Utilizing new capabilities of XML languages to verify OCL constraints

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Aim & Outline

- Aim: Automatically generate Schematron schemas verifying integrity constraints

- Outline
  - Modeling XSDs with UML
    - (is someone offended already?)
  - Introduction of OCL
  - Translation of OCL to Schematron
  - OCL + XPath/XSLT 3.0 ⇒ *OclX*
  - Optimizing/simplifying expressions

Modeling XSDs with UML

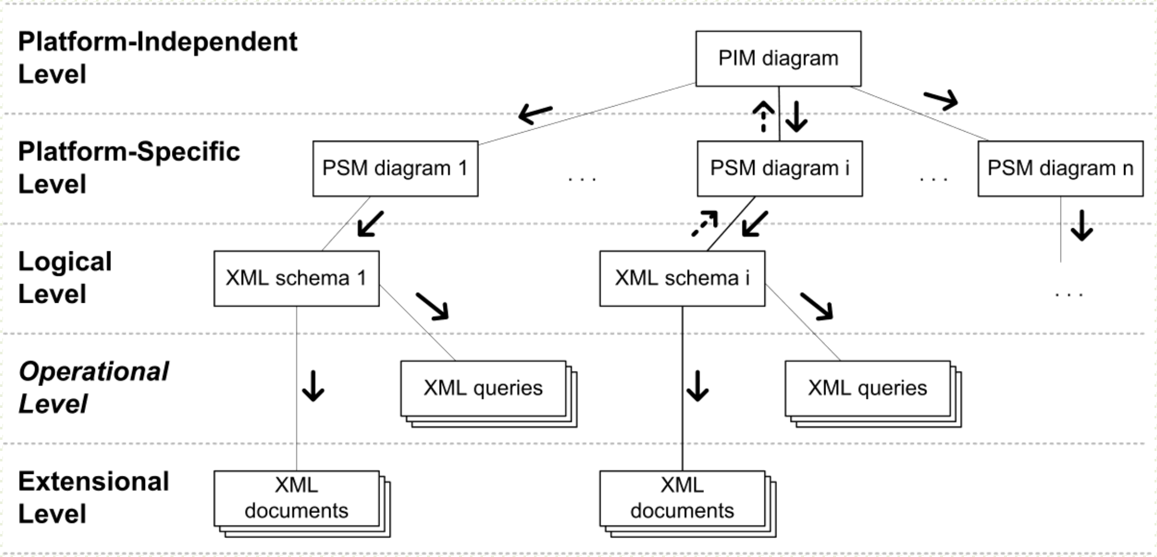
- UML works well for objects
  - less well for documents
  - but when XML represents objects…
- Even for “data-oriented” XSDs, another layer is needed
  - One concept (class) has different representations in different schemas

PIM & PSM

- Main idea:

1 PIM schema: N PSM schemas

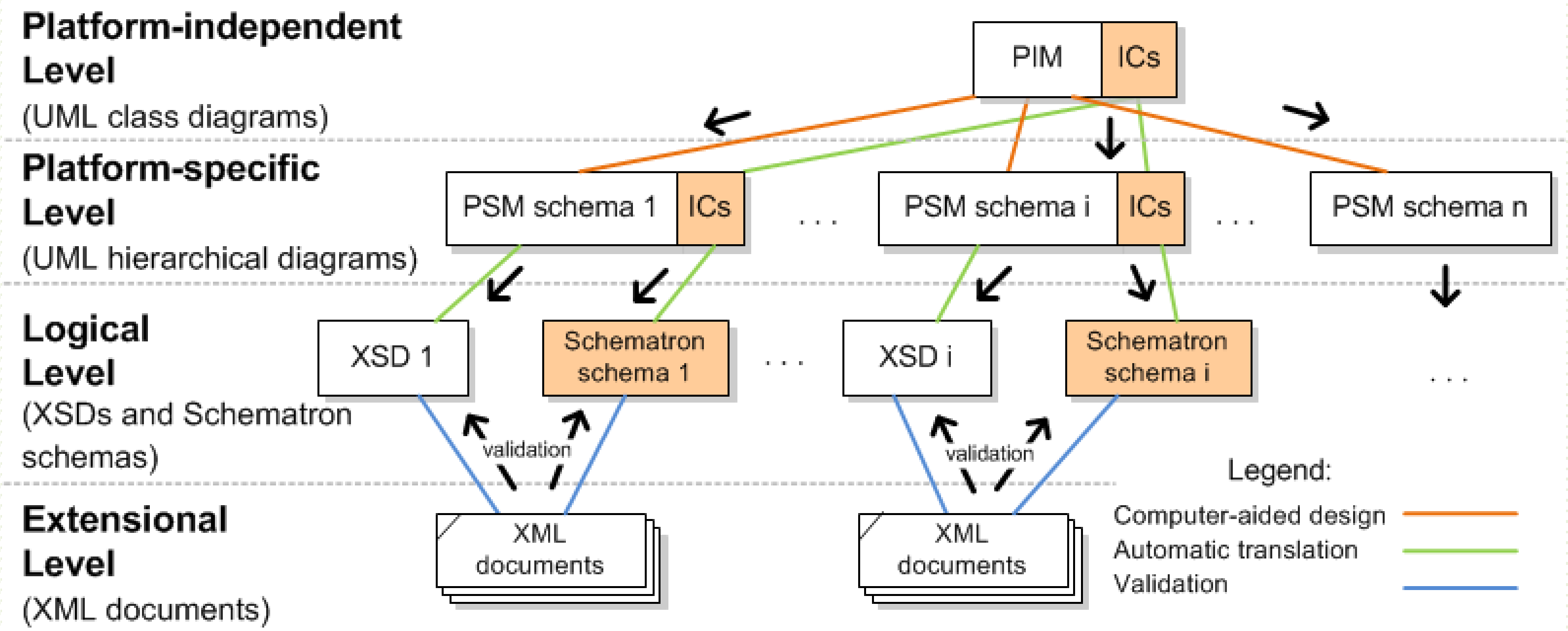
- **PIM** keeps the model coherent
  - and can be mapped to other platforms (other PSMs), such as Java classes, SQL DB schema, OWL ont.
- **PSM** offers regular tree grammar capabilities
  - and can be translated to XML schemas automatically



DEMO

Extension of the Model – Integrity Constraints

- Some properties can not be described only by diagrams
  - Formal language allowing expressions over data is required
  - **UML uses OCL, XML uses XPath/Schematron**



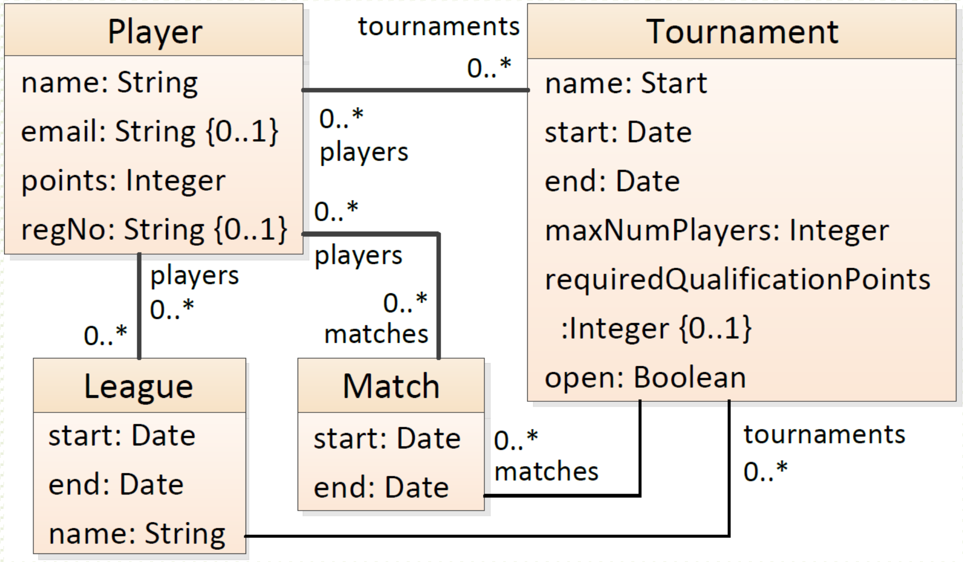
OCL – Introduction

- OCL is a fusion of
  - mathematical notation
  - functional language (restricted)
  - expression language
  - query language
- Expressions contain
  - variables, standard arithmetic and bool algebra, conditional expressions
  - primitive types, collections, tuples, **concepts from the UML model**
  - predefined operations (string handling, collection operations etc.)
  - iterator expressions, e.g.:

```
people->select(p | p.age > 21) … /* filtering */
if (numbers->forAll(j | j mod 2 = 0)) then … else … /* quantification */
departments->collect(d | d.employee) /* mapping */
```

OCL – Example/Introduction

- OCL – formal language of logical expressions over UML model
  - where classes and associations do not describe all required properties
  - improves accuracy
  - **platform independent**
  - **can be used to generate code**



Player
name: String
email: String {0..1}
points: Integer
regNo: String {0..1}

Tournament
name: Start
start: Date
end: Date
maxNumPlayers: Integer
requiredQualificationPoints :Integer {0..1}
open: Boolean

League
start: Date
end: Date
name: String

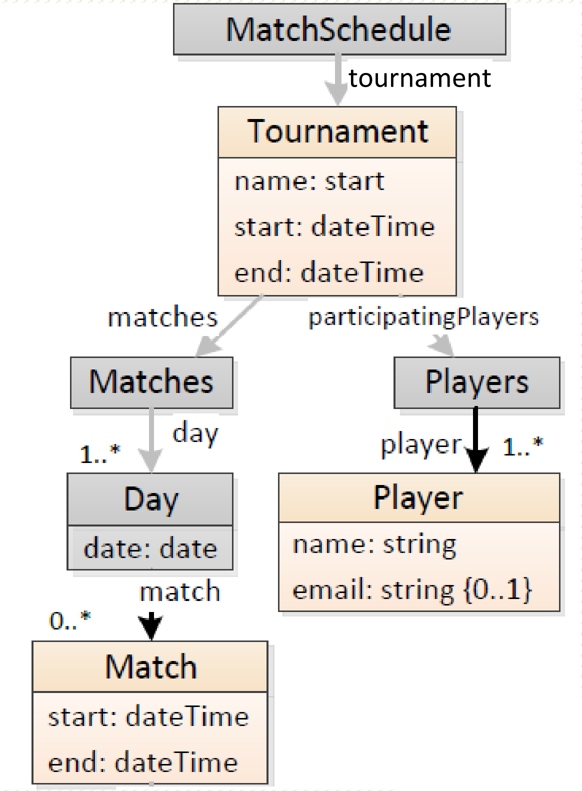
Match
start: Date
end: Date

```
context t:Tournament
/* PIM1: dates consistency */
inv: t.start <= t.end


/* PIM2: all Matches within
the Tournaments time frame */
inv: t.matches->forAll(m |
 m.start > t.start and m.end < t.end)
```

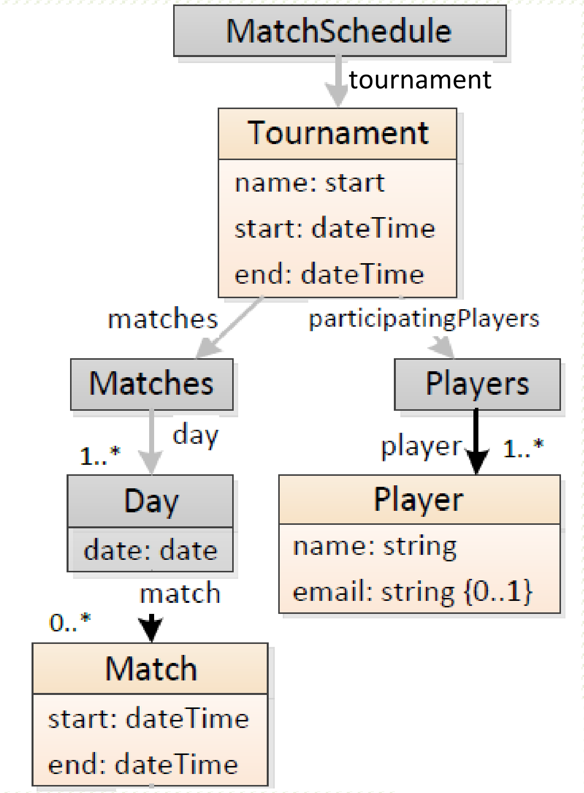
∀m ∈ t.matches : m.start > t.start …

PSM OCL Example with Sample Data



```
<tournament>
  <name>dictum</name>
  <start>2012-01-01T09:00:00</start>
  <end>2012-01-03T18:00:00</end>
  <matches>
    <day>
      <date>2012-01-01</date>
      <match>
        <start>2012-01-01T09:00:00</start>
        <end>2012-01-01T10:30:00</end>
      </match>
      ...
    </day>
    ...
  </matches>
  <participatingPlayers>
    <player>
      <name>John Smith</name>
      <email>smith@domain.org</email>
    </player>
    ...
  </participatingPlayers>
</tournament>
```

PSM OCL Example with Constraints



- 2 PSM OCL constraints

```
context t:Tournament
/* PSM1: dates consistency */
inv: start <= end
/* PSM2: all Matches within the Tournaments time frame */
inv: t.matches.day.match->forAll(m |
          m.start > t.start and m.end < t.end)
```

- Translation to XPath/Schematron

```
…
<sch:rule context='/tournament’>
  <sch:assert test=`start le end’ />
</sch:rule>
<sch:rule context=`/tournament’>
  <sch:let name=`t’ value=`.’ />
  <sc:assert test='oclX:forAll(matches/day/match,
   function($m){$m/start ge $t/start and $m/end le $t/end})
</sch:rule>
…
```

Issues

- OCL must be extended for XML
  - PSM diagrams allow additional constructs
    - (choice, sequence …)
  - PSM diagrams are hierarchical
    - position in the tree has some semantic meaning
  - XML offers a collection of axes (most prominently **child** and **parent**), OCL has only associations
- Translation of
  OCL expression ➔ XPath expression
  - OCL and XPath are not that much alike

OCL and XPath

+ both expression languages
- but OCL has
  - iterator expressions
  - anonymous types
    - *Tuple { firstName = ‘John’, lastName =‘Smith’ }*
  - special values: *null* and *invalid* in OCL
    - *if (oclIsInvalid(…)) then … else …*
  - 4 types of collections
    - sequence, set, bag, ordered set

OCL ⇒ XPath Translation

OCL	**XPath 2.0 / XSLT 2.0**
Iterator expressions	Dynamic evaluation ?? FXSL[1] ??
Tuples (anonymous types)	? (temporary trees are not suitable)
Error handling *invalid, oclIsInvalid(...)*	?
Let expressions	?
Sets, ordered sets, bags	? (simulate with sequences)

[1] FXSL -- the Functional Programming Library for XSLT, D. Novatchev

OCL ⇒ XPath Translation (3.0)

OCL	XPath 3.0 / XSLT 3.0
Iterator expressions	**Higher-order functions** `<xsl:iterate>`
Tuples (anonymous types)	**maps**
Error handling *invalid, oclIsInvalid(...)*	`<xsl:try>/<xsl:catch>`
Let expressions	`let $i := … return …`
Sets, ordered sets, bags	? (simulate with sequences and/or maps)

NOTE: we use XSLT for required extensions,
which thus limits us to XSLT-based Schematron validators

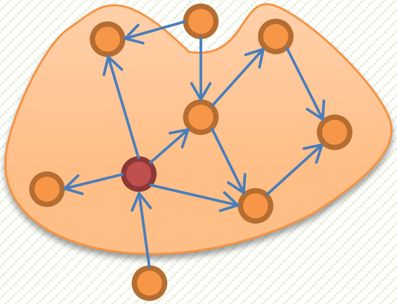
OCL Iterator Expressions

- *iterate* (general iteration with accumulator)

  iterate(i; acc = {accumulator-init} | {body-exp})

  *numbers->iterate(i; acc = 1 | acc * i)*

- *closure* (transitive closure)

  nodes->closure(n | n.adjacentEdges.targetNode)

- Other iterator expressions derived from *iterate* (*forAll, exists, select, collect, ..*)
- How to translate iterator expressions to XPath?

  c->collect(i | {expr}) ⇒ *for $i in c return {expr}*

  c->forAll/c->exists ⇒ *every/some … in c satisfies …*

  select, iterate, closure ⇒ **???**

… and not supporting these would decrease the expressive power!

HOF Solution for *iterate*

```
<xsl:function name="oclX:iterate" as="item()*">
  <xsl:param name="collection" as="item()*"/>
  <xsl:param name="accInit" as="item()*"/>
  <xsl:param name="body" as=
    "function(item(), item()*) as item()*"/>

  <xsl:iterate select="1 to count($collection)">
    <xsl:param name="acc" as="item()*"
      select="$accInit" />
    <xsl:next-iteration>
      <xsl:with-param name="acc" select=
        "$body($collection[current()], $acc)" />
    </xsl:next-iteration>
    <xsl:on-completion>
      <xsl:sequence select="$acc" />
    </xsl:on-completion>
  </xsl:iterate>
</xsl:function>
```

- OCL expression is **parameterized** by body **expression**

- XSLT function is parameterized by body **function**

See the proceedings for alternative solutions (dynamic evaluation, generated functions)

HOF Solution for *closure*

```
<xsl:function name="oclX:closure" as="item()*">
  <xsl:param name="collection" as="item()*"/>
  <xsl:param name="body" as="function(item()) as item()*"/>

  <xsl:sequence select="oclXin:closure-rec(reverse($collection), (), $body)"/>
</xsl:function>

<xsl:function name="oclXin:closure-rec" as="item()*">
  <xsl:param name="toDoStack" as="item()*"/>
  <xsl:param name="result" as="item()*"/>
  <xsl:param name="body" as="function(item()) as item()*"/>

  <xsl:choose>
    <xsl:when test="count($toDoStack) eq 0">
      <xsl:sequence select="$result"/>
    </xsl:when>
    <xsl:otherwise>
      <xsl:variable name="i" select="$toDoStack[last()]" as="item()"/>
      <xsl:variable name="contribution" select="$body($i)" as="item()*"/>
      <xsl:sequence
        select="oclXin:closure-rec(
          ($toDoStack[position() lt last()], reverse($contribution)),
          ($result, $i), $body) " />
    </xsl:otherwise>
  </xsl:choose>
</xsl:function>
```

XSLT has no transitive closures, recursion is used instead

HOF + try/catch for *oclIsInvalid*

- *oclIsInvalid* = error is expected and in fact right

```
<xsl:function name="oclX:oclIsInvalid" as="xs:boolean">
  <xsl:param name="func" as="function() as item()*" />

  <!-- evaluate func and forget the result,
       return false if evaluation succeeds -->
  <xsl:try select="let $result := $func() return false()">
    <xsl:catch>
      <xsl:if test="$debug">
        <xsl:message … />
      </xsl:if>
      <!-- if function call fails, return true  -->
      <xsl:sequence select="true()" />
    </xsl:catch>
  </xsl:try>
</xsl:function>
```

Tuples as Maps

- OCL tuple = anonymous „temporary“ class
  - composed of *parts*

    Tuple { firstName = 'Jakub', lastName = 'Malý', age = 26 }
  - used to compute cartesian product (=> relational. compl.)
- XPath: trees?

`<Tuple>`
  ~~`<firstName>Jakub</firstName>`~~
  ~~`<lastName>Malý</lastName>`~~
  ~~`<age>26</age>`~~
`</Tuple>`

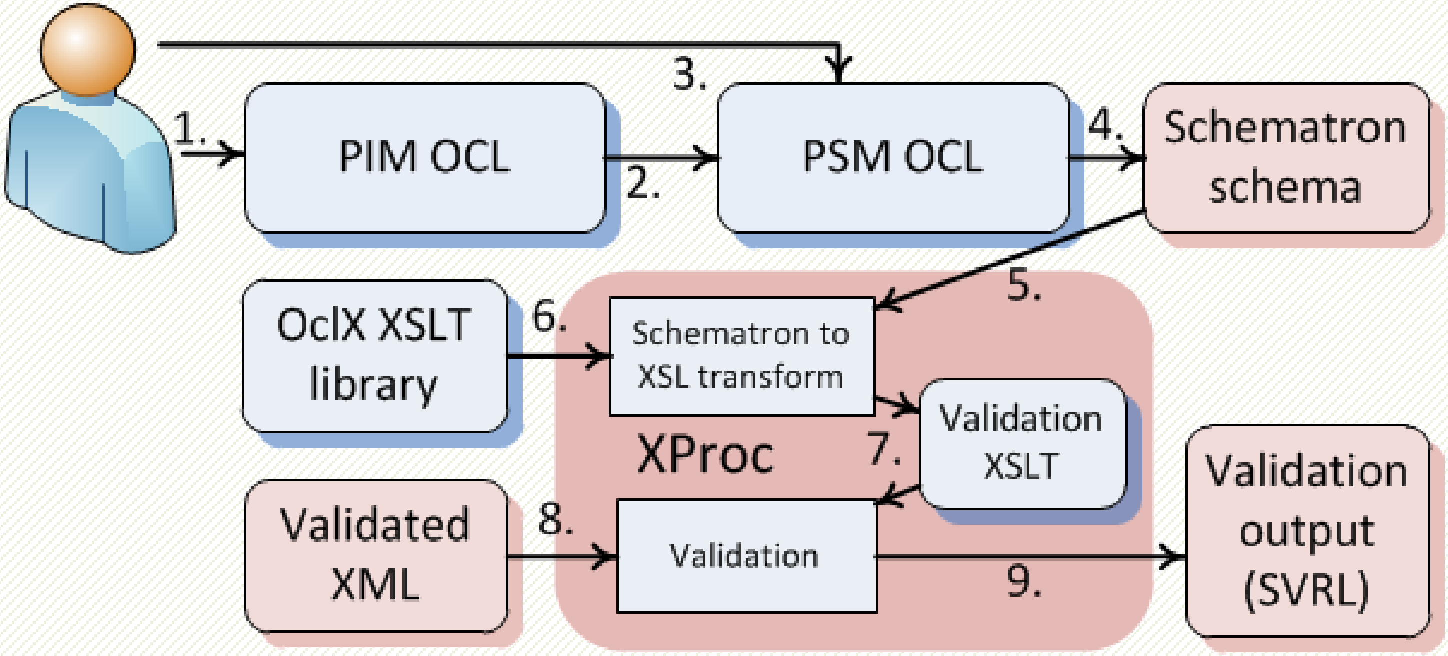
we need a structure, where we can insert nodes without loosing their original position in the document

- *XPath axes can be used on the individual parts*
- *no unnecessary copying*

- XSLT 3.0: maps!

```
map{'firstName' := 'Jakub', 'lastName' := 'Malý', 'age' := 26}
```

Workflow



DEMO

Rewriting Expression

- OCL expression can be translated
  - but the translation may be overly complex
  - XML developer would create more concise equivalent expression

```
1.   oclX:collect(matches/day, function($d) { $d/match } )
2.   oclX:closure(departments/department,
          function($c) {$c/subdepartments/department } )
```

```
1.   for $d in matches/day return $d/match
2.   departments/descendant::department
```

DEMO

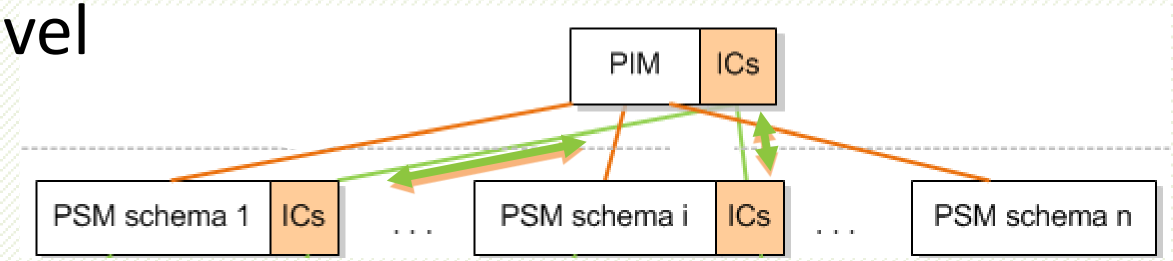
```
1.   matches/day/match
```

Contributions

- OCL => XPath/Schematron mapping
- Our tool can (in concord with MDA principles):
  - (semi)automatically convert the ICs from PIM to PSM
  - automatically translate PSM ICs into XPath expressions/Schematron schemas
- OclX
  - can be used as a stand-alone (HO)function library
  - may appeal to functional-oriented developers
- Implementation: **eXolutio + OclX** - http://exolutio.com

Future Work

- Automatic conversion of constraints between PIM and PSM level



  - current implementation only supports
    - PIM ➔ PSM conversion
    - only for schemas with structure corresponding to the structure of the constraint

- Using OCL for formal description of non-trivial scenarios of document adaptation

Thank you for your attention

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P.S.: More on Collections

- OCL has 4 types of collections
  - all can be nested without limitations

OCL	XPath 3.0 / XSLT 3.0
sequence	sequence
set	sequence/map
bag	map (count occurrences)
ordered set	sequence

- Nesting?
  - XPath can’t do nested sequences!
  - However…

this effectively encodes a nested sequence ((1,2),(3),()):

```
let $ns := map{'s':=(map{'s':=(1,2)}, map{'s':=(3)}, map{'s':=()})}
(: to get the second item in the first nested sequence (i.e. 2) :)
return $ns('s')[1]('s')[2]
```