

XMLSchema2ShEx: Converting XML validation to RDF validation

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Abstract. RDF validation is a field where the Semantic Web community is currently focusing attention. In other communities, like XML or databases, data validation and quality is considered a key part of their ecosystem. Besides, there is a recent trend to migrate data from different sources to semantic web formats. These transformations and mappings between different technologies have an economical and technological impact on society. In order to facilitate this transformation, we propose a set of mappings that can be used to convert from XML Schema to Shape Expressions (ShEx)—a validation language for RDF. We also present a prototype that implements a subset of the mappings proposed, and an example application to obtain a ShEx schema from an XML Schema. We consider that this work and the development of other format mappings could drive to an improvement of data interoperability due to the reduction of the technological gap.

Keywords: ShEx, XML Schema, Shape Expressions, formats mapping, data validation

1. Introduction

Data validation is a key area when normalisation and confidence are desired. Normalisation—which can be defined, in this context, as using an homogeneous schema or structure across different sources of similar information—is desired as a way of making a dataset more reliable and even more useful to possible consumers because of its standardised schema. Validation can excel data cleansing, querying and standardisation of datasets. In words of P.N. Fox et.al. [16]: *“Procedures for data validation increase the value of data and the users’ confidence in predictions made from them. Well-designed data management systems may strengthen data validation itself, by providing better estimates of expected values than were available previously.”*. Therefore, validation is a key field of data management.

XML Schema [5] was designed as a language to make XML validation possible with more expressiveness than DTDs [4]. Using XML Schema developers can define the structure, constraints and documenta-

tion of an XML vocabulary. Besides DTD and XML Schema, other alternatives for XML validation (such as Relax NG [11] and Schematron [18]) were proposed.

In the Semantic Web, RDF was missing a standard constraints validation language which cover the same features that XML Schema does for XML. Some alternatives were OWL [17] and RDF Schema [10]; however, they do not cover completely what XML Schema does for XML [38]. For this purpose, Shape Expressions (ShEx) [32,33] was proposed to fulfill the requirement of a standard constraints validation language for RDF, and SHACL [20] (another proposed language for RDF validation) has recently become a W3C recommendation.

As many documents and data are persisted in XML, the need for migration and interoperability to more flexible data is nowadays more pressing than ever, many authors have proposed conversions from XML to RDF [27,12,2,6], with the goal of transforming XML data to Semantic Web formats.

Although these conversions enable users to migrate their data to Semantic Web, means for validating the output data after converting XML to RDF are missing. Therefore, we should ensure that the conversion has

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been done correctly and that both versions—in different languages—are defining the same meaning.

Conversions between XML and RDF, and between XML Schema and ShEx are necessary to alleviate the gap between semantic technologies and more traditional ones (e.g., XML, JSON, CSV, relational databases, etc.). With that in mind, providing generic transformation tools from in-use technologies to semantic technologies can enhance the migration possibilities; in other words, if we can create tools that ease the transformation and adaptation among technologies we will encourage future migrations. Although we consider that generic approaches for some of these conversions are not going to be valid in all cases, for instance small companies or low budget projects can make their point as initial or by-default transformations. Taking Text Encoding Initiative (TEI) [14] as an example, digital humanities can take benefit from Semantic Web approaches [37,35]. There are many manuscripts transcribed to XML—using TEI—that can be converted to RDF. But transcribers are hesitant to deal with the underlying technology although they can benefit from it [26]. Those are the cases where generic approaches, as the one introduced here, can offer a solution and automatic conversion of schemata has its place when transformations are to be checked.

Taking into account what we previously exposed, the questions that we want to address in the present work are the following:

- RQ1: What components should have a mapping from XML Schema to ShEx?
- RQ2: How to ensure that both schemata are equivalent?
- RQ3: Is it possible to ensure a backwards conversion in all cases?
- RQ4: Are non-deterministic schemata (i.e., ambiguous schemata) possible to translate and validate?

In this paper, we describe a solution on how to make the conversion from XML Schema to ShEx. We describe how each element in XML Schema can be translated into ShEx. Moreover, we present a prototype that can convert a subset of what is defined in the following sections.

The rest of the paper is structured as follows: Section 2 presents the background; Section 3 gives a brief introduction to ShEx; Section 4 describes a possible set of mappings between XML Schema and ShEx; Section 5 presents a prototype used to validate a subset of previously presented mappings and how this conver-

sion works against existing RDF validators; Section 6 discusses the problem of Non-Deterministic schemata and what are the implications in this work. Finally, Section 7 draws some conclusions and future lines of work and improvement.

2. Background

Migration to Semantic Web technologies is a task that has several previous works which can be divided in three main categories: conversions from XML to Semantic Web formats, conversions from XML schemata to other schemata and conversions from XML schemata to RDF schemata.

2.1. From XML to Semantic Web formats

Prior to schemata conversions, data migration has to be tackled. Therefore many authors have worked on this topic of converting from XML to Semantic Web formats and more specifically to RDF. For this conversions there are plenty of strategies that have been proposed and followed by other authors.

In [27], authors describe their experience on developing this transformation for business to business industry in the case of the Semantic Mediation tools. An XML Schema to RDF Schema transformation is performed as part of the requirement of the Semantic Mediation tool.

In [12] a transformation between XML and RDF depending on an ontology is described. This transformation takes an XML document, a mapping document and an ontology document and makes the transformations to RDF instances compliant with the input ontology. XML Schema is used to describe the mapping between it and the OWL document.

In [1], the author makes an explanation of how XML can be converted to RDF—and vice versa—using XML Schema as the base for the mappings. This work is then expanded in [2] where the author tries to solve the lift problem (the problem of how to map heterogeneous data sources in the same representational framework) from XML to RDF and backwards by using the Gloze mapping approach on top of Apache Jena.

In [40], the authors present a mechanism to query XML data as RDF. Firstly, a matching from XML Schema to RDF Schema class hierarchy is performed. Then XML elements can be interpreted as RDF triples. The same procedure but using DTDs is described in [39].

In [9], the author presents a technique for making standard transformations between XML and RDF using XSLT. A case study in the field of astronomy is used to illustrate the solution.

Another approach using XSLT is [36] where authors describe a mapping mechanism using XSLT that can be attached to schemata definition.

In [3] a transformation from RDF to other kind of formats, including XML, is proposed using embedded SPARQL into XSLT stylesheets which by means of these extensions, could query, merge and transform data from the Semantic Web.

In [6], authors describe XSPARQL which is a framework that enables the transformation between XML and RDF based on XQuery and SPARQL and solves the disadvantages of using XSLT for these transformations.

However, these works (except [27]) are not covering the schemata mapping problem.

2.2. From XML schemata to other schemata

Although data migration is important, during this process is desirable to transform the constraint rules or schemas too. This is also a way to certify that the transformations have been done correctly. Therefore, many authors have proposed different techniques and transformation from XML Schema.

In [29] a transformation from XML Schema to JSON Schema is proposed. This transformations are made using equivalent constraints when it is possible and concrete transformations when no equivalent constraints exists.

In [31] an algorithm that converts from XML Schemata to ER diagrams is proposed. This algorithm (called Xere mapping) is proposed as a part of the Xere technique to assist the integration of XML data.

In [24], the authors propose an algorithm to convert from a relational schema to an XML Schema and two algorithms to convert from a XML Schema to a relational schema. All these techniques preserve the structure and the semantics.

However, none of these works bring XML schemata to Semantic Web technologies.

2.3. From XML schemata to RDF schemata

In the Semantic Web community there has been an effort to convert XML schemata to OWL [15,34] and to RDF Schema [27]. Moreover, when no schema is

available the transformation can be performed from XML to OWL [7,21,30,23].

However, RDF Schema and OWL were not designed as RDF validation languages. Their use of Open World and Non-Unique Name Assumptions can pose some difficulties to define the integrity constraints that RDF validation languages require [38].

2.4. FHIR approach

Another approach for transformation between schemas is to take a domain model as the main representation of data structure and constraints and then transform between that model and other schema formats like XML Schema, JSON Schema or ShEx. This has been the approach followed by FHIR¹. However, this technique needs the creation of a domain model as an abstract representation which is not the goal of our work.

2.5. RDF validation languages and its conversions

Various languages have recently been developed for RDF validation. Shapes Constraint Language (SHACL) [20] has been developed by the W3C Data Shapes Working Group and Shape Expressions (ShEx) [33] is being developed by the W3C Shape Expressions Community Group.

To the best of our knowledge, no conversion between XML Schema and ShEx/SHACL has been proposed to date. This might be due to the recent introduction of ShEx and SHACL.

In this paper, ShEx is used to describe the mappings due to its compact syntax and its support for recursion whereas in SHACL recursion depends on the implementation. However, we consider that converting the mappings proposed in this paper to SHACL is feasible and can be an interesting line of future work given that it has already been accepted as a W3C recommendation and that there are some ways to simulate recursion by target declarations or property paths.

3. Brief introduction to ShEx

ShEx was proposed as a language for RDF validation in 2014 [33]. It was one of the foundations for the W3C Data Shapes Working Group which developed the Shapes Constraint Language (SHACL) for the same purpose. SHACL was also inspired by

¹<https://www.hl7.org/fhir/>

SPIN [19] and although both languages can perform RDF validation there are some differences between them like the support of recursion or the emphasis on validation versus constraint checking (see chapter 7 of [22] for more details). In this paper we will focus on ShEx because it has a well-defined semantics for recursion [8] and its semantics are more inspired by grammar-based formalisms like Relax NG.

ShEx syntax was inspired by Turtle, SPARQL and Relax NG with the aim to offer a concise and easy to use syntax. In July 2017, version 2.0 was released with a draft community group report and the community group is currently developing the 2.1 version.

ShEx uses shapes to group different validations associated with the same node 'type'. That is, a shape can define how a node and its triples should be in order to be valid. Listing 1 illustrates an example of a ShEx shape.

```
PREFIX : <http://example.com/>
PREFIX schema: <http://schema.org>
PREFIX
  xs: <http://www.w3.org/2001/XMLSchema#>

:PurchaseOrder {
  :orderId      /Order\d{2}/ ;
  schema:customer @:User ;
  schema:orderDate xs:date ? ;
  schema:orderedItem @:Item +
}
:Item {
  schema:name xs:string ;
  :quantity xs:positiveInteger OR
            xs:integer MININCLUSIVE 1
}
:User {
  a [ schema:Person ] ;
  :purchaseOrder @:PurchaseOrder*
}
```

Listing 1: ShEx shape example

Listing 1 defines a shape with a `:PurchaseOrder` type. Prefixes are defined at the beginning of the snippet and use the same similar syntax as in Turtle. Triple constraints are defined inside the shape where a purchase order must have an `orderId` of type that matches the regular expression `Order\d{2}`, it must have a `schema:customer` which must be a node that conforms to shape `:User`, a `schema:orderDate` whose value must be an `xs:date` and can have one or more (represented by the plus sign) `schema:orderedItem` whose values must conform to the `:Item` shape.

The `:Item` shape must have a `schema:name` of value string and a `schema:orderQuantity` of value `xs:positiveInteger`, while the `:User` shape declares that the values must have type `schema:Person`, and can contain zero or more values of `:purchaseOrder` which must conform to the `:PurchaseOrder` shape.

```
### Pass validation as :PurchaseOrder
:order1 :orderId      "Order23" ;
  schema:customer      :alice ;
  schema:orderDate      "2017-03-02"^^xs:date;
  schema:orderedItem    :item1 .
:alice a               schema:Person ;
        :purchaseOrder :order1 .
:item1 schema:name      "Lawn" ;
        :quantity      2 .

### Fails validation as :PurchaseOrder
:order2 :orderId      "MyOrder" ;
  schema:customer      :bob;
  schema:orderDate      2017;
  schema:orderedItem    :item1.
:bob a                 schema:Person ;
        :purchaseOrder :unknown.
```

Listing 2: RDF validation example

In Listing 2 there is an example of two purchase orders defined in RDF. The first of them passes validation and conforms to the shapes declaration whereas `:order2` fails for several reasons: the value of `:orderId` does not conform to the required regular expression, the value of `schema:customer` does not conform to shape `:User` and the value of `schema:orderDate` does not have datatype `xs:date`.

ShEx supports different serialization formats:

- ShExC: a concise human readable compact syntax which is the one presented in previous example.
- ShExJ: a JSON-LD syntax which is used as an abstract syntax in the ShEx specification [32].
- ShExR: an RDF representation syntax based on ShExJ.

ShEx defines an extension mechanism through which users can embed portions of code written in a programming language or SPARQL. This feature is known as Semantic Actions and are introduced between definition of triples with the `%interpreter{%}` syntax where `interpreter` is the name of the interpreter to be used (e.g., `js`, `sparql`, `java`, etc.). See Listings 22 and 23 for Semantic Actions examples.

In this paper ShExC syntax was used because it is easy to read and understand. The goal of this intro-

duction was to provide a basic understanding of ShEx. For more examples and a longer comparison between ShEx and SHACL readers can consult [22].

4. Mappings between XML Schema and ShEx

XML Schema defines a set of elements and datatypes for validation that need to be converted to ShEx. In this section, we describe different XML Schema elements and a possible conversion to ShEx. All examples use the default prefix `:` for URIs. It is intended to be replaced by different prefixes depending on the required namespaces. For XML Schema elements and datatypes `xs` prefix is used in the examples.

4.1. Element

Elements are treated as a triple predicate and object, i.e., we convert them to a triple constraint whose predicate is the name of the element:

```
### XML Schema
<xs:element name="birthday" type="xs:date"/>

### ShEx
:birthday xs:date ;
```

Listing 3: Element mapping

The `name` attribute is used as the fragment of the URI in the predicate and the type is transcribed directly, as ShEx has built-in support for XML Schema datatypes. If the `ref` attribute is present, the type must be defined somewhere in the document to link the corresponding type or shape. When an `xs:complexType` type is a `xs:complexType`, the type should be referenced to a new shape where the `xs:complexType` is converted (see Section 4.3 where we explain how to convert `xs:complexType` to a shape). See Listings 3, 4 and 5 for a list of examples on how to convert an element.

```
### XML Schema
<xs:element name="purchaseOrder"
  type="PurchaseOrderType"/>

<xs:complexType name="PurchaseOrderType">
  ...
</xs:complexType>

### ShEx
:purchaseOrder @<PurchaseOrderType> ;
```

Listing 4: Element mapping with linked type

```
### XML Schema
<xs:element name="item"
  minOccurs="0"
  maxOccurs="unbounded">
  <xs:complexType>
    ...
  </xs:complexType>
</xs:element>

### ShEx
:item @<item> * ;
```

Listing 5: Element mapping with nested type

4.1.1. Cardinality

Cardinality in ShEx is defined with the following symbols: `*` for 0 or more repetitions, `+` for 1 or more repetitions, `?` for 0 or 1 repetitions (optional element) or `{m, n}` for m to n repetitions where m is `minOccurs` and n `maxOccurs`. As in XML Schema, the default cardinality in ShEx is 1 for lower and upper bounds. Therefore, transformation of `minOccurs` and `maxOccurs` in the previously defined cardinality marks is done as showed in Listing 6.

```
### XML Schema
<xs:element name="nameZeroUnbounded"
  type="xs:string"
  minOccurs="0"
  maxOccurs="unbounded">
<xs:element name="nameOneUnbounded"
  type="xs:string"
  minOccurs="1"
  maxOccurs="unbounded">
<xs:element name="nameOptional"
  type="xs:string"
  minOccurs="0"
  maxOccurs="1">
<xs:element name="nameFourToTen"
  type="xs:string"
  minOccurs="4"
  maxOccurs="10">

### ShEx
:nameZeroUnbounded xs:string * ;
:nameOneUnbounded xs:string + ;
:nameOptional xs:string ? ;
:nameFourToTen xs:string {4, 10} ;
```

Listing 6: Cardinality mapping

As presented in Listing 6, when an element has its complex type nested the shape name will be the `name` of the element.

4.2. Attribute

ShEx treats attributes like elements because it makes no difference between an attribute and an element. This difference is part of XML data model whereas the RDF data model does not have the concept of attributes. One possibility to transform attributes is to use their **name** and **type** as performed with elements (see Section 4.1). This allows better readability of the corresponding RDF data, but limits roundtrip conversions between XML to RDF and back.

4.3. ComplexType

Complex types are translated directly to ShEx shapes. The **name** of the **xs:complexType** will be the name of the shape to which elements can refer to (see Listing 7 for an example). Complex types consist of various statements so we provide a detailed transformation of each possibility in the following sections.

```
### XML Schema
<xs:complexType name="PurchaseOrderType">
  ...
</xs:complexType>

### ShEx
<PurchaseOrderType> {
  ...
}
```

Listing 7: Complex type mapping

4.3.1. Sequence

While sequences in XML Schema define sequential order of elements, representing the same modeling in ShEx is complex due to RDF graph structure. There are several ways to represent order in RDF, the most obvious one is using RDF lists (c.f., other ways to represent it [13,25]).

The example in Listing 8 shows how the mapping is done for a **xs:sequence** using RDF lists:

```
### XML Schema
<xs:complexType name="Address">
  <xs:sequence>
    <xs:element name="street"
      type="xs:string"/>
    <xs:element name="city"
      type="xs:string"/>
    <xs:element name="state"
      type="xs:string"/>
    <xs:element name="zip"
      type="xs:string"/>
```

```

      type="xs:decimal"/>
    </xs:sequence>
  </xs:complexType>

### ShEx
<address> {
  rdf:first @<street> ;
  rdf:rest @<i1> ;
}
<i1> {
  rdf:first @<city> ;
  rdf:rest @<i2> ;
}
<i2> {
  rdf:first @<state> ;
  rdf:rest @<i3> ;
}
<i3> {
  rdf:first @<zip> ;
  rdf:rest [ rdf:nil ] ;
}
<street> {
  :street xs:string ;
}
<city> {
  :city xs:string ;
}
<state> {
  :state xs:string ;
}
<zip> {
  :zip xs:decimal ;
}
```

Listing 8: Sequence mapping

4.3.2. Choice

Choices in XML Schema are the disjunction operator to select between two options, for instance: choice between two elements. This operator is supported in ShEx using the *oneOf* operator ('|'). The object and predicate of the RDF statement must be one of the enclosed ones. Therefore, translation is performed as shown in the snippet of Listing 9:

```
### XML Schema
<xs:choice>
  <xs:element name="name"
    type="xs:string"/>
  <xs:all>
    <xs:element name="givenName"
      type="xs:string"
      maxOccurs="unbounded"/>
    <xs:element name="familyName"
      type="xs:string"/>
  </xs:all>
</xs:choice>
```

```

### ShEx
( :name xs:string |
  :givenName xs:string + ;
  :familyName xs:string
) ;

```

Listing 9: Choice mapping

4.3.3. All

While sequences are an ordered set of elements, **xs:all** is instead a set of unordered elements. Indeed, **xs:all** has a better representation using ShEx elements and the transformation is simpler than the **xs:sequence** one as there is no need to keep track of the order of elements. See Listing 10 for an example.

```

### XML Schema
<xs:all>
  <xs:element name="street"
    type="xs:string"/>
  <xs:element name="city"
    type="xs:string"/>
  <xs:element name="state"
    type="xs:string"/>
  <xs:element name="zip"
    type="xs:decimal"/>
</xs:all>

### ShEx
:street xs:string ;
:city xs:string ;
:state xs:string ;
:zip xs:decimal ;

```

Listing 10: All mapping

4.4. XSD Types

XSD Types can be used in ShEx as they are used on XML Schema, e.g. whenever a string type is required we can use **xs:string**. Therefore, translation is done directly using the same types that are defined in the XML Schema document.

4.4.1. Enumerations (using NMTokens)

Enumerations in XML Schema can be used to declare the possible values that an element can have. In ShEx, this is supported using the symbols '[' and ']'. The enclosed values are the possible values that the RDF object can take. See Listing 11 for an example.

```

### XML Schema
<xs:simpleType name="PublicationType">

```

```

  <xs:restriction base="xs:NMTOKEN">
    <xs:enumeration value="Book"/>
    <xs:enumeration value="Magazine"/>
    <xs:enumeration value="Journal"/>
  </xs:restriction>
</xs:simpleType>

<xs:element name="pubType"
  ref="PublicationType"/>
<xs:attribute name="country"
  type="xs:NMTOKEN"
  fixed="US"/>

### ShEx
:pubType ["Book" "Magazine" "Journal"] ;
:country ["US"] ;

```

Listing 11: Enumerations (using NMTokens) mapping

4.4.2. Pattern

Xs:pattern is used in XML Schema to define the format and allowed contents of a string value. **Xs:pattern** in ShEx uses a syntax similar to the JavaScript language except that backslash is required to be escaped, i.e., double backslash has to be used to correctly escape. Therefore, the conversion is a transformation between XML Schema and JavaScript Regular Expression syntaxes as shown in Listing 12.

```

### XML Schema
<xs:simpleType name="SKU">
  <xs:restriction base="xs:string">
    <xs:pattern value="\d{3}-[A-Z]{2}"/>
  </xs:restriction>
</xs:simpleType>
<xs:attribute name="partNum"
  type="SKU"
  use="required"/>

### ShEx
:partNum /\d{3}-[A-Z]{2}/ ;

```

Listing 12: Pattern mapping

4.5. SimpleType

Simple types in XML Schema are based on XSD Types (see Section 4.4) and allow some enhancements like: restrictions, lists and unions. Depending on the content, translation is performed following different strategies which we detail below. For translation of restrictions, see Section 4.7.

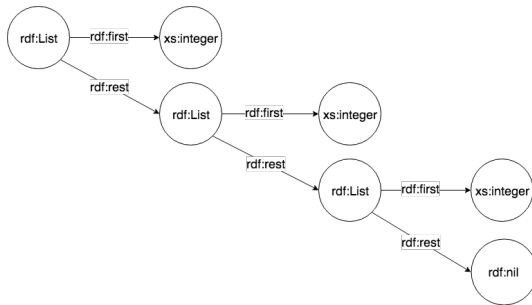


Fig. 1. Example of a RDF list construction

4.5.1. List

Lists inside simple types define a way of creating collections of a base XSD type in XML Schema. These lists are supported in RDF using RDF Collections². As previously discussed, there can be several approaches to represent ordered lists in RDF (see Section 4.3.1). A commonly accepted approach is the use of RDF lists: the **rdf:first** edge points to the first element and the **rdf:rest** edge to the rest of the list which recursively follows the same structure until the **rdf:nil** element is declared to represent the end of the list. This way, it is possible to create the desired list and preserve the order. Figure 1 shows how an RDF list is constructed for a better understanding of this section. Hence, translation into ShEx is made by using RDF lists and the use of recursion that defines a type with a pointer to itself in the **rdf:rest** edge. See Listing 13 for an example.

```

### XML Schema
<xs:simpleType name="IntegerList">
  <xs:list itemType="xs:integer" />
</xs:simpleType>

### ShEx
<IntegerList> {
  rdf:first xs:integer ;
  rdf:rest @<IntegerList> OR [rdf:nil];
}

```

Listing 13: List mapping

4.5.2. Union

Unions are the mechanism that XML Schema offers to make new types that are the combination of two simple types. With this kind of disjunction, a new type which allows any value admitted by any of the mem-

bers of the **xs:union** is created. For the translation into ShEx we create a new type that is the combination of the types involved in the **xs:union** as shown in Listing 14.

```

### XML Schema
<xs:attribute name="fontsize">
  <xs:simpleType>
    <xs:union memberTypes="fontbynumber
                          fontbystringname"
    />
  </xs:simpleType>
</xs:attribute>

<xs:simpleType name="fontbynumber">
  <xs:restriction
    base="xs:positiveInteger">
    <xs:maxInclusive value="72" />
  </xs:restriction>
</xs:simpleType>

<xs:simpleType name="fontbystringname">
  <xs:restriction base="xs:string">
    <xs:enumeration value="small" />
    <xs:enumeration value="medium" />
    <xs:enumeration value="large" />
  </xs:restriction>
</xs:simpleType>

### ShEx
:fontsize
  @<Fontbynumber> OR @<Fontbystringname>

<Fontbynumber>
  xs:positiveInteger MAXINCLUSIVE 72

<Fontbystringname> [ "small"
                    "medium"
                    "large"
                  ]

```

Listing 14: Union mapping

4.6. Complex Content and Simple Content

Complex contents and simple contents are a way to define a new type from a base type using restrictions or extensions. The base type is the one that is used as a base for the restriction (or extension) clause and the new type is the one that is been restricted (or extended). Complex content allows to extend or restrict a base **xs:complexType** with mixed content or elements only. Simple content allows to extend or restrict a **xs:complexType** with character data or with a **xs:simpleType**. For the translation into ShEx, the re-

²<https://www.w3.org/TR/rdf11-mt/#rdf-collections>

spective `xs:restriction` or `xs:extension` have to be taken into account to define the new type.

4.6.1. Restriction

Restrictions are used in XML Schema to restrict possible values of a base type. A new type can be defined using restrictions applied to a base type. Depending on how the type and the restrictions are defined, the translation strategies vary.

- Simple Content: If `xs:simpleContent` is present XSD Facets/Restrictions must be used (see Section 4.7 for more information). When restricting using a `xs:simpleType`, the transformation is done using the known base type (see Section 4.4) and putting some format restrictions to it. Translation into ShEx will be performed using the base type and translating the XSD Facets as they are defined in every specific case (see Section 4.7).
- Complex Content: If `xs:complexContent` is present, the base `xs:complexType` is restricted using `xs:group`, `xs:all`, `xs:choice`, `xs:sequence`, `xs:attributeGroup` or `xs:attribute`. Complex content restriction will restrict allowed values and elements types. This is a case of inheritance by restriction. For translation into ShEx, the `xs:restriction` elements must be taken and transformed directly into a new shape that defines the resulting child shape³.

4.6.2. Extension

With extensions in XML Schema, it is possible to define a new type as an extension of a previously defined one. This is a case of classic inheritance, where the child inherits its parent elements that are added to its own defined elements. Depending on the content, i.e., `xs:complexContent` or `xs:simpleContent`, different translation strategies can be used.

- Simple content: If `xs:simpleContent` is present extension of the base type is performed by adding more attributes or attribute groups to the new type. Therefore, the translation into ShEx is made by the concatenation of both the type and its `xs:extension` to create the new shape.
- Complex content: If `xs:complexContent` is present extension of base type is performed by adding more attributes and elements to a new base one. Therefore, translation is done by combining the

base type and its `xs:extension` to create a new shape.

Restrictions and extensions in ShEx are not supported directly in the current version (i.e., ShEx has no support for extensions, restriction or inheritance) with the same semantics as XML Schema. Therefore, we use the normal syntax provided by ShEx and create the two resulting shapes—by solving the `xs:restriction` or `xs:extension` before the translation to ShEx—from the respective `xs:restriction` or `xs:extension` as can be seen in Listing 15. However, this translation suffers from a loss of semantics—which is in line with RQ3—which makes impossible a backwards conversion.

```
### XML Schema
<xs:simpleType name="mountainBikeSize">
  <xs:restriction base="xs:string">
    <xs:enumeration value="small" />
    <xs:enumeration value="medium" />
    <xs:enumeration value="large" />
  </xs:restriction>
</xs:simpleType>

<xs:complexType name="FamilyMountainBikes">
  <xs:simpleContent>
    <xs:extension base="mountainBikeSize">
      <xs:attribute name="familyMember">
        <xs:simpleType>
          <xs:restriction base="xs:string">
            <xs:enumeration value="child" />
            <xs:enumeration value="male" />
            <xs:enumeration value="female" />
          </xs:restriction>
        </xs:simpleType>
      </xs:attribute>
    </xs:extension>
  </xs:simpleContent>
</xs:complexType>

### ShEx
<MountainBikeSize> ["small" "medium" "large"]

<FamilyMountainBikes> {
  :mountainBikeSize @<MountainBikeSize> ;
  :familyMember ["child" "male" "female"];
}
```

Listing 15: Restrictions and extensions mapping, where extensions and restrictions are directly transformed into the equivalent shape

³Future versions of ShEx are planning to include inheritance. See: <https://github.com/shexSpec/shex/issues/50>

4.7. XSD Types Restrictions/Facets

4.7.1. Enumeration

Xs:enumeration restriction uses a base type to restrict the possible values of a type. It is declared using a set of possible values. In ShEx this is defined using the '[' and ']' operators. The values that are allowed are enclosed inside the square brackets. This is the same mechanism how the example in Section 4.5.1 works. However, Listing 16 shows a more complex example using extensions and restrictions.

```
### XML Schema
<xs:simpleType name="Mountainbikesize">
  <xs:restriction base="xs:string">
    <xs:enumeration value="small"/>
    <xs:enumeration value="medium"/>
    <xs:enumeration value="large"/>
  </xs:restriction>
</xs:simpleType>

<xs:complexType
  name="FamilyMountainBikeSizes">
  <xs:simpleContent>
    <xs:extension base="mountainbikesize">
      <xs:attribute name="familyMember"
        type="xs:string" />
    </xs:extension>
  </xs:simpleContent>
</xs:complexType>

<xs:complexType
  name="ChildMountainBikeSizes">
  <xs:simpleContent>
    <xs:restriction
      base="FamilyMountainBikeSizes" >
      <xs:enumeration value="small"/>
      <xs:enumeration value="medium"/>
    </xs:restriction>
  </xs:simpleContent>
</xs:complexType>

### ShEx
<MountainBikeSize> ["small" "medium" "large"]

<FamilyMountainBikes> {
  :mountainBikeSize @<MountainBikeSize> ;
  :familyMember ["child" "male" "female"];
}

<ChildMountainBikeSizes>
  @<FamilyMountainBikes> AND {
    :mountainBikeSize ["small" "medium"]
  }
```

Listing 16: Enumeration mapping

4.7.2. Fraction digits

Xs:fractionDigits are used in XML Schema when a decimal type is defined (e.g., **xs:decimal**) and the number of decimal digits is desired to be restricted in the representation. ShEx supports this feature in a similar way as XML Schema. Hence, **FRACTIONDIGITS** keyword is used followed by the integer number of fraction digits that should be allowed. See Listing 17 for an example.

```
### XML Schema
<xs:element name="itemValue">
  <xs:simpleType>
    <xs:restriction base="xs:decimal">
      <xs:fractionDigits value="2"/>
    </xs:restriction>
  </xs:simpleType>
</xs:element>

### ShEx
:itemValue xs:decimal FRACTIONDIGITS 2 ;
```

Listing 17: Fraction digits mapping

4.7.3. Total digits

This feature allows to restrict the total number of digits permitted in a numeric type. In ShEx this is possible using **TOTALDIGITS** keyword as shown in Listing 18.

```
### XML Schema
<xs:element name="age">
  <xs:simpleType>
    <xs:restriction base="xs:integer">
      <xs:totalDigits value="3"/>
    </xs:restriction>
  </xs:simpleType>
</xs:element>

### ShEx
:age xs:integer
TOTALDIGITS 3 ;
```

Listing 18: Total digits mapping

4.7.4. Length

Xs:length is used to restrict the number of characters allowed in a string type. In ShEx this is supported with the **LENGTH** keyword followed by the integer number that defines the desired length as shown in Listing 19.

```
### XML Schema
```

```
<xs:element name="group">
  <xs:simpleType>
    <xs:restriction base="xs:string">
      <xs:length value="1"/>
    </xs:restriction>
  </xs:simpleType>
</xs:element>

### ShEx
:group xs:string LENGTH 1 ;
```

Listing 19: Length mapping

4.7.5. Max Length and Min Length

`xs:maxLength` and `xs:minLength` are used to restrict the number of characters allowed in a text type. But instead of restricting to a fixed number of characters, with these features restriction to a length interval is possible. In ShEx the definitions of minimum and maximum length are made by using the `MINLENGTH` and `MAXLENGTH` keywords as shown in Listing 20.

```
### XML Schema
<xs:element name="comments">
  <xs:simpleType>
    <xs:restriction base="xs:string">
      <xs:minLength value="1"/>
      <xs:maxLength value="1000"/>
    </xs:restriction>
  </xs:simpleType>
</xs:element>

### ShEx
:comment xs:string
  MINLENGTH 1
  MAXLENGTH 1000;
```

Listing 20: Max length and min length mapping

4.7.6. Max-min exclusive and max-min inclusive

These features allow restricting number types to an interval of desired values. This is the same notion as in open and closed intervals. In ShEx, these features are supported directly. Therefore, transformation is done as shown in Listing 21.

```
### XML Schema
<xs:element name="cores">
  <xs:simpleType>
    <xs:restriction base="xs:integer">
      <xs:minExclusive value="0"/>
      <xs:maxExclusive value="9"/>
    </xs:restriction>
  </xs:simpleType>
```

```
</xs:element>

<xs:element name="coresOpenInterval">
  <xs:simpleType>
    <xs:restriction base="xs:integer">
      <xs:minInclusive value="1"/>
      <xs:maxInclusive value="8"/>
    </xs:restriction>
  </xs:simpleType>
</xs:element>

### ShEx
:cores xs:integer
  MINEXCLUSIVE 0
  MAXEXCLUSIVE 9 ;
:coresOpenInterval xs:integer
  MININCLUSIVE 1
  MAXINCLUSIVE 8 ;
```

Listing 21: Max exclusive, min exclusive, min inclusive and max inclusive mapping

4.7.7. Whitespace

`xs:whiteSpace` allows to specify how white spaces in strings are handled. In XML Schema, there are three options:

- Preserve: This option will not remove any white space character from the given string.
- Replace: This option will replace all white space characters (line feeds, tabs, spaces and carriage returns) with spaces.
- Collapse: This option will remove all white spaces characters:
 - * Line feeds, tabs, spaces and carriage returns are replaced with spaces.
 - * Leading and trailing spaces are removed.
 - * Multiple spaces are reduced to a single space.

In ShEx, `xs:whiteSpace` options are not supported. Their behaviour could be simulated using semantic actions (see Listing 22).

```
### XML Schema
<xs:complexType name="whiteSpaces">
  <xs:all>
    <xs:element name="preserve">
      <xs:simpleType>
        <xs:restriction base="xs:string">
          <xs:whiteSpace value="preserve"/>
        </xs:restriction>
      </xs:simpleType>
    </xs:element>
    <xs:element name="replace">
      <xs:simpleType>
```

```

    <xs:restriction base="xs:string">
      <xs:whiteSpace
        value="replace"/>
    </xs:restriction>
  </xs:simpleType>
</xs:element>
<xs:element name="collapse">
  <xs:simpleType>
    <xs:restriction base="xs:string">
      <xs:whiteSpace
        value="collapse"/>
    </xs:restriction>
  </xs:simpleType>
</xs:element>
</xs:all>
</xs:complexType>

### ShEx
<whiteSpaces> {
  :preserve xs:string ;
  :replace xs:string
  %js{
    _.o.lex = _.o.lex
      .replace("/\r|\n|\r\n|\s/g", " ");
    return true;
  }
  % ;
  :collapse xs:string
  %js{
    var replacedText = _.o.lex
      .replace("/\r|\n|\r\n|\s/g", " ");
    _.o.lex = replacedText.trim();
    return true;
  }
  %
}

```

Listing 22: WhiteSpace mapping

4.7.8. Unique

xs:unique is used in XML Schema to define that an element of some type is unique, i.e., there cannot be the same values among elements defined in the rule. This is useful for cases like IDs, where a unique ID is the way to identify an element. Currently, ShEx does not support **Unique** function but it is expected to be supported in future versions⁴. As a temporal solution, semantic actions could be used to implement this kind of constraint (see Listing 23).

```

### XML Schema
<xs:element name="Person"
  maxOccurs="unbounded">

```

⁴https://www.w3.org/2001/sw/wiki/ShEx/Unique_UNIQUE

```

<xs:complexType>
  <xs:all>
    <xs:element name="name"
      type="xs:string" />
    <xs:element name="surname"
      type="xs:string" />
    <xs:element name="id"
      type="xs:integer" />
  </xs:all>
</xs:complexType>
<xs:unique name="onePersonPerID">
  <xs:selector xpath="."/>
  <xs:field xpath="id"/>
</xs:unique>
</xs:element>

### ShEx
%js{
  var ids = [];
  return true;
}
%
<Person> {
  :name xs:string ;
  :surname xs:string ;
  :id xs:integer
  %js{ if(ids.indexOf(_.o.lex) >= 0)
    return false;
    ids.push(_.o.lex);
    return true;
  }%
}

```

Listing 23: Unique mapping

5. XMLSchema2ShEx prototype

In addition to the proposed mappings from XML Schema to Shape Expressions and in order to answer RQ2 a prototype has been developed. This prototype uses a subset of the presented mappings and converts a given XML Schema input to a ShEx output.

The prototype has been developed in Scala and is available online⁵. It is a work-in-progress implementation, so not all the mappings are supported yet (see Table 1 for a list of supported features).

The tool is built on top of Scala parser combinators [28]. Once the XML Schema input is analysed and verified, it is converted to ShEx based on different elements and types declared on it. These conversions

⁵<https://github.com/herminiogg/XMLSchema2ShEx>

Table 1

Supported and pending of implementation features in XMLSchema2ShEx prototype. * Not natively supported in ShEx 2.0.

Supported features	Complex type, Simple type, All, Attributes, Restriction, Element, Max exclusive, Min exclusive, Max inclusive, Min inclusive, Enumeration, Pattern, Cardinality
Pending implementation	Choice, List, Union, Extension, Fraction Digits, Length, Max Length, Min Length, Total digits, Whitespace*, Unique*

are made recursively and printed to the output in ShEx Compact Format (ShExC).

The input XML Schema document example presented in Listing 24 is used to ensure that the prototype can work and do the transformation as expected. This example includes complex types, attributes, elements, simple types and patterns among others. Complex types are converted to shapes, elements and attributes to triple predicates and objects, restrictions (max/minExclusive and max/minInclusive) to numeric intervals, cardinality attributes to ShEx cardinality and so on. Although it is a small example, it has the structure of typical XML Schemas used nowadays and the prototype can convert it properly as it is stated in Listing 24.

```

### XML Schema
<xs:schema
  xmlns:xs="http://www.w3.org/2001/XMLSchema"
  targetNamespace="http://tempuri.org/po.xsd"
  xmlns="http://tempuri.org/po.xsd"
  elementFormDefault="qualified">

  <xs:element name="purchaseOrder"
    type="PurchaseOrderType"/>

  <xs:element name="comment"
    type="xs:string"/>

  <xs:complexType name="PurchaseOrderType">
    <xs:all>
      <xs:element name="shipTo"
        type="USAddress"/>
      <xs:element name="billTo"
        type="USAddress"/>
      <xs:element ref="comment"
        minOccurs="0"/>
      <xs:element name="items"
        type="Items"/>
    </xs:all>
    <xs:attribute name="orderDate"

```

```

      type="xs:date"/>
    </xs:complexType>

    <xs:complexType name="USAddress">
      <xs:all>
        <xs:element name="name"
          type="xs:string"/>
        <xs:element name="street"
          type="xs:string"/>
        <xs:element name="city"
          type="xs:string"/>
        <xs:element name="state"
          type="xs:string"/>
        <xs:element name="zip"
          type="xs:integer"/>
      </xs:all>
      <xs:attribute name="country"
        type="xs:NMTOKEN"
        fixed="US"/>
    </xs:complexType>

    <xs:complexType name="Items">
      <xs:all>
        <xs:element name="item"
          minOccurs="0"
          maxOccurs="unbounded">
          <xs:complexType>
            <xs:all>
              <xs:element
                name="productName"
                type="xs:string"/>
              <xs:element
                name="quantity">
                <xs:simpleType>
                  <xs:restriction
                    base="xs:positiveInteger">
                      <xs:maxExclusive
                        value="100"/>
                    </xs:restriction>
                </xs:simpleType>
              </xs:element>
              <xs:element name="USPrice"
                type="xs:decimal"/>
              <xs:element ref="comment"
                minOccurs="0"/>
              <xs:element name="shipDate"
                type="xs:date" minOccurs="0"/>
            </xs:all>
            <xs:attribute name="partNum" type="SKU"
              use="required"/>
          </xs:complexType>
        </xs:element>
      </xs:all>
    </xs:complexType>

    <xs:simpleType name="SKU">
      <xs:restriction base="xs:string">
        <xs:pattern value="\d{3}-[A-Z]{2}" />
      </xs:restriction>
    </xs:simpleType>
  </xs:schema>

```

```

### ShEx
PREFIX : <http://www.example.com/>
PREFIX
  xs: <http://www.w3.org/2001/XMLSchema#>

<Items> {
  :item          @<item> * ;
}
<item> {
  :productName  xs:string ;
  :quantity      xs:positiveInteger
                 MAXEXCLUSIVE 100 ;
  :USPrice       xs:decimal ;
  :comment       xs:string ? ;
  :shipDate      xs:date ? ;
  :partNum       /\d{3}-[A-Z]{2}/ ;
}
<PurchaseOrderType> {
  :shipTo        @<USAddress> ;
  :billTo        @<USAddress> ;
  :comment       xs:string ? ;
  :items         @<Items> ;
  :orderDate     xs:date ;
}
<USAddress> {
  :name          xs:string ;
  :street        xs:string ;
  :city          xs:string ;
  :state         xs:string ;
  :zip           xs:integer ;
  :country       ["US"] ;
}

```

Listing 24: XML Schema to ShEx example

5.1. Validation example

```

### XML
<?xml version="1.0"?>
<purchaseOrder
  xmlns="http://tempuri.org/po.xsd"
  orderDate="1999-10-20">
  <shipTo country="US">
    <name>Alice Smith</name>
    <street>123 Maple Street</street>
    <city>Mill Valley</city>
    <state>CA</state>
    <zip>90952</zip>
  </shipTo>
  <billTo country="US">
    <name>Robert Smith</name>
    <street>8 Oak Avenue</street>
    <city>Old Town</city>
    <state>PA</state>
    <zip>95819</zip>
  </billTo>

```

```

<comment>
  Hurry, my lawn is going wild!
</comment>
<items>
  <item partNum="872-AA">
    <productName>
      Lawnmower
    </productName>
    <quantity>1</quantity>
    <USPrice>148.95</USPrice>
    <comment>
      Confirm this is electric
    </comment>
  </item>
  <item partNum="926-AA">
    <productName>
      Baby Monitor
    </productName>
    <quantity>1</quantity>
    <USPrice>39.98</USPrice>
    <shipDate>1999-05-21</shipDate>
  </item>
</items>
</purchaseOrder>

### RDF
:order1
  :shipTo [
    :name "Alice Smith" ;
    :street "123 Maple Street" ;
    :city "Mill Valley" ;
    :state "CA" ;
    :zip 90952 ;
    :country "US"
  ] ;
  :billTo [
    :name "Robert Smith" ;
    :street "8 Oak Avenue" ;
    :city "Old Town" ;
    :state "PA" ;
    :zip 95819 ;
    :country "US"
  ] ;
  :comment "Hurry, my lawn is going wild!";
  :items [
    :item [
      :productName "Lawnmower" ;
      :quantity "1"^^xs:positiveInteger ;
      :USPrice 148.95 ;
      :comment "Confirm this is electric";
      :partNum "872-AA"
    ] ;
    :item [
      :productName "Baby Monitor" ;
      :quantity "1"^^xs:positiveInteger ;
      :USPrice 39.98 ;
      :shipDate "1999-05-21"^^xs:date ;
      :partNum "926-AA"
    ] ;
  ] ;
  :orderDate "1999-10-20"^^xs:date .

```

Listing 25: XML to RDF example

Once conversion from XML Schema to ShEx is done, it must be verified that the same validation that was performed on XML data using XML Schema, but now on RDF data using ShEx, is working equivalently. The translation of a valid XML to RDF is executed which is presented in Listing 25. The conversion presented in the snippet uses blank nodes to represent the nested types. This is done to avoid creating a fictitious node every time a triple is pointing to another triple (in other words, every time it has a nested type). The conversion was performed following similar equivalences to those proposed in the mappings. That is, complex types to triple subjects or predicates, simple types to triple objects, cardinality translated directly and so on.

For RDF validation using ShEx there are various implementations in different programming languages that are being developed⁶. One of these implementations is made in Scala by one of the authors of this paper and it is available online⁷.

Using the examples given above the validation can be performed with the mentioned tool which allows the RDF and the ShEx inputs in various formats and then the option to validate the RDF against ShEx or SHACL schema. As seen in Figure 2, validation is performed trying to match the shapes with the existing graphs, whenever the tool matches a pattern it shows the evidence in green and a short explanation of why this graph has matched.

6. Non-Deterministic schemata

There is an issue that arises in XML Schema documents that should be solved when proposing a transformation from XML Schema. This is the topic of Non-Deterministic schemata where the parser is unable to determine the sequence to validate due to the Unique Particle Attribution. This issue appears, for example, in a choice between two sequences that begin with the same element. This event can be formulated with the regular expression: $(ab \mid ac)$ and in XML Schema as shown in Listing 26.

```
### XML Schema
<xs:complexType name="nondeterministic">
  <xs:choice>
    <xs:sequence>
      <xs:element name="a"/>
      <xs:element name="b"/>
    </xs:sequence>
    <xs:sequence>
      <xs:element name="a"/>
      <xs:element name="c"/>
    </xs:sequence>
  </xs:choice>
</xs:complexType>

### ShEx
<nondeterministic> {
  a @<ab> OR @<ac> ;
}

<ab> {
  rdf:first @<a> ;
  rdf:rest @<ab1> ;
}

<ac> {
  rdf:first @<a> ;
  rdf:rest @<ac1> ;
}

<ab1> {
  rdf:first @<b> ;
  rdf:rest [rdf:nil] ;
}

<ac1> {
  rdf:first @<c> ;
  rdf:rest [rdf:nil] ;
}

<a> {
  :namea xs:string ;
}

<b> {
  :nameb xs:string ;
}

<c> {
  :namec xs:string ;
}
```

Listing 26: Non-Deterministic schema and its ShEx counterpart

These sequences are translated as shown in Section 4.3.1 and the final result can be seen in Listing 26. The question is that if this non-determinism is also transferred to the converted schemata. In order to check the

⁶A list of ShEx implementations is available at: <https://shex.io>

⁷<http://shaclex.herokuapp.com>

Shaclex
RDF Data
Schema
Validation
SPARQL
API
About

Node	Shape	Evidence
<code>_:ecc82efbdc291b1236cf805dfa21364d</code>	<code>+<USAddress></code>	CA has datatype xsd:string Mall Valley has datatype xsd:string Alice Smith has datatype xsd:string 123 Maple Street has datatype xsd:string US == "US" 90952 has datatype xsd:integer
<code>_:8ca570fbfb3fae8e94e55128803cd88e8</code>	<code>+<item></code>	926-AA satisfies Pattern(\d{3}-[A-Z]{2}) with lexical form 926-AA 1999-05-21 has datatype xsd:date Baby Monitor has datatype xsd:string 1 has datatype xsd:positiveInteger 1 satisfies MaxExclusive(NumericInt(100)) 39.98 has datatype xsd:decimal
<code>:order1</code>	<code>+<PurchaseOrderType></code>	Hurry, my lawn is going wild! has datatype xsd:string 1999-10-20 has datatype xsd:date
<code>_:1e85813875f8a76cfe00f524180b5923</code>	<code>+<item></code>	Confirm this is electric has datatype xsd:string 872-AA satisfies Pattern(\d{3}-[A-Z]{2}) with lexical form 872-AA 1 has datatype xsd:positiveInteger 1 satisfies MaxExclusive(NumericInt(100)) 148.95 has datatype xsd:decimal Lawnmower has datatype xsd:string
<code>_:86be1fb2430ea549618c583a1cd74133</code>	<code>+<USAddress></code>	Old Town has datatype xsd:string 95819 has datatype xsd:integer Robert Smith has datatype xsd:string US == "US" PA has datatype xsd:string 8 Oak Avenue has datatype xsd:string
<code>_:f8eb142cdb9adbce809df073d1bfcaa3</code>	<code>+<Items></code>	

► Detalles

Schema Engine (current: ShEx) ShEx Schema embedded: ☐

RDF Data

By input
By URL
By File
By Endpoint

```

1 PREFIX : <http://www.example.com/>
2 PREFIX xsd: <http://www.w3.org/2001/XMLSchema#>
3
4 :order1 :shipTo {
5     :name "Alice Smith" ;
6     :street "123 Maple Street" ;
7     :city "Mall Valley" ;
8     :state "CA" ;
9     :zip 90952 ;
10    :country "US"
11  } ;
12  :order1 :billTo {
13    :name "Robert Smith" ;
14    :street "8 Oak Avenue" ;
15    :city "Old Town" ;
16    :state "PA" ;
17    :zip 95819 ;
18    :country "US"
19  } ;
20  :comment "Hurry, my lawn is going wild!" ;
21  :items {
22    :item {
23      :productName "Lawnmower" ;
24      :quantity "1"^^xsd:positiveInteger ;
25      :USPrice 148.95 ;
26      :comment "Confirm this is electric" ;
27      :partNum "872-AA"
28    } ;
29    :item {
30      :productName "Baby Monitor" ;
31      :quantity "1"^^xsd:positiveInteger ;
32      :USPrice 39.98 ;
33      :shipDate "1999-05-21"^^xsd:date ;

```

Data Format TURTLE

Schema

By input
By URL
By File

```

1 PREFIX : <http://www.example.com/>
2 PREFIX xsd: <http://www.w3.org/2001/XMLSchema#>
3
4 <Items> {
5   :item @<item> * ;
6 }
7 <item> {
8   :productName xsd:string ;
9   :quantity xsd:positiveInteger MAXEXCLUSIVE 100 ;
10  :USPrice xsd:decimal ;
11  :comment xsd:string ? ;
12  :shipDate xsd:date ? ;
13  :partNum /\d{3}-[A-Z]{2}/ ;
14 }
15 <PurchaseOrderType> {
16   :shipTo @<USAddress> ;
17   :billTo @<USAddress> ;
18   :comment xsd:string ? ;
19   :items @<Items> ;
20   :orderDate xsd:date ;
21 }
22 <USAddress> {
23   :name xsd:string ;
24   :street xsd:string ;
25   :city xsd:string ;
26   :state xsd:string ;
27   :zip xsd:integer ;
28   :country ["US"] ;
29 }

```

Schema Format ShExC

Inference before
Mode NONE
Trigger mode
Mode ShapeMap
Shape map
By input
By URL
By File

```

1 :order1@<PurchaseOrderType>

```

Shape map format COMPACT

permalink

Other options
Editor theme: Eclipse

Fig. 2. Validation result using Shaclex validator. The RDF data is entered in the left text area whereas the ShEx schema is entered on the right text area. In the bottom, a ShapeMap is declared to make the validator know where and how to begin the validation, in this case we commanded to validate `:order1` node with `<PurchaseOrderType>` shape. In the top of the page, the result is shown detailing how each node was validated and what are the evidences or failures for the validation. A link to the validation example can be found in Supplementary Material.

actual behaviour we have run this example on Shaclex validator which shows that the validation is performed correctly (see Figure 3).

This behaviour is motivated by two things: firstly, the structure of RDF lists is different from XML Schema sequences which makes the validation to be performed in a different form; consequently, the validation in ShEx is performed recursively trying to match shape by shape. Therefore, if an element match with a shape this will scale up into the recursion tree without creating ambiguity problems.

7. Conclusions and Future work

In this work, a possible set of mappings between XML Schema and ShEx has been presented. With this set of mappings, automation of XML Schema conversions to ShEx is a new possibility for schema translation which is demonstrated by the prototype that has been developed and presented in this paper. Using an existing validator helped to demonstrate that an XML and its corresponding XML Schema are still valid when they are converted to RDF and ShEx.

One future line of work that should be tackled is the loss of semantics: with this kind of transformations some of the elements could not be converted back to their XML Schema origin. Nevertheless, it is a difficult problem due to the difference between ShEx and XML data models and it would involve some sort of modifications and additions to the ShEx semantics (like previously mentioned inheritance).

To cover more business cases and make this solution more compatible with existing systems, there is the need to create mappings for Schematron and Relax NG as a future work. Relax NG is grammar-based but Schematron is rule based, which will make conversion from Relax NG to ShEx more straightforward than from Schematron to ShEx, as ShEx is also grammar-based. Another line of future work is to adapt the presented mappings to SHACL: most of the mappings follow a similar structure. Moreover, the rule-based Schematron conversion seems more feasible using the advanced SHACL-SPARQL features which allow to expand the core SHACL language by using SPARQL queries to validate complex constraints.

With the present work, validation of existing transformations between XML and RDF is now possible and convenient. This kind of validations makes the transformed data more reliable and trustworthy and it

also facilitates migrations from non-semantic data formats to semantic data formats.

Conversions from other formats (such as JSON Schema, DDL, CSV Schema, etc.) will also be investigated to permit an improvement of data interoperability by reducing the technological gap.

Acknowledgments

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Shaclex
RDF Data
Schema
Validation
SPARQL
API
About

Node	Shape	Evidence
:nondeterministic2	+<nondeterministic>	_:4e268a43-570b-4f05-932a-29a16ed79898 passes OR
_:55d6e66e-bbbb-4694-bea9-d892699dc102	+<ac1>	rdf:nil == rdf:nil
:nondeterministic1	+<nondeterministic>	_:677b25f0-363d-4ae8-b030-f0a30309076b passes OR
:a	+<a>	a has datatype xs:string a has datatype xs:string
_:677b25f0-363d-4ae8-b030-f0a30309076b	+<ab>	
:b	+	b has datatype xs:string
_:4e268a43-570b-4f05-932a-29a16ed79898	+<ac>	
_:6bed528f-adad-4ff1-83a5-4442d454ee9a	+<abl>	rdf:nil == rdf:nil
:c	+<c>	c has datatype xs:string

► Detalles

Schema Engine (current: ShEx) ShEx Schema embedded: ☐

RDF Data

By input
By URL
By File
By Endpoint

```

1 @prefix : <http://www.example.com> .
2 @prefix rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#> .
3
4 :c :namec "c" .
5
6 :nondeterministic1 a ( :a :b ) .
7
8 :a :namea "a" .
9
10 :nondeterministic2 a ( :a :c ) .
11
12 :b :nameb "b" .
13

```

Data Format
TURTLE

Schema

By input
By URL
By File

```

1 PREFIX rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
2 PREFIX xs: <http://www.w3.org/2001/XMLSchema#>
3 PREFIX : <http://www.example.com>
4
5 <nondeterministic> {
6   a <ab> OR <ac> ;
7 }
8
9 <ab> {
10   rdf:first <a> ;
11   rdf:rest <abl> ;
12 }
13
14 <ac> {
15   rdf:first <a> ;
16   rdf:rest <ac1> ;
17 }
18
19 <abl> {
20   rdf:first <b> ;
21   rdf:rest [rdf:nil] ;
22 }
23
24 <ac1> {
25   rdf:first <c> ;
26   rdf:rest [rdf:nil] ;
27 }
28
29 <a> {
30   :namea xs:string ;
31 }
32
33 <b> {

```

Schema Format
ShExC

Inference before
Mode
NONE

Trigger mode
Mode
ShapeMap

Shape map

By input
By URL
By File

```

1 :nondeterministic1<nondeterministic>,:nondeterministic2<nondeterministic>

```

Shape map format
COMPACT

permalink

Other options

Editor theme:
Eclipse

Fig. 3. Validation result using Shaclex validator of a ShEx schema converted from a non-deterministic XML Schema document. In the Shape map input area text we have indicated to Shaclex validator to check if :nondeterministic1 and :nondeterministic2 hold the form of shape <nondeterministic>. In the top of the page the satisfactory result is shown in green.

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Answers to Emir Muñoz

First of all, we would like to thank the reviewer for this second review. We think that this review has contributed to polish some of the paper open issues and to make a better version of it.

We have rewritten and reorganised the related work section. We opted to categorise the related work to discuss category by category which are the advances and limitations of them in comparison with our goal.

We have also added references to research questions along the sections to discuss the reached conclusions. Section 6 is a new one that tackles directly with the RQ4. We have also changed the research questions to be more specific with the goals of this present work.

In the next points, we answer the reviewer's comments:

Abstract

1. We changed the sentence to "These transformations and mappings between different technologies have an economical and technological impact on society". This is more accurate because the change to new platforms drives to a cost in technology adoption and migration and therefore in an economical cost (human and time cost which is, most of the time, translated to economical cost).
2. Corrected

Section 1

1. Changed
2. We meant confidence. We changed reliance for confidence.
3. For this context, we have defined normalisation as using a homogeneous schema or structure across different sources of similar information. This definition was included at the very beginning of the introduction but without interfering with the already present writing.
4. Changed
5. There was no comma after "than DTDs".
6. Changed
7. Changed
8. Added
9. We changed the sentence and added some context. Result: "In the Semantic Web, RDF lacked a standard schema language which cover the same features that XML Schema does for XML."
10. It stands for OWL 2.0, the reference to OWL [17] was included.
11. Added a reference to RDF Schema.
12. Changed
13. Changed
14. We moved the reference to SHACL specification next to SHACL mention, moreover we added a clarification of what SHACL is.

15. Changed
16. Changed
17. Changed
18. Changed
19. We simplified the sentence and removed the how-to questions.
20. Added
21. We changed the sentence for this one: "With that in mind, providing generic transformation tools from in-use technologies to semantic technologies can enhance the migration possibilities; in other words, if we can create tools that ease the transformation and adaptation among technologies we will encourage future migrations." which is more accurate and explanatory.
22. Changed
23. Changed
24. TEI (Text Encoding Initiative) is a standard for the representation of texts in XML and it is used in digital humanities to represent manuscripts (among other kind of texts). In this case, we are referring to TEI as a case study where if this tool can convert the XML Schema to ShEx and then XML is converted to RDF (with other existing tools) we will be contributing to the migration of this knowledge to semantic technologies and all will be validated like it was before.
25. Changed
26. Changed
27. Changed
28. We removed the therefore as it is not a conclusion.
29. We were referring to the exposition made in the introduction. Therefore, we changed "With that problem in mind" for "Taking into account what we previously exposed".
30. We changed the RQ1 for the one you proposed.
31. We stated our research questions more clearly and we mention our conclusions in the sections 5, 6 and 7.
32. We changed RQ2 and RQ3 because a part of RQ3 was indeed saying the same as RQ2. Now RQ3 is different from RQ2.
33. Changed
34. Changed
35. Changed
36. We refer to a possible set of mappings because this is our solution but other authors can propose other sets of mappings that are valid and different from our ones.

Section 2

1. Changed 'field' for 'task' and rephrased.
2. We categorised the related work in different approaches and we pointed out what things they lack from our work objective.
3. Changed
4. Changed
5. In our opinion, retrieve is very general for getting data and query suppose filtering data and more complex transformations. However, retrieve is a subpart of query so we omitted retrieve from the sentence.

6. Removed because of reorganisation in this section.
7. Changed

Section 3

1. Changed
2. Changed
3. Changed

Section 4

1. Changed
2. Referenced 5, also 3 and 4.
3. Changed
4. Changed
5. Changed for “in the following sections”.
6. Reference included.
7. Changed
8. Solved by the previous one.
9. Changed
10. Reference included
11. Reference included
12. Reference included
13. Reference included
14. Changed
15. Reference included
16. Solved. However, it can change (without much control) because of Latex content distribution.
17. Changed
18. Reference included
19. Reference included
20. Reference included
21. Reference included
22. Reference included
23. Reference included
24. It is implemented using the XPath query “.”. However, if another XPath query is used it can be translated using the same strategy shown in the example. The only thing to consider is where to put the semantic action that is indicated by the XPath query. So, it is not a local assumption it is just a local example.
25. Changed and footnote with link to the Wiki issue of UNIQUE included.
26. Reference included

Section 5

1. Changed
2. Changed
3. Changed
4. Removed
5. Changed
6. Changed

7. Changed

Section 6

1. We made some more research of ambiguity problems in XML Schema and what are the implications in our proposed transformation. This topic is now described in the new Section 6.
2. We added a little explanation on the same sentence. SHACL-SPARQL features allow to expand the core language by using SPARQL queries to make complex constraints.

References

1. Added
2. We added an URL for 18, a source for 21 and the venue for 29.
3. Changed

We hope that this review could reach and solve reviewer's concerns. We are looking forward to hearing from him.

Best Regards,
Herminio García-González
José Emilio Labra-Gayo

Answers to Simon Steyskal

First of all, we would like to thank the reviewer for this second review. We think that this review has contributed to polish some of the paper open issues and to make a better version of it.

We have changed pompous statements and made them more relaxed or directly removed them. We have linked all Listings with the text. About the xs or xsd prefix, we have opted to use xs along the whole paper and now the consistency has improved.

We have also added references to research questions along the sections to discuss the reached conclusions. Section 6 is a new one that tackles directly with the RQ4. We rewrote RQ4 to deal with the non-deterministic schemata which was the reason for that research question. We have also changed the research questions to be more specific with the goals of this present work.

We have thought about the recap of the RQs. However, we opted to make a mention about the RQ in discussion when it is not clear. In addition, the RQs are now clearer and, in the conclusions, they can be followed up clearly. With that in mind RQ1 is approached in Section 4, RQ2 in Section 5, RQ3 is discussed in Section 4 and Section 7 and RQ4 in Section 6. However, if the reviewer see that this recap is going to improve the manuscript we can add it.

In the next points, we answer the reviewer's comments in the handwritten scan of the manuscript:

Abstract

- We removed new from the first sentence of the abstract. Indeed, it is not a new topic.
- We also rephrased the first sentence.
- On the other hand -> Besides
- Come at a price -> have an economical and technological impact on society.
- One of the recent RDF validation languages -> a validation language for RDF
- To a new era of semantic-aware and interoperable data -> to an improvement of data interoperability due to the reduction of the technological gap.

Section 1

- Trustworthy -> reliable (It is more reliable because patterns are normalized and therefore data consuming is easier.)
- Predictable -> standardised
- Querying and standardisation -> querying and standardization of datasets
- Reference moved up
- And with more features -> with more expressiveness
- Documentation -> We are referring to documentation because many tools can generate documentation from an XML Schema.

- Alongside the appearance of DTDs and XML Schema -> Besides DTD and XML Schema.
- Other alternatives for XML validation (whole sentence rephrased).
- Lacked -> was missing
- A standard schema -> a standard constraints validation.
- Does with -> does for
- Validation language -> standard constraints validation language
- Before -> ever
- Semantic Web technologies -> Semantic Web
- A lacking process when converting XML to RDF is validation -> means for validating the output data after converting XML to RDF are missing
- We say in Section 2 that to the far of our knowledge no other similar conversion was proposed.
- Are defining the same type -> are defining the same meaning.
- And more traditional ones -> and more traditional ones (e.g., XML, JSON, CSV, relational databases, etc.).
- Can take the benefit of -> can take benefit from
- Are not going to deal -> are hesitant to deal
- Can offer a solution and, therefore, automatic conversion -> can offer a solution and automatic conversion
- Space -> place
- The four Research Questions have been rephrased to be more concise and different from the other ones.

Section 2

- Conversion to Semantic Web technologies is a field that presents several previous works. -> Migration to Semantic Web technologies is a task that has several previous works.
- Many conversions to RDF —and backwards— -> many conversions from/to
- Is also a key question [12] -> is also a key question (c.f., [12])
- a domain model as the main representation -> a domain model as the main representation of data structure and constraints
- In this paper, a transformation... (Removed)

Section 3

- W3C data shapes working group -> W3C Data Shapes Working Group
- Vs -> versus
- It is not an attribute that is desirable by itself. But, for demonstration purposes, it has a more concise syntax which make examples shorter and more understandable.
- RelaxNG -> Relax NG
- Working group -> community group
- In Listing 1 there is an example -> Listing 1 illustrates an example
- orderId (formatted)
- xsd:date -> xs:date
- Added a reference to ShEx specification

- Indeed, ShExR is the JSON-LD interpretation of ShExJ in RDF representation.
- Was selected -> was used
- Because it is intended for humans and it is more easy to read -> because it is easy to read
- Technologies (removed)

Section 4

- Doing the (removed)
- And what a possible conversion to ShEx can be -> and a possible conversion to ShEx.
- Reference included for Listing 3
- There is a direct match between them (removed)
- With ref no further restrictions are needed. The referenced element should appear somewhere in the paper but there are no other restrictions for ref attribute.
- Reference included for Listing 4.
- Reference included for Listing 5.
- Whole first paragraph of attribute section rephrased.
- Complex types can be compound of different statements -> Complex types consist of various statements
- Reference included for Listing 7.
- In ShEx this is more complex due to the RDF graph structure -> representing the same modeling in ShEx is complex due to RDF graph structure
- The most obvious is using -> the most obvious one is using
- However, this is one of the possible ways of doing that and there can be other ways to represent it [9,18] -> (c.f., other ways to represent it [9, 18])
- Sequence -> xs:sequence
- The following examples shows how the mapping is done for a -> The example in Listing 8 shows how the mapping is done for a
- [rdf:nil] In fact this is ShEx specific and this is used because rdf:nil is not interpreted like a datatype like the case of xsd datatypes. In this case, it is just a value. So in order to tell to ShEx validator that one possible value is rdf:nil we enclose rdf:nil into '[' and ']' which is the operator for a list of possible values.
- In RDF the list can be, indeed, modeled like a list of BN. For example, see Figure 3 in the new Section 6.
- In Listing 9 we changed sequence for all for the simplicity of the example.
- Reference for Listing 9 included.
- All -> xs:all
- Reference for Listing 10 included.
- XSDTypes -> XSD Types
- Can be used on ShEx -> can be used in ShEx
- Is desired -> is required
- NMTokens is a type for string data and it is used for enumerations. We included in the Section title and in the Listing caption the clarification: "(using NMTokens)"
- Reference for Listing 11 included.

- Pattern is used in XML Schema to define how a string value should be or what type of format is allowed -> Pattern is used in XML Schema to define the format and allowed contents of a string value.
- Double backslash has to be used to be correctly escaped -> double backslash has to be used to correctly escape
- Reference for Listing 12 included.
- In -> on
- Translation into ShEx (removed)
- Following a different criteria -> following different strategies
- Bellow -> below
- An edge point to the first element and another to the rest of the list -> the rdf:first edge points to the first element and the rdf:rest to the rest of the list
- In this way -> This way
- Reference for Listing 13 included.
- Figure 1 font resized and prefixes included.
- Union -> combination
- ComplexContent and SimpleContent -> Complex Content and Simple Content
- And putting some formats restrictions depending on the base type -> and putting some format restrictions to it.
- —ShEx supports the built-in XSD Types defined for XML Schema, therefore translation is done directly— (removed)
- specific case, see Section 4.7 -> specific case (see Section 4.7)
- will restrict allowable values and element type restrictions -> will restrict allowed values and elements types.
- Yes, it is not supported by ShEx and we are proposing a conversion which firstly solves the restriction or extension and then translate the resulting type to ShEx. It is a way to make the translation possible but it leads to a loss of information which we comment in the conclusions section. We have included a better explanation of this process and a note to the loss of information.
- Shapes with : shape guards changed.
- 4.7.1 and 4.4.1 are different examples for the same thing but 4.7.1 is a more complex one due to the introduction of simpleContent once they are explained. We added a bit explanation linking to Section 4.4.1 and what is the difference in the Listing.
- Reference for Listing 17 included.
- Reference for Listing 18 included.
- xs:length is now in bold.
- Maximum and minimum length -> MaxLength and minLength
- xs:minLength and xs:maxLength are now in bold
- Reference for Listing 19 included.
- Allow to restrict -> allow restricting
- Exclusive restrict the use of the given value and inclusive does not restrict the use of given value (removed)
- Reference for Listing 20 included.
- Reference for Listing 21 included.
- xs:totalDigits is now in bold.

- Section 4.7.6 moved up to 4.7.3
- White spaces on strings -> white spaces in strings
- We added a little explanation about Semantic Actions at the end of the Section 3.
- xs:whiteSpace and xs:unique are now in bold (The bold it is not just bold is syntax highlighting so we opted to add the forgotten one to the keywords list to be highlighted).
- Constraint -> rule
- Nowadays -> Currently

Section 5

- For the sake of hypothesis demonstration -> in order to answer RQ2
- And it is available -> and is available
- See Table 1 -> See Table 1 for a list of supported features
- Not supported in ShEx 2.0 -> Not natively supported in ShEx 2.0
- Indentation fixed
- In the snippet is a possible one that uses -> in the snippet uses
- This is done for avoiding to creating a fictional node every time -> This is done to avoid creating a fictitious node

Section 6

- Is a new possibility -> is a new possibility for schema translation
- Like the inheritance case -> like previously mentioned inheritance
- To cover all the business cases -> to cover more business cases
- Make this solution more compatible -> make this solution more compatible with existing systems
- This future line should be tackled... (Removed sentence)
- Grammar based -> grammar-based
- Is also based in grammar -> is also grammar-based
- Plausible -> feasible
- From Schematron -> from Schematron to ShEx
- SHACL-sparql -> SHACL-SPARQL
- Removed redundant paragraph
- However, a big path should be travelled (removed)
- Should -> will
- Treated -> investigated
- Encouraged (removed)
- To permit a migration to a new set of semantic-aware and interoperable data.
-> to permit an improvement of data interoperability by reducing the technological gap.

We hope that this review could reach and solve reviewer's concerns. We are looking forward to hearing from him.

Best Regards,
Herminio García-González
José Emilio Labra-Gayo