---------------|--------------|---------------|---------|------------|----------|
| class   | SSN           |              |               | xsd:string | xsd:pattern | [0-9]{3}-[0-9]{2}-[0-9]{4}. |

### 38.2 Simple Example

There are multiple use cases associated with the requirement to match literals according to given patterns.

Luke’s droids can only have the numbers ”R2-D2” or ”C-3PO”. The universal restriction part of this constraint can be expressed by OWL 2 DL: LukesDroids ⊑ ∨ droidNumber.DroidNumber. The restriction of the datatype DroidNumber, however, cannot be expressed in DL, but OWL 2 DL can be used anyway:

```
DroidNumber
a rdfs:Datatype ;
owl:equivalentClass [ a rdfs:Datatype ;
owl:onDatatype xsd:string ;
owl:withRestrictions ( [ xsd:pattern ”R2-D2|C-3PO” ] ) ] .
```

The second axiom defines DroidNumber as an abbreviation for a datatype restriction on xsd:string. The first axiom explicitly declares DroidNumber to be a datatype. The datatype DroidNumber can be used just like any other datatype like in the universal restriction above. The literal pattern matching constraint validates DroidNumber literals according to the stated regular expression causing a constraint violation for the triples Luke hasDroid Droideka and Droideka droidNumber ”Droideka”^^DroidNumber, but not for the triples Luke hasDroid R2-D2 and R2-D2 droidNumber "R2-D2"^^DroidNumber.

Not expressible in DL!

Mapping to RDF-CO:

| c. type | context class | left p. list | right p. list | classes | c. element | c. value |
|---------|---------------|--------------|---------------|---------|------------|----------|
| property| LukesDroids   | DroidNumber  |               | DroidNumber | xsd:string | R2-D2(C-3PO) |
39 Negative Literal Pattern Matching

Negative Literal Pattern Matching corresponds to the requirement R-44-PATTERN-MATCHING-ON-RDF-LITERALS indicating negative pattern matching on literals.

### Examples:
1. `dbo:isbn` format is different '!' from `''([iIsbBnN 0-9-])*$'`
2. `dbo:postCode` format is different '!' from `''([0-9])6$'`
3. `foaf:phone` contains any letters (`'[A-Za-z]'`)

39.1 Example

### Test binding (DQTP):
- `dbo:isbn` format is different '!' from `''([iIsbBnN 0-9-])*$'`
- `P1` => `dbo:isbn`
- `NOP` => `!`
- `REGEX` => `''([iIsbBnN 0-9-])*$'`

### DQTP:
- `SELECT DISTINCT ?s WHERE { ?s %%P1%% ?value . FILTER ( %%NOP%% regex(str(?value), %%REGEX%) ) }

- MATCH Pattern [3]
- `P1` is the property we need to check against REGEX and NOP can be a not operator (!) or empty.

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

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

Not expressible in DL!

### Mapping to RDF-CO:

| c. type | context class | left p. list | right p. list | classes | c. element | c. value |
|---------|---------------|--------------|---------------|---------|------------|----------|
| property | | | | | | |
| class | `A` | `dbo:isbn` | `-` | `-` | `A` | domain | `-` |
| class | `A` | `-` | `-` | `xsd:string` | `regex` | `''([iIsbBnN 0-9-])*$'` |

40 Literal Value Comparison

Literal Value Comparison corresponds to the requirement R-43-LITERAL-VALUE-COMPARISON. Examples are:
- `dbo:deathDate` before '<' `dbo:birthDate`
- `dbo:releaseDate` after '>' `dbo:latestReleaseDate`
- `dbo:demolitionDate` before '<' `dbo:buildingStartDate`
40.1 Simple Example

```sql
# DQTP:
SELECT ?s WHERE {
  ?s %P1% ?v1 .
  ?s %P2% ?v2 .
  FILTER ( ?v1 %OP% ?v2 )
}
```

This constraint corresponds to the COMP Pattern [3]. Depending on the property semantics, there are cases where two different literal values must have a specific ordering with respect to an operator. P1 and P2 are the datatype properties we need to compare and OP is the comparison operator (<, <=, >, >=, =, !=).

```sql
# test binding (DQTP):
dbo:deathDate before '<' dbo:birthDate
P1 => dbo:deathDate
P2 => dbo:birthDate
OP => <
```

Not expressible in DL!

Mapping to RDF-CO:

| c. type | context class | left p. list | right p. list | classes | c. element | c. value |
|---------|---------------|--------------|---------------|---------|------------|----------|
| property |               | dbo:birthDate | dbo:deathDate | xsd:date | >          |          |

40.2 Simple Example

Duplicate strings are not allowed:

```xml
dc:subject "foo"@en
dc:subject "foo"@fr
dc:subject "bar"@fr
dc:subject "foo"
```

There are no identical strings.

Not expressible in DL!

Mapping to RDF-CO:

| c. type | context class | left p. list | right p. list | classes | c. element | c. value |
|---------|---------------|--------------|---------------|---------|------------|----------|
| property |               | dc:subject   | dc:subject    | xsd:string | p |
41 Negative Literal Ranges

Negative Literal Ranges corresponds to the requirement R-142-NEGATIVE-RANGES-OF-RDF-LITERAL-VALUES. The literal value of a resource (having a certain type) must (not) be within a specific range. P1 is a data property of an instance of class T1 and its literal value must be between the range of $[V_{\text{min}}, V_{\text{max}}]$ or outside ($!$).

41.1 Simple Example

- dbo:height of a dbo:Person is not within $[0.4, 2.5]$.

41.2 Simple Example

- geo:lat of a spatial:Feature is not within $[-90, 90]$.

41.3 Simple Example

- geo:long of a gml:Feature must be in range $[-180, 180]$.

42 Literal Ranges

Literal Ranges corresponds to the requirement R-45-RANGES-OF-RDF-LITERAL-VALUES. P1 is a data property (of an instance of class C1) and its literal value must be between the range of $[V_{\text{min}}, V_{\text{max}}]$.

42.1 Example

```plaintext
# OWL 2 DL (functional-style syntax):
Declaration( Datatype( NumberPlayersPerWorldCupTeam ) )
DatatypeDefinition( NumberPlayersPerWorldCupTeam DatatypeRestriction( xsd:nonNegativeInteger xsd:minInclusive "1"^^xsd:nonNegativeInteger xsd:maxInclusive "23"^^xsd:nonNegativeInteger ) )
DataPropertyRange( position NumberPlayersPerWorldCupTeam )
```

```plaintext
# OWL 2 DL (turtle syntax):
NumberPlayersPerWorldCupTeam a rdfs:Datatype ;
owl:equivalentClass [ a rdfs:Datatype ;
owl:equivalentClass xsd:nonNegativeInteger ;
owl:withRestrictions ( [ xsd:minInclusive "1"^^xsd:nonNegativeInteger ] [ xsd:maxInclusive "23"^^xsd:nonNegativeInteger ] ) ] .
position rdfs:range NumberPlayersPerWorldCupTeam .
```
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.

1 valid data:
MarioGoetze
position "19"^^:NumberPlayersPerWorldCupTeam .

1 invalid data:
MarioGoetze
position "99"^^:NumberPlayersPerWorldCupTeam .

Not expressible in DL!

Mapping to RDF-CO:

| c. type | context class | left p. list | right p. list | classes | c. element | c. value |
|---------|---------------|--------------|---------------|---------|------------|----------|
| property |              | position     | -             | 1-23    | range      | 1        |
| class    | 1-23         | -            | -             | xsd:nonNegativeInteger ≥ 1 |
| class    | 1-23         | -            | -             | xsd:nonNegativeInteger ≤ 23 |

43 Define Order

Define Order corresponds to the requirements R-121-SPECIFY-ORDER-OF-RDF-RESOURCES and R-217-DEFINE-ORDER-FOR-FORMS/DISPLAY. With this constraint objects of object properties can be ordered as well as literals of data properties and objects of object properties.

43.1 Simple Example

Define the order of the property listElement for the class rdf:List. List elements are of datatype xsd:string.

Not expressible in DL!

Mapping to RDF-CO:

| c. type | context class | left p. list | right p. list | classes | c. element | c. value |
|---------|---------------|--------------|---------------|---------|------------|----------|
| property | rdf:List      | listElement  | -             | xsd:string | order      | 1        |

44 Validation Levels

Validation Levels corresponds to the requirements

- R-205-VARYING-LEVELS-OF-ERROR,
- R-135-CONSTRAINT-LEVELS,
- R-158-SEVERITY-LEVELS-OF-CONSTRAINT-VIOLATIONS, and
Different levels of severity, priority should be assigned to constraints. Possible validation levels could be: informational, warning, error, fail, should, recommended, must, may, optional, closed (only this) constraints, open (at least this).

Not expressible in DL!

45 String Operations

String Operations corresponds to the requirement R-194-PROVIDE-STRING-FUNCTIONS-FOR-RDF-LITERALS. Some constraints require building new strings out of other strings. Calculating the string length would also be another constraint of this type.

45.1 Simple Example

The length of strings of the property hasISBN for the context class Book must be exactly 3.

Not expressible in DL!

Mapping to RDF-CO:

| c. type | context class | left p. list | right p. list | classes | c. element | c. value |
|---------|---------------|--------------|---------------|---------|------------|---------|
| property| Book          | hasISBN      | -             | xsd:string | length     | 3       |

46 Context-Specific Valid Classes

Context-Specific Valid Classes corresponds to the requirements R-209-VALID-CLASSES. What types of resources (rdf:type) are valid in a specific context? Context can be an input stream, a data creation function, or an API.

46.1 Simple Example

Within the context AP (application profile) the classes Book and Paper are valid.

Not expressible in DL!

Mapping to RDF-CO:

| c. type | context class | left p. list | right p. list | classes | c. element | c. value |
|---------|---------------|--------------|---------------|---------|------------|---------|
| class   | AP            |              |               | Book, Paper | context-specific valid classes | true    |
47  Context-Specific Valid Properties

Context-Specific Valid Properties corresponds to the requirement R-210-VALID-PROPERTIES. What properties can be used within this context? Context can be an data receipt function, data creation function, or API.

47.1  Simple Example

Within the context AP (application profile) the properties dcterms:subject and dcterms:title are invalid.

Not expressible in DL!

Mapping to RDF-CO:

| c. type | context class | left p. list | right p. list | classes | c. element | c. value |
|---------|--------------|--------------|---------------|---------|------------|---------|
| property | AP           | dcterms:subject, dcterms:title |               | content-specific valid properties | false |

48  Default Values

Default Values corresponds to the requirements R-31-DEFAULT-VALUES-OF-RDF-OBJECTS and R-38-DEFAULT-VALUES-OF-RDF-LITERALS. Default values for objects and literals are inferred automatically. It should be possible to declare the default value for a given property, e.g. so that input forms can be pre-populated and to insert a required property that is missing in a web service call.

48.1  Simple Example

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

```sparql
# rule (SPIN)
# -----------
owl:Thing
  spin:rule { 
    a sp:Construct ;
    sp:text ""
    CONSTRUCT {
      ?this laserSwordColor "blue"^^xsd:string ;
      ?this numberLaserSwords "1"^^xsd:nonNegativeInteger .
    }
    WHERE { 
      ?this a Jedi .
      } *** ; } .

owl:Thing
  spin:rule { 
    a sp:Construct ;
    sp:text ""
    CONSTRUCT {
      ?this laserSwordColor "red"^^xsd:string ;
      ?this numberLaserSwords "2"^^xsd:nonNegativeInteger .
    }
    WHERE { 
      ?this a Sith .
      } *** ; } .
```
# data:
Joda a Jedi .
DarthSidious a Sith .

# inferred triples:
Joda
laserSwordColor "blue"^^xsd:string ;
numberLaserSwords "1"^^xsd:nonNegativeInteger .
DarthSidious
laserSwordColor "red"^^xsd:string ;
numberLaserSwords "2"^^xsd:nonNegativeInteger .

Not expressible in DL!

Mapping to RDF-CO:

| c. type | context class | left p. list | right p. list | classes | c. element | c. value |
|---------|---------------|--------------|---------------|---------|------------|----------|
| property | Jedi          | laserSwordColor | -             | -       | default values | 'blue'   |
| property | Jedi          | numberLaserSwords | -             | -       | default values | '1'      |
| property | Sith          | laserSwordColor | -             | -       | default values | 'red'    |
| property | Sith          | numberLaserSwords | -             | -       | default values | '2'      |

49 Mathematical Operations

Mathematical Operations corresponds to the requirements

- R-42-MATHEMATICAL-OPERATIONS and
- R-41-STATISTICAL-COMPUTATIONS.

Examples are:

- adding 2 dates
- add number of days to start date
- area = width * height
- Statistical Computations: average, mean, sum

49.1 Simple Example

Calculate rectangle areas.

Not expressible in DL!

Mapping to RDF-CO:

| c. type | context class | left p. list | right p. list | classes | c. element | c. value |
|---------|---------------|--------------|---------------|---------|------------|----------|
| property | Rectangle     | area         | width, height | xsd:integer | multiplication |
50  Language Tag Matching

Language Tag Matching corresponds to the requirement R-47-LANGUAGE-TAG-MATCHING.

50.1  Simple Example

Only English names are allowed.

Not expressible in DL!

Mapping to RDF-CO:

| c. type | context class | left p. list | right p. list | classes | c. element | c. value |
|---------|---------------|-------------|--------------|---------|------------|---------|
| property | name          | -           | -            | language tag | en        |

51  Language Tag Cardinality

Language Tag Cardinality corresponds to the requirements

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

51.1  Simple Example

Check that no language is used more than once per property

```sql
# DQTP:
SELECT DISTINCT ?s WHERE { ?s P1 ?c
  BIND ( lang(?c) AS ?l )
  FILTER (isLiteral (?c) && lang(?c) = V1)}
GROUP BY ?s HAVING COUNT (?l) > 1
```

This corresponds to the test pattern ONELANGPattern [3]. 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.

| # test binding (DQTP): |
|------------------------|
| P1 => foaf:name        |
| V1 => en               |

A single English (“en”) foaf:name.

| # valid data:           |
|-------------------------|
| :LeiaSkywalker          |
| foaf:name ‘Leia Skywalker’en . |

| # invalid data:         |
|-------------------------|
| :LeiaSkywalker          |
| foaf:name ‘Leia Skywalken ; |
| foaf:name ‘Leia’en .    |
52 Whitespace Handling

Whitespace Handling corresponds to the requirement R-50-WHITESPACE-HANDLING-OF-RDF-LITERALS. Avoid whitespaces in literals neither leading nor trailing white spaces.

52.1 Simple Example

Check if literals of the property p do not include whitespaces.

Not expressible in DL!

53 HTML Handling

HTML Handling corresponds to the requirement R-51-HTML-HANDLING-OF-RDF-LITERALS. Check if there are no HTML tags included in literals (of specific data properties within the context of specific classes).

53.1 Simple Example

Check if literals of the property p of the class C do not include HTML tags.

Not expressible in DL!

54 Required Properties

Required Properties corresponds to the requirement R-68-REQUIRED-PROPERTIES.
54.1 Simple Example

For persons the property `hasAncestor` has to be stated pointing to persons.

\[
\text{Person} \sqsubseteq \exists \text{hasAncestor}.\text{Person}
\]

Mapping to RDF-CO:

| c. type | context class | left p. list | right p. list | classes | c. element | c. value |
|---------|---------------|--------------|--------------|---------|------------|---------|
| property | Person        | hasAncestor  | Person       | 3       | -          | -       |

55 Optional Properties

Optional Properties corresponds to the requirement R-69-OPTIONAL-PROPERTIES.

55.1 Simple Example

For persons the property `hasAncestor` pointing to persons is optional.

\[
\exists \text{hasAncestor}.\text{Person} \sqsubseteq \text{Person}
\]

Same as the definition of domains.

Mapping to RDF-CO:

| c. type | context class | left p. list | right p. list | classes | c. element | c. value |
|---------|---------------|--------------|--------------|---------|------------|---------|
| property | Person        | hasAncestor  | Person       | 3       | hasAncestor | -       |

syntactic sugar:

| c. type | context class | left p. list | right p. list | classes | c. element | c. value |
|---------|---------------|--------------|--------------|---------|------------|---------|
| property | Person        | hasAncestor  | Person       | 3       | -          | -       |

56 Repeatable Properties

Repeatable Properties corresponds to the requirement R-70-REPEATABLE-PROPERTIES.

56.1 Simple Example

The property `commandsVessel` is repeatable for individuals of the class `Captain`.

\[
\text{Captain} \sqsupseteq 1 \text{commandsVessel}.\top
\]

Mapping to RDF-CO:

| c. type | context class | left p. list | right p. list | classes | c. element | c. value |
|---------|---------------|--------------|--------------|---------|------------|---------|
| property | Captain       | commandsVessel | - | - | 1 |

syntactic sugar:

| c. type | context class | left p. list | right p. list | classes | c. element | c. value |
|---------|---------------|--------------|--------------|---------|------------|---------|
| property | Captain       | commandsVessel | - | - | repeatable |

57  Conditional Properties

Conditional Properties corresponds to the requirement R-71-CONDITIONAL-PROPERTIES.

Multiple conditions are possible:

- universal quantification on object and data properties,
- existential quantification on object and data properties,
- if specific properties are present, then specific other properties also have to be present

57.1  Simple Example

If an individual has a parentOf property relationship, then this individual also has a ancestorOf property relationship.

parentOf ⊆ ancestorOf

Mapping to RDF-CO:

| c. type       | context class | left p. list | right p. list | classes | c. element | c. value |
|---------------|---------------|--------------|---------------|---------|------------|---------|
| property      | parentOf      | ancestorOf   |               |         |            | ⊆       |

58  Recommended Properties

Recommended Properties corresponds to the requirement R-72-RECOMMENDED-PROPERTIES. Which properties are not required but recommended within a particular context.

58.1  Simple Example

Property p is recommended to use within the context of the class C.

Not expressible in DL!

Mapping to RDF-CO:

| c. type       | context class | left p. list | right p. list | classes | c. element | c. value |
|---------------|---------------|--------------|---------------|---------|------------|---------|
| property      | C             | p            |               |         | recommended|         |

59  Negative Property Constraints

Negative Property Constraints corresponds to the requirements

- R-52-NEGATIVE-OBJECT-PROPERTY-CONSTRAINTS and
- R-53-NEGATIVE-DATA-PROPERTY-CONSTRAINTS.

Instances of a specific class must not have some object property. In OWL 2 DL, this can be expressed as follows: ObjectComplementOf ( ObjectSomeValuesFrom ( ObjectPropertyExpression owl:Thing ) ).
59.1 Example

```shex
# ShEx:
<FeelingForce> {
  feelingForce (true) ,
  attitude xsd:string }
<JediMentor> {
  feelingForce (true) ,
  attitude ('good') ,
  laserSwordColor xsd:string ,
  numberLaserSwords xsd:nonNegativeInteger ,
  mentorOf @<JediStudent> ,
  !studentOf @<JediMentor> }
<JediStudent> {
  feelingForce (true) ,
  attitude ('good') ,
  laserSwordColor xsd:string ,
  numberLaserSwords xsd:nonNegativeInteger ,
  !mentorOf @<JediStudent> ,
  studentOf @<JediMentor> }
```

A matching triple has any predicate except those excluded by the ‘!’ operator.

```
# individuals matching 'FeelingForce' and 'JediMentor' data shapes:
Obi-Wan
  feelingForce true ;
  attitude 'good' ;
  laserSwordColor 'blue' ;
  numberLaserSwords '1'^^xsd:nonNegativeInteger ;
  mentorOf Anakin .
```

```
# individuals matching 'FeelingForce' and 'JediStudent' data shapes:
Anakin
  feelingForce true ;
  attitude 'good' ;
  laserSwordColor 'blue' ;
  numberLaserSwords '1'^^xsd:nonNegativeInteger ;
  studentOf Obi-Wan .
```

\[ \text{JediMentor} \sqsubseteq \neg (\exists \text{studentOf.JediMentor}) \]

Mapping to RDF-CO:

| c. type | context class | left p. list | right p. list | classes | c. element | c. value |
|---------|---------------|--------------|---------------|---------|------------|----------|
| property class | studentOf.JediMentor | | | | | |
| class | JediMentor | | | | | |

60 Handle RDF Collections

Handle RDF Collections corresponds to the requirement `R-120-HANDLE-RDF-COLLECTIONS`. Examples are:

- size of collection
- first / last element of list must be a specific literal
- compare elements of collection
are collections identical?
actions on RDF lists
2. list element equals 'XXX'
Does the list have more than 10 elements?

60.1 Example

Get 2. list element:

```
# SPIN:
getListItem
  a spin:Function ; rdfs:subClassOf spin:Functions ;
  spin:constraint [
    rdf:type spl:Argument ;
    spl:_predicate sp:arg1 ;
    spl:valueType rdf:List ;
    rdfs:comment "list" ; ] ;
  spin:constraint [
    rdf:type spl:Argument ;
    spl:predicate sp:arg2 ;
    spl:valueType xsd:nonNegativeInteger ;
    rdfs:comment "item position (starting with 0)" ; ] ;
  spin:body [
    a sp:SELECT ;
    sp:text ""
    SELECT ?item
    WHERE {
      ?arg1 contents/rdf:rest(?arg2)/rdf:first ?item "} *** ; ] ;
  spin:returnType rdfs:Resource .
```

# data:
Jinn students
  ( Xanatos Kenobi ) .

# SPIN:
BIND ( getListItem( ?list, "1"xsd:nonNegativeInteger ) AS ?listItem ) .

- SPIN function call
- retrieves the 2. item from the list (2. student of Jedi mentor Jinn)

# result:

Kenobi

Not expressible in DL!

60.2 Simple Example

Append a string list element 'list element' to a list the property p of the class C is pointing to.

Not expressible in DL!

Mapping to RDF-CO:

| c. type | context class | left p. list | right p. list | classes | c. element | c. value |
|---------|---------------|--------------|---------------|---------|------------|---------|
| property | C             | p            | -             | xsd:string | append list element | list element |

See [http://www.snee.com/bobdc.blog/2014/04/rdf-lists-and-sparql.html](http://www.snee.com/bobdc.blog/2014/04/rdf-lists-and-sparql.html)
61 Recursive Queries

Recursive Queries corresponds to the requirement R-222-RECURSIVE-QUERIES. If we want to define Resource Shapes, remember that it is a recursive language (the valueShape of a Resource Shape is in turn another Resource Shape). There is no way to express that in SPARQL without hand-waving "and then you call the function again here" or "and then you embed this operation here" text. The embedding trick doesn't work in the general case because SPARQL can't express recursive queries, e.g. "test that this Issue is valid and all of the Issues that references, recursively". Most SPARQL engines already have functions that go beyond the official SPARQL 1.1 spec. The cost of that sounds manageable.

61.1 Simple Example

```shex
# ShEx:
IssueShape {
  related $IssueShape*
}
```

Mapping to RDF-CO:

| c. type | context class | left p. list | right p. list | classes | c. element | c. value |
|---------|---------------|--------------|---------------|---------|------------|----------|
| property | IssueShape    | related      | IssueShape    | 2       | 1          |          |

62 Value is Valid for Datatype

Make sure that a value is valid for its datatype.

62.1 Simple Example

A date is really a date, as an example. SPARQL regex can be used for this purpose.

62.2 Simple Example

```spin
# SPIN:
FILTER ( datatype( ?shoeSize ) = xsd:nonNegativeInteger )
isNumeric ( ?shoeSize )
```

The datatype of ?showSize is xsd:nonNegativeInteger. The datatype is really numeric.

Mapping to RDF-CO:

| c. type | context class | left p. list | right p. list | classes | c. element | c. value |
|---------|---------------|--------------|---------------|---------|------------|----------|
| property | shoeSize      | xsd:nonNegativeInteger | value valid for datatype |  |  |  |
63 Individual Equality

Individual equality states that two different names are known to refer to the same individual [4].

63.1 Simple Example

\( \{ \text{julia} \} = \{ \text{john} \} \)

Mapping to RDF-CO:

| c. type | context class | left p. list | right p. list | classes | c. element | c. value |
|---------|---------------|--------------|---------------|---------|------------|----------|
| class   | \{ julia \}   | -            | -             | \{ john \} | \{ julia \} | =        |

64 Individual Inequality

This is by default because of the UNA.

64.1 Simple Example

\( \{ \text{julia} \} \neq \{ \text{john} \} \)

Asserts that Julia and John are actually different individuals.

Mapping to RDF-CO:

| c. type | context class | left p. list | right p. list | classes | c. element | c. value |
|---------|---------------|--------------|---------------|---------|------------|----------|
| class   | \{ julia \}   | -            | -             | \{ john \} | \{ julia \} | \neq     |

65 Equivalent Properties

An equivalent object properties axiom EquivalentObjectProperties( OPE1 ... OPEn ) states that all of the object property expressions OPEi, 1 \( \leq i \leq n \), are semantically equivalent to each other. This axiom allows one to use each OPEi as a synonym for each OPEj — that is, in any expression in the ontology containing such an axiom, OPEi can be replaced with OPEj without affecting the meaning of the ontology. The axiom EquivalentObjectProperties( OPE1 OPE2 ) is equivalent to the following two axioms SubObjectPropertyOf( OPE1 OPE2 ) and SubObjectPropertyOf( OPE2 OPE1 ).

An equivalent data properties axiom EquivalentDataProperties( DPE1 ... DPEn ) states that all the data property expressions DPEi, 1 \( \leq i \leq n \), are semantically equivalent to each other. This axiom allows one to use each DPEi as a synonym for each DPEj — that is, in any expression in the ontology containing such an axiom, DPEi can be replaced with DPEj without affecting the meaning of the ontology. The axiom EquivalentDataProperties( DPE1 DPE2 ) can be seen as a syntactic shortcut for the following axiom SubDataPropertyOf( DPE1 DPE2 ) and SubDataPropertyOf( DPE2 DPE1 ).
65.1 Simple Example

```owl
# OWL 2:
hasBrother owl:equivalentProperty hasMaleSibling .
Chris hasBrother Stewie .
Stewie hasMaleSibling Chris .
```

entailments:

```owl
Chris hasMaleSibling Stewie .
Stewie hasBrother Chris .
```

\[ \text{hasBrother} \sqsubseteq \text{hasMaleSibling} \quad \text{\textneg hasMaleSibling} \sqsubseteq \text{hasBrother} \]

Mapping to RDF-CO:

| c. type | context class | left p. list | right p. list | classes | c. element | c. value |
|---------|---------------|--------------|---------------|---------|------------|----------|
| property |              | hasBrother   | hasMaleSibling|         |            |          |
| property | T             | hasMaleSibling | has Brother   |         |            |          |

\[ \text{hasBrother} \equiv \text{hasMaleSibling} \]

66 Property Assertions

Property Assertions corresponds to the requirement R-96-PROPERTY-ASSERTIONS and includes positive property assertions and negative property assertions. A positive object property assertion ObjectPropertyAssertion( OPE a1 a2 ) states that the individual a1 is connected by the object property expression OPE to the individual a2. A negative object property assertion NegativeObjectPropertyAssertion( OPE a1 a2 ) states that the individual a1 is not connected by the object property expression OPE to the individual a2. A positive data property assertion DataPropertyAssertion( DPE a lt ) states that the individual a is connected by the data property expression DPE to the literal lt. A negative data property assertion NegativeDataPropertyAssertion( DPE a lt ) states that the individual a is not connected by the data property expression DPE to the literal lt.

66.1 Simple Example

```owl
# OWL 2:
NegativeObjectPropertyAssertion( hasSon Peter Meg )
```

Meg is not a son of Peter.

\[ \text{hasSon}(Peter, Meg) \]

The negation of such an assertion is not necessary, as it's meaningless!

Mapping to RDF-CO:

| c. type | context class | left p. list | right p. list | classes | c. element | c. value |
|---------|---------------|--------------|---------------|---------|------------|----------|
| property | [Peter]       | hasSon       | [Meg]         | \#      |            |          |
66.2 Simple Example

```owl
DataPropertyAssertion( :hasAge :Meg "17"^^xsd:integer )
```

Meg is seventeen years old.

\[\text{hasAge}(\text{Meg}, "17" \text{xsd}\text{:integer})\]

Mapping to RDF-CO:

| c. type | context class | left p. list | right p. list | classes | c. element | c. value |
|---------|---------------|--------------|---------------|---------|------------|----------|
| property | (Meg)         | hasAge       |               |         | =          | 17       |

67 Functional Properties

An object property functionality axiom \(\text{FunctionalObjectProperty}(\text{OPE})\) states that the object property expression \(\text{OPE}\) is functional — that is, for each individual \(x\), there can be at most one distinct individual \(y\) such that \(x\) is connected by \(\text{OPE}\) to \(y\). Each such axiom can be seen as a syntactic shortcut for the following axiom: \(\text{SubClassOf}(\text{owl}\text{:Thing ObjectMaxCardinality}(1 \text{OPE}))\).

67.1 Simple Example

```owl
hasFather rdf:type owl:FunctionalProperty .
Stewie hasFather Peter_Griffin .
```

Each object can have at most one father.

entailment:

```owl
Peter_Griffin owl:sameAs Peter .
```

(funct hasFather)

Mapping to RDF-CO:

| c. type | context class | left p. list | right p. list | classes | c. element | c. value |
|---------|---------------|--------------|---------------|---------|------------|----------|
| property |               | hasFather    | functional    |         |            |          |

68 Inverse-Functional Properties

An object property inverse functionality axiom \(\text{InverseFunctionalObjectProperty}(\text{OPE})\) states that the object property expression \(\text{OPE}\) is inverse-functional - that is, for each individual \(x\), there can be at most one individual \(y\) such that \(y\) is connected by \(\text{OPE}\) with \(x\). Each such axiom can be seen as a syntactic shortcut for the following axiom: \(\text{SubClassOf}(\text{owl}\text{:Thing ObjectMaxCardinality}(1 \text{ObjectInverseOf( OPE ))})\).
### 68.1 Simple Example

```owl
# OWL 2:
fatherOf rdf:type owl:InverseFunctionalProperty .
Peter fatherOf Stewie .
Peter_Griffin fatherOf Stewie .
```

Each object can have at most one father.

Entailment:

```owl
Peter owl:sameAs Peter_Griffin .
```

\[(\text{funct hasFather})\]

**Mapping to RDF-CO:**

| c. type | context class | left p. list | right p. list | classes | c. element | c. value |
|---------|----------------|--------------|---------------|---------|------------|----------|
| property | property       |              |              |         | father     |          |

### 69 Value Restrictions

Individual Value Restrictions: A has-value class expression ObjectHasValue( OPE a ) consists of an object property expression OPE and an individual a, and it contains all those individuals that are connected by OPE to a. Each such class expression can be seen as a syntactic shortcut for the class expression ObjectSomeValuesFrom( OPE ObjectOneOf( a ) ).

Literal Value Restrictions: A has-value class expression DataHasValue( DPE lt ) consists of a data property expression DPE and a literal lt, and it contains all those individuals that are connected by DPE to lt. Each such class expression can be seen as a syntactic shortcut for the class expression DataSomeValuesFrom( DPE DataOneOf( lt ) ).

#### 69.1 Simple Example

\[\text{FatherOfStewie} \subseteq \exists \text{fatherOf}\{\text{Stewie}\}\]

```owl
# OWL 2:
fatherOfStewie fatherOf Stewie .
ObjectHasValue( fatherOfStewie )
```

The has-value class expression contains those individuals that are connected through the fatherOf property with the individual Stewie. Peter is classified as its instance.

**Mapping to RDF-CO:**

| c. type | context class | left p. list | right p. list | classes | c. element | c. value |
|---------|----------------|--------------|---------------|---------|------------|----------|
| property | FatherOfStewie |              |              |         | fatherOf   | {Stewie}  |
70  Self Restrictions

A self-restriction ObjectHasSelf( OPE ) consists of an object property expression OPE, and it contains all those individuals that are connected by OPE to themselves.

70.1  Simple Example

```
# OWL 2:
Peter likes Peter.
ObjectHasSelf( likes )
```

LikesThemselves  $\subseteq \exists$ likes.Self

Mapping to RDF-CG:

| c. type | context class | left p. list | right p. list | classes | c. element | c. value |
|---------|---------------|--------------|---------------|---------|------------|----------|
| property | likes . Self  | likes        | Self          | T, 3 likes . Self | $\subseteq$ |

The self-restriction contains those individuals that like themselves. Peter is classified as its instance.

71  Data Property Facets

**Data Property Facets** corresponds to the requirement R-46-CONSTRAINING-FACETS. For datatype properties it should be possible to declare frequently needed "facets" to drive user interfaces and validate input against simple conditions, including min/max value, regular expressions, string length etc. similar to XSD datatypes. Constraining facets to restrict datatypes of RDF literals. Constraining facets may be: `xsd:length`, `xsd:minLength`, `xsd:maxLength`, `xsd:pattern`, `xsd:enumeration`, `xsd:whiteSpace`, `xsd:maxInclusive`, `xsd:maxExclusive`, `xsd:minExclusive`, `xsd:minInclusive`, `xsd:totalDigits`, `xsd:fractionDigits`.

71.1  Simple Example

```
# OWL 2 QL (functional-style syntax):
Declaration( Datatype( SSN ) )
DatatypeDefinition( SSN
  DatatypeRestriction( xsd:string xsd:pattern "[0-9]{3}-[0-9]{2}-[0-9]{4}" )
  DataPropertyRange( hasSSN SSN )
```
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.

Not expressible in DL!

## 72 Primary Key Properties

It is often useful to declare a given (datatype) property as the "primary key" of a class, so that the system can enforce uniqueness and also automatically build URIs from user input and data imported from relational databases or spreadsheets.

### 72.1 Simple Example

The Primary Key Properties constraint is often useful to declare a given (datatype) property as the "primary key" of a class, so that a system can enforce uniqueness. Starfleet officers, e.g., are uniquely identified by their command authorization code (e.g. to activate and cancel auto-destruct sequences). It means that the property commandAuthorizationCode is inverse functional - mapped to DL and the RDF-CO as follows:

$$(\text{funct} \ commandAuthorizationCode-)$$
Keys, however, are even more general, i.e., a generalization of inverse functional properties [6]. A key can be a datatype property, an object property, or a chain of properties. For this generalization purposes, as there are different sorts of key, and as keys can lead to undecidability, DL is extended with key boxes and a special key for construct [5]. This leads to the following DL and RDF-CO mappings (only one simple property constraint):

commandAuthorizationCode key for StarfleetOfficer

73 Exploiting Class/Property Specialization Ontology Axioms

Exploiting Class/Property Specialization Ontology Axioms corresponds to the requirement R-224-instance-level-data-validation-exploitingclass/property-specialization-axioms-in-ontologies. Validation of instances data (direct or indirect) exploiting the subclass or sub-property link in a given ontology. This validation can indicate when the data is verbose (redundant) or expressed at a too general level, and could be improved. Examples are:

- If dc:date and one of its sub-properties dcterms:created or dcterms:issued are present, check that the value in dc:date is not redundant with dcterms:created or dcterms:issued for ingestion
- Check if dc:rights has the same value than edm:rights either as rdf:resource or literal, if yes dc:rights is redundant
- If one or more dc:coverage are present, suggest the use of one of its sub-properties, dcterms spatial or dcterms:temporal.

73.1 Simple Example

If dc:date and one of its sub-properties dcterms:created or dcterms:issued are present, check that the value in dc:date is not redundant with dcterms:created or dcterms:issued for ingestion

Not expressible in DL!
74 Cardinality Shortcuts

In most Library applications, cardinality shortcuts tend to appear in pairs, with repeatable / non-repeatable establishing maximum cardinality and optional / mandatory establishing minimum cardinality.

- Optional & Non-Repeatable = \([0,1]\)
- Optional & Repeatable = \([0,\ast]\)
- Mandatory & Non-Repeatable = \([1,1]\)
- Mandatory & Repeatable = \([1,\ast]\)

Can be expressed in DL using minimum and maximum cardinality restrictions. We propose to use syntactic sugar instead:

**Mapping to RDF-CO:**

| c. type | context class | left p. list | right p. list | classes | c. element | c. value |
|---------|---------------|--------------|---------------|---------|------------|---------|
| property| C             | p            | q             |         | count      |         |

75 Aggregations

Some constraints require aggregating multiple values, especially via COUNT, MIN and MAX.

75.1 Simple Example

\[ p = \text{COUNT} \ (q) \]

Context class is C.

Not expressible in DL

**Mapping to RDF-CO:**

| c. type | context class | left p. list | right p. list | classes | c. element | c. value |
|---------|---------------|--------------|---------------|---------|------------|---------|
| property| C             | p            | q             |         | count      |         |

76 Evaluation

76.1 Evaluation of Constraint Languages

We evaluated to which extent the most promising five constraint languages fulfill each requirement. Tilde means that this constraint may be fulfilled by that particular constraint language - either by limitations, workarounds, or extensions. We also evaluated if a specific constraint is fulfilled by OWL 2 QL or if the more expressive OWL 2 DL is needed. Inferencing may be performed prior to validating constraints. This is marked with an asterisk.
| constraint                      | DSP | OWL2 DL | OWL2-QL | ReSh | ShEx | SPIN |
|-------------------------------|-----|---------|---------|------|-----|------|
| *Subsumption                  | ✓   |         |         | X    |     | ✓    |
| *Class Equivalence            | ✓   |         |         |     |     | X    |
| *Sub Properties               | ✓   |         |         | X    |     | X    |
| *Property Domain              | ✓   |         |         | X    |     | X    |
| *Property Range               | ✓   |         |         | X    |     | X    |
| *Inverse Object Properties    | ✓   |         |         |     |     | X    |
| *Symmetric Object Properties  | ✓   |         |         | X    |     | X    |
| *Asymmetric Object Properties | ✓   |         |         | X    |     | X    |
| *Reflexive Object Properties  | ✓   |         |         | X    |     | X    |
| *Irreflexive Object Properties| ✓   |         |         | X    |     | X    |
| Disjoint Properties           | ✓   |         |         |     |     | X    |
| Disjoint Classes              | ✓   |         |         |     |     | X    |
| Context-Sp. Property Groups   | ✓   |         |         | X    |     | X    |
| Context-Sp. Inclusive OR of P.| ✓   |         |         | X    |     | X    |
| Context-Sp. Inclusive OR of P. Groups | ✓   |         |         | X    |     | X    |
| Recursive Queries             | ✓   | ✓       | ✓       | ✓    | ✓   | ✓    |
| Individual Inequality         | ✓   | ✓       | ✓       | ✓    | ✓   | ✓    |
| *Equivalent Properties        | ✓   |         |         | X    |     | X    |
| Property Assertions           | ✓   |         |         |     |     | X    |
| Data Property Facets          | ✓   |         |         |     |     | X    |
| Literal Pattern Matching      | ✓   |         |         | X    |     | X    |
| Negative Literal Pattern Matching | ✓   |         |         | X    |     | X    |
| *Object Property Paths        | ✓   |         |         |     |     | X    |
| *Intersection                 | ✓   |         |         |     |     | X    |
| *Disjunction                  | ✓   |         |         | X    |     | X    |
| *Negation                     | ✓   |         |         | X    |     | X    |
| *Existential Quantification   | ✓   |         |         |     |     | X    |
| *Universal Quantification     | ✓   |         |         | X    |     | X    |
| *Minimum Unqualified Cardinality | ✓   |         |         | X    |     | X    |
| *Minimum Qualified Cardinality | ✓   |         |         | X    |     | X    |
| *Maximum Unqualified Cardinality | ✓   |         |         | X    |     | X    |
| *Maximum Qualified Cardinality | ✓   |         |         | X    |     | X    |
| *Exact Unqualified Cardinality | ✓   |         |         | X    |     | X    |
| *Exact Qualified Cardinality  | ✓   |         |         | X    |     | X    |
| Transitive Object Properties   | ✓   |         |         | X    |     | X    |
| Context-Sp. Exclusive OR of P. | ✓   |         |         | X    |     | X    |
| Context-Sp. Exclusive OR of P. Groups | ✓   |         |         | X    |     | X    |
| Allowed Values                | ✓   |         |         | X    |     | X    |
| Not Allowed Values            | ✓   |         |         | X    |     | X    |
| Literal Ranges                | ✓   |         |         | X    |     | X    |
| Negative Literal Ranges       | ✓   |         |         | X    |     | X    |
| Required Properties           | ✓   |         |         | X    |     | X    |
| Optional Properties           | ✓   |         |         | X    |     | X    |
| Repeatable Properties         | ✓   |         |         | X    |     | X    |
| Negative Property Constraints | ✓   |         |         | X    |     | X    |
| *Individual Equality          | ✓   |         |         | X    |     | X    |
| *Functional Properties        | ✓   |         |         | X    |     | X    |
| *Inverse-Functional Properties| ✓   |         |         | X    |     | X    |
| *Value Restrictions           | ✓   |         |         | X    |     | X    |
| *Self Restrictions            | ✓   |         |         | X    |     | X    |
| Primary Key Properties        | ✓   |         |         | X    |     | X    |
| *Class-Specific Property Range | ✓   |         |         | X    |     | X    |
| *Class-Sp. Reflexive Object P. | X   |         |         | X    |     | X    |
| Membership in Controlled Vocabularies | ✓   |         |         | X    |     | X    |
| IRI Pattern Matching          | ✓   |         |         | X    |     | X    |
| Literal Value Comparison      | ✓   |         |         | X    |     | X    |
| Define Order                  | ✓   |         |         | X    |     | X    |
| Validation Levels             | ✓   |         |         | X    |     | X    |
| String Operations             | ✓   |         |         | X    |     | X    |
### 76.2 Evaluation of Constraints Classes

We evaluated to which extend the most promising five constraint languages fulfill each of the overall 74 requirements to formulate RDF constraints [2]. If a constraint can be expressed in DL, we added the mapping to DL and to the generic constraint. If a constraint cannot be expressed in DL, we only added the mapping to the generic constraint. Therefore, we show that each constraint can be mapped to a generic constraint. The following table shows the absolute numbers and the relative percentages for each of the three dimensions to classify constraints:

| Constraint Classes                      | #  | %     |
|-----------------------------------------|----|-------|
| Property Constraints                    | 48 | 65 (64.86) |
| Class Constraints                       | 17 | 23 (22.96) |
| Property and Class Constraints          | 9  | 12 (12.16) |
| Simple Constraints                      | 46 | 62 (62.16) |
| Simple Constraints (Syntactic Sugar)    | 10 | 14 (13.51) |
| Complex Constraints                     | 18 | 24 (24.32) |
| DL Expressible                          | 51 | 69 (68.92) |
| DL Not Expressible                      | 23 | 31 (31.08) |
| Total                                   | 74 | 100   |

Legend of the detailed evaluation:

- **property constraint**: property constraint (✓) vs. class constraint (✗) vs. property and class constraints (~)
- **simple constraint**: simple constraint (✓) vs. simple constraint [syntactic sugar] (~) vs. complex constraint (✗)
- **DL**: expressible in DL (✓) vs. not expressible in DL (✗)
| constraint                          | property c | simple c | DL    |
|-----------------------------------|------------|---------|-------|
| *Subsumption                      | X          |         | ✓     |
| *Class Equivalence                | X          | X       | ✓     |
| *Sub Properties                   | ✓          |         | ✓     |
| *Property Domain                  | ✓          | ✓       | ✓     |
| *Property Range                   | ✓          |         | ✓     |
| *Inverse Object Properties        | ✓          | ✓       | ✓     |
| *Symmetric Object Properties      | ✓          |         | ✓     |
| *Asymmetric Object Properties     | ✓          |         | ✓     |
| *Reflexive Object Properties      | ✓          |         | ✓     |
| *Irreflexive Object Properties    | ✓          |         | ✓     |
| Disjoint Properties               | ✓          | ✓       | ✓     |
| Disjoint Classes                  | ✓          | ✓       | ✓     |
| Context-Sp. Property Groups       | ~          | X       | ✓     |
| Context-Sp. Inclusive OR of P.    | ~          | X       | ✓     |
| Context-Sp. Inclusive OR of P. Groups | ~      | X       | ✓     |
| Recursive Queries                 | ✓          | ✓       | ✓     |
| Individual Inequality             | X          |         | ✓     |
| *Equivalent Properties            | ✓          |         | ✓     |
| Property Assertions               | ✓          | ✓       | ✓     |
| Data Property Facets              | X          | ✓       | ✓     |
| Literal Pattern Matching          | X          |         | ✓     |
| Negative Literal Pattern Matching | X          |         | ✓     |
| *Object Property Paths            | ✓          |         | ✓     |
| *Intersection                     | X          |         | ✓     |
| *Disjunction                      | X          |         | ✓     |
| *Negation                         | X          |         | ✓     |
| *Existential Quantification       | ✓          |         | ✓     |
| *Universal Quantification         | ✓          |         | ✓     |
| *Minimum Unqualified Cardinality  | ✓          |         | ✓     |
| *Minimum Qualified Cardinality    | ✓          |         | ✓     |
| *Maximum Unqualified Cardinality  | ✓          |         | ✓     |
| *Maximum Qualified Cardinality    | ✓          |         | ✓     |
| *Exact Unqualified Cardinality    | ✓          |         | ✓     |
| *Exact Qualified Cardinality      | ✓          |         | ✓     |
| *Transitive Object Properties     | ✓          |         | ✓     |
| Context-Sp. Exclusive OR of P.    | ~          | X       | ✓     |
| Context-Sp. Exclusive OR of P. Groups | ~      | X       | ✓     |
| Allowed Values                    | X          |         | ✓     |
| Not Allowed Values                | X          |         | ✓     |
| Literal Ranges                    | X          | X       | ✓     |
| Negative Literal Ranges           | X          |         | ✓     |
| Required Properties               | ✓          | ✓       | ✓     |
| Optional Properties               | ✓          |         | ✓     |
| Repeatable Properties             | ✓          |         | ✓     |
| Negative Property Constraints     | ~          | X       | ✓     |
| *Individual Equality              | X          |         | ✓     |
| *Functional Properties            | ✓          |         | ✓     |
| *Inverse-Functional Properties    | ✓          |         | ✓     |
| *Value Restrictions               | ✓          |         | ✓     |
| *Self Restrictions                | ~          |         | ✓     |
| Primary Key Properties            | ✓          |         | ✓     |
| *Class-Specific Property Range    | ✓          |         | ✓     |
| *Class-Sp. Reflexive Object P.   | ✓          |         | ✓     |
| Membership in Controlled Vocabularies | ~          | X       | ✓     |
| IRI Pattern Matching              | X          | ✓       | ✓     |
| Literal Value Comparison          | ✓          | ✓       | ✓     |
| Define Order                      | ✓          | ✓       | ✓     |
| Validation Levels                 | ~          | ✓       | ✓     |
| String Operations                 | ✓          | ✓       | ✓     |
Constraints can be classified as **property constraints** and **class constraints**. Two thirds of the total amount of constraints are property constraints, one fifth are class constraints, and approx. 10% are composed of both property and class constraints. Constraints may be either atomic (**simple constraints** or created out of simple and/or complex constraints (**complex constraints**). Almost two thirds are simple constraints, a quarter are complex constraints. Almost 15 percent are complex constraints which can be formulated as simple constraints when using them in terms of syntactic sugar. Constraints can either be expressible in DL or not. The majority - nearly 70% - of the overall constraints are expressible in DL.

### Conclusion and Future Work

There is no standard way to validate RDF data conforming to RDF constraints like XML Schemas serve to validate XML documents. Two working groups currently try to achieve a solution for RDF validation - the W3C RDF Data Shapes working group and the DCMI RDF Application Profiles working group. We initiated a comprehensive database on RDF validation requirements: [http://purl.org/net/rdf-validation](http://purl.org/net/rdf-validation). The intention of this database is to collaboratively work on case studies, use cases, requirements, and solutions on RDF validation. In this paper, we evaluated to which extend the five most promising constraint languages on being the standard (DSP, OWL2, ReSh, ShEx, and SPIN) fulfill each of the requirements to formulate RDF constraints. Each of these requirements corresponds to a type of constraint. The majority of the constraints can be expressed in DL, which serves as a logical underpinning of related requirements. We developed an ontology to express any constraint generically, so that constraints expressed by a constraint language $\alpha$ can be transformed into constraints expressed by a constraint language $\beta$ without any information loss. By expressing any constraint generically, we can provide a validation of the generically expressed constraint. When specific constraints are then transformed into generic constraints, we can...
provide the validation of the semantically equivalent specific constraints (expressed by multiple constraint languages) out-of-the-box without any additional effort and without any difference in validation results. As not every constrains can be represented in DL, we need to represent constraints expressible by DL as well as constraints not expressible by DL by means of this ontology. We shown in terms of an evaluation that any constraint can be expressed using the developed ontology. As part of future work, we will continuously add, modify, and maintain case studies, use cases, requirements, and solutions within the RDF validation requirements database.

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