An Introduction to XML and Web Technologies

Schema Languages

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Objectives

- The **purpose** of using schemas
- The schema languages **DTD** and **XML Schema** (and **DSD2** and **RELAX NG**)
- **Regular expressions** – a commonly used formalism in schema languages

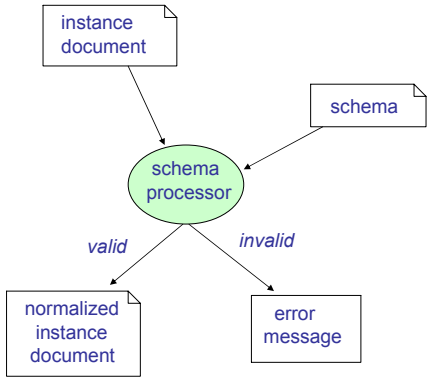
Motivation

- We have designed our Recipe Markup Language
- ...but so far only **informally** described its **syntax**
- *How can we make tools that check that an XML document is a **syntactically correct** Recipe Markup Language document (and thus meaningful)?*
- Implementing a specialized validation tool for Recipe Markup Language is *not* the solution...

XML Languages

- ***XML language***:
  a set of XML documents with some semantics
- ***schema***:
  a formal definition of the syntax of an XML language
- ***schema language***:
  a notation for writing schemas

Validation



Why use Schemas?

- Formal but human-readable descriptions
- Data validation can be performed with existing schema processors

General Requirements

- Expressiveness
- Efficiency
- Comprehensibility

Regular Expressions

- Commonly used in schema languages to describe **sequences** of **characters** or **elements**
- Σ: an alphabet (typically Unicode characters or element names)
- $\sigma \in \Sigma$ matches the string σ
- $\alpha?$ matches zero or one α
- $\alpha*$ matches zero or more α's
- $\alpha+$ matches one or more α's
- $\alpha\ \beta$ matches any concatenation of an α and a β
- $\alpha \mid \beta$ matches the union of α and β

Examples

- A regular expression describing **integers**:

```
0|-?(1|2|3|4|5|6|7|8|9)(0|1|2|3|4|5|6|7|8|9)*
```

- A regular expression describing the valid contents of `table` elements in XHTML:

```
caption? ( col* | colgroup* ) thead? tfoot? ( tbody+ | tr+ )
```


DTD – Document Type Definition

- Defined as a subset of the DTD formalism from SGML
- Specified as an integral part of XML 1.0
- A starting point for development of more expressive schema languages
- Considers elements, attributes, and character data – processing instructions and comments are mostly ignored

Document Type Declarations

- Associates a DTD schema with the instance document

```
<?xml version="1.1"?>
<!DOCTYPE collection SYSTEM "http://www.brics.dk/ixwt/recipes.dtd">
<collection>
...
</collection>
```

```
<!DOCTYPE html
    PUBLIC "-//W3C//DTD XHTML 1.0 Transitional//EN"
    "http://www.w3.org/TR/xhtml1/DTD/xhtml1-transitional.dtd">
```

```
<!DOCTYPE collection [ ... ]>
```


Element Declarations

<!ELEMENT *element-name content-model* >

Content models:

- **EMPTY**
- **ANY**
- ***mixed content***: (#PCDATA | e_1 | e_2 | ... | e_n)*
- ***element content***: regular expression over element names
  (concatenation is written with "**,**")

Example:

```
<!ELEMENT table
        (caption?,(col*|colgroup*),thead?,tfoot?,(tbody+|tr+)) >
```

Attribute-List Declarations

<!ATTLIST *element-name attribute-definitions* >

Each attribute definition consists of

- an attribute name
- an attribute *type*
- a *default declaration*

Example:

```
<!ATTLIST input maxlength CDATA #IMPLIED
               tabindex CDATA #IMPLIED>
```


Attribute Types

- CDATA: any value
- *enumeration*: $(s_1 | s_2 | ... | s_n)$
- ID: must have unique value
- IDREF (/ IDREFS): must match some ID attribute(s)
- ...

Examples:

```
<!ATTLIST p align (left|center|right|justify) #IMPLIED>

<!ATTLIST recipe id ID #IMPLIED>
<!ATTLIST related ref IDREF #IMPLIED>
```


Attribute Default Declarations

- #REQUIRED
- #IMPLIED (= optional)
- "*value*" (= optional, but default provided)
- #FIXED "*value*" (= required, must have this value)

Examples:

```
<!ATTLIST form
      action CDATA #REQUIRED
      onsubmit CDATA #IMPLIED
      method (get|post) "get"
      enctype CDATA "application/x-www-form-urlencoded" >

<!ATTLIST html
      xmlns CDATA #FIXED "http://www.w3.org/1999/xhtml">
```


Entity Declarations (1/3)

- ***Internal*** entity declarations – a simple macro mechanism

Example:

- Schema:

```
<!ENTITY copyrightnotice "Copyright &#169; 2005 Widgets'R'Us.">
```

- Input:

```
A gadget has a medium size head and a big gizmo subwidget.
&copyrightnotice;
```

- Output:

```
A gadget has a medium size head and a big gizmo subwidget.
Copyright &#169; 2005 Widgets'R'Us.
```

Entity Declarations (2/3)

- ***Internal parameter*** entity declarations – apply to the DTD, not the instance document

  Example:
  - Schema:

    ```
    <!ENTITY % Shape "(rect|circle|poly|default)">
    ```
  - ```
    <!ATTLIST area shape %Shape; "rect">
    ```

    corresponds to

    ```
    <!ATTLIST area shape (rect|circle|poly|default) "rect">
    ```


Entity Declarations (3/3)

- ***External parsed*** entity declarations – references to XML data in other files

  Example:
  - ```
    <!ENTITY widgets
      SYSTEM "http://www.brics.dk/ixwt/widgets.xml">
    ```

not widely used!

- ***External unparsed*** entity declarations – references to **non**-XML data

  Example:
  - ```
    <!ENTITY widget-image
      SYSTEM "http://www.brics.dk/ixwt/widget.gif"
      NDATA gif >
    ```
  - ```
    <!NOTATION gif
      SYSTEM "http://www.iana.org/assignments/media-types/image/gif">
    ```
  - ```
    <!ATTLIST thing img ENTITY #REQUIRED>
    ```


Conditional Sections

- Allow parts of schemas to be enabled/disabled by a switch

  Example:
  - ```
    <![%person.simple; [
      <!ELEMENT person (firstname,lastname)>
    ]]>
    <![%person.full; [
      <!ELEMENT person (firstname,lastname,email+,phone?)>
      <!ELEMENT email (#PCDATA)>
      <!ELEMENT phone (#PCDATA)>
    ]]>
    <!ELEMENT firstname (#PCDATA)>
    <!ELEMENT lastname (#PCDATA)>
    ```
  - ```
    <!ENTITY % person.simple "INCLUDE" >
    <!ENTITY % person.full "IGNORE" >
    ```


Checking Validity with DTD

A DTD processor (also called a *validating* XML parser)

- parses the input document (includes checking well-formedness)
- checks the root element name
- for each element, checks its contents and attributes
- checks uniqueness and referential constraints (`ID`/`IDREF(S)` attributes)
    ```

RecipeML with DTD (1/2)

```
<!ELEMENT collection (description,recipe*)>
<!ELEMENT description (#PCDATA)>
<!ELEMENT recipe
  (title,date,ingredient*,preparation,comment?,
   nutrition,related*)>
<!ATTLIST recipe id ID #IMPLIED>
<!ELEMENT title (#PCDATA)>
<!ELEMENT date (#PCDATA)>
<!ELEMENT ingredient (ingredient*,preparation)?>
<!ATTLIST ingredient name CDATA #REQUIRED
                     amount CDATA #IMPLIED
                     unit CDATA #IMPLIED>
```


RecipeML with DTD (2/2)

```
<!ELEMENT preparation (step*)>
<!ELEMENT step (#PCDATA)>
<!ELEMENT comment (#PCDATA)>
<!ELEMENT nutrition EMPTY>
<!ATTLIST nutrition calories CDATA #REQUIRED
                    carbohydrates CDATA #REQUIRED
                    fat CDATA #REQUIRED
                    protein CDATA #REQUIRED
                    alcohol CDATA #IMPLIED>
<!ELEMENT related EMPTY>
<!ATTLIST related ref IDREF #REQUIRED>
```


Problems with the DTD description

- `calories` should contain a non-negative number
- `protein` should contain a value on the form *N*`%` where *N* is between 0 and 100;
- `comment` should be allowed to appear anywhere in the contents of `recipe`
- `unit` should only be allowed in an elements where `amount` is also present
- nested `ingredient` elements should only be allowed when `amount` is absent

– our DTD schema permits in some cases too much and in other cases too little!

Limitations of DTD

1. Cannot constraint **character data**
2. Specification of **attribute values** is too limited
3. Element and attribute declarations are **context insensitive**
4. **Character data** cannot be combined with the **regular expression** content model
5. The content models lack an "**interleaving**" operator
6. The support for **modularity**, **reuse**, and **evolution** is too primitive
7. The normalization features lack **content defaults** and proper **whitespace** control
8. **Structured embedded self-documentation** is not possible
9. The **ID/IDREF** mechanism is too simple
10. It does not itself use an **XML syntax**
11. No support for **namespaces**

Requirements for XML Schema

- W3C's proposal for replacing DTD

Design principles:

- More expressive than DTD
- Use XML notation
- Self-describing
- Simplicity

Technical requirements:

- Namespace support
- User-defined datatypes
- Inheritance (OO-like)
- Evolution
- Embedded documentation
- ...

Types and Declarations

- **Simple type definition**:
  defines a family of Unicode text strings
- **Complex type definition**:
  defines a content and attribute model
- **Element declaration**:
  associates an element name with a simple or complex type
- **Attribute declaration**:
  associates an attribute name with a simple type

Example (1/3)

Instance document:

```
<b:card xmlns:b="http://businesscard.org">
  <b:name>John Doe</b:name>
  <b:title>CEO, Widget Inc.</b:title>
  <b:email>john.doe@widget.com</b:email>
  <b:phone>(202) 555-1414</b:phone>
  <b:logo b:uri="widget.gif"/>
</b:card>
```


Example (2/3)

Schema:

```
<schema xmlns="http://www.w3.org/2001/XMLSchema"
        xmlns:b="http://businesscard.org"
        targetNamespace="http://businesscard.org">

  <element name="card" type="b:card_type"/>
  <element name="name" type="string"/>
  <element name="title" type="string"/>
  <element name="email" type="string"/>
  <element name="phone" type="string"/>
  <element name="logo" type="b:logo_type"/>
  <attribute name="uri" type="anyURI"/>
```

Example (3/3)

```
  <complexType name="card_type">
    <sequence>
      <element ref="b:name"/>
      <element ref="b:title"/>
      <element ref="b:email"/>
      <element ref="b:phone" minOccurs="0"/>
      <element ref="b:logo" minOccurs="0"/>
    </sequence>
  </complexType>

  <complexType name="logo_type">
    <attribute ref="b:uri" use="required"/>
  </complexType>
</schema>
```


Connecting Schemas and Instances

```
<b:card xmlns:b="http://businesscard.org"
  xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
  xsi:schemaLocation="http://businesscard.org
                      business_card.xsd">
  <b:name>John Doe</b:name>
  <b:title>CEO, Widget Inc.</b:title>
  <b:email>john.doe@widget.com</b:email>
  <b:phone>(202) 555-1414</b:phone>
  <b:logo b:uri="widget.gif"/>
</b:card>
```


Element and Attribute Declarations

Examples:

- `<element name="serialnumber" type="nonNegativeInteger"/>`
- `<attribute name="alcohol" type="r:percentage"/>`

Simple Types (Datatypes) – Primitive

string	*any Unicode string*
boolean	true, false, 1, 0
decimal	3.1415
float	6.02214199E23
double	42E970
dateTime	2004-09-26T16:29:00-05:00
time	16:29:00-05:00
date	2004-09-26
hexBinary	48656c6c6f0a
base64Binary	SGVsbG8K
anyURI	http://www.brics.dk/ixwt/
QName	rcp:recipe, recipe
...	

Derivation of Simple Types – Restriction

Constraining facets:

- length
- minLength
- maxLength
- pattern
- enumeration
- whiteSpace
- maxInclusive
- maxExclusive
- minInclusive
- minExclusive
- totalDigits
- fractionDigits

Examples

```
<simpleType name="score_from_0_to_100">
  <restriction base="integer">
    <minInclusive value="0"/>
    <maxInclusive value="100"/>
  </restriction>
</simpleType>

<simpleType name="percentage">
  <restriction base="string">
    <pattern value="([0-9]|[1-9][0-9]|100)%"/>
  </restriction>
</simpleType>
```

regular expression

Simple Type Derivation – List

```
<simpleType name="integerList">
  <list itemType="integer"/>
</simpleType>
```

matches whitespace separated lists of integers

Simple Type Derivation – Union

```
<simpleType name="boolean_or_decimal">
  <union>
    <simpleType>
      <restriction base="boolean"/>
    </simpleType>
    <simpleType>
      <restriction base="decimal"/>
    </simpleType>
  </union>
</simpleType>
```

Built-In Derived Simple Types

- normalizedString
- token
- language
- Name
- NCName
- ID
- IDREF
- integer
- nonNegativeInteger
- unsignedLong
- long
- int
- short
- byte
- ...

Complex Types with Complex Contents

- Content models as **regular expressions**:
  - Element reference `<element ref="name"/>`
  - Concatenation `<sequence> ... </sequence>`
  - Union `<choice> ... </choice>`
  - All `<all> ... </all>`
  - Element wildcard: `<any namespace="..." processContents="..."/>`
- Attribute reference: `<attribute ref="..."/>`
- Attribute wildcard: `<anyAttribute namespace="..." processContents="..."/>`

Cardinalities: `minOccurs`, `maxOccurs`, `use`

Mixed content: `mixed="true"`

Example

```
<element name="order" type="n:order_type"/>

<complexType name="order_type" mixed="true">
  <choice>
    <element ref="n:address"/>
    <sequence>
      <element ref="n:email"
               minOccurs="0" maxOccurs="unbounded"/>
      <element ref="n:phone"/>
    </sequence>
  </choice>
  <attribute ref="n:id" use="required"/>
</complexType>
```


Complex Types with Simple Content

```
<complexType name="category">
  <simpleContent>
    <extension base="integer">
      <attribute ref="r:class"/>
    </extension>
  </simpleContent>
</complexType>
```

```
<complexType name="extended_category">
  <simpleContent>
    <extension base="n:category">
      <attribute ref="r:kind"/>
    </extension>
  </simpleContent>
</complexType>
```

```
<complexType name="restricted_category">
  <simpleContent>
    <restriction base="n:category">
      <totalDigits value="3"/>
      <attribute ref="r:class" use="required"/>
    </restriction>
  </simpleContent>
</complexType>
```

Derivation with Complex Content

```
<complexType name="basic_card_type">
 <sequence>
  <element ref="b:name"/>
 </sequence>
</complexType>

<complexType name="extended_type">
 <complexContent>
  <extension base=
           "b:basic_card_type">
   <sequence>
    <element ref="b:title"/>
    <element ref="b:email"
           minOccurs="0"/>
   </sequence>
  </extension>
 </complexContent>
</complexType>
```

```
<complexType name="further_derived">
 <complexContent>
  <restriction base=
              "b:extended_type">
   <sequence>
    <element ref="b:name"/>
    <element ref="b:title"/>
    <element ref="b:email"/>
   </sequence>
  </restriction>
 </complexContent>
</complexType>
```

Note: `restriction` ***is not the opposite of*** `extension`***!***

Global vs. Local Descriptions

Global (toplevel) style:

```
<element name="card"
         type="b:card_type"/>
<element name="name"
         type="string"/>

<complexType name="card_type">
  <sequence>
    <element ref="b:name"/>
    ...
  </sequence>
</complexType>
```

Local (inlined) style:

```
<element name="card">
  <complexType>
    <sequence>
      <element name="name"
               type="string"/>
      ...
    </sequence>
  </complexType>
</element>
```

inlined

Global vs. Local Descriptions

- Local type definitions are **anonymous**
- Local element/attribute declarations can be **overloaded**
  – a simple form of *context sensitivity*
  (particularly useful for attributes!)
- Only globally declared elements can be starting points for validation (e.g. **roots**)
- Local definitions permit an alternative **namespace** semantics (explained later...)

Requirements to Complex Types

- **Two element declarations** that have the **same name** and appear **in the same complex type** must have **identical types**

```
<complexType name="some_type">
  <choice>
    <element name="foo" type="string"/>
    <element name="foo" type="integer"/>
  </choice>
</complexType>
```

  - This requirement makes efficient implementation easier
- `all` can only contain `element` (e.g. not `sequence`!)
  - so we cannot use `all` to solve the problem with `comment` in RecipeML
- ...

Namespaces

- `<schema targetNamespace="..." ...>`
- **Prefixes** are also used in certain **attribute *values***!
- ***Unqualified Locals***:
  - if enabled, the name of a **locally declared** element or attribute in the instance document must have **no namespace prefix** (i.e. **the empty namespace URI**)
  - such an attribute or element **"belongs to" the element declared in the surrounding global definition**
  - always change the default behavior using `elementFormDefault="qualified"`

Derived Types and Subsumption

- Assume that
  - *T* is some type
  - *T*- is derived from *T* by restriction
  - *T*+ is derived from *T* by extension
- **Subsumption:** Whenever a *T* instance is required,
  - a *T*- instance may be used instead (trivial)
  - a *T*+ instance may be used instead – if the instance has `xsi:type="T+"` (with `xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"`)
- Derivation, instantiation, and subsumption can be constrained using `final`, `abstract`, and `block`

Substitution Groups

- Assume *D* is (in some number of steps) derived from *B*, E_D is an element declaration of type *D*, and E_B is an element declaration of type B
- If E_D is in **substitution group** of E_B then an E_D element may be used whenever an E_B is required
- (This is subsumption based on element declarations, not on types)

Uniqueness, Keys, References

```
<element name="w:widget" xmlns:w="http://www.widget.org">
  <complexType>
  ...
  </complexType>
  <key name="my_widget_key">
    <selector xpath="w:components/w:part"/>
    <field xpath="@manufacturer"/>
    <field xpath="w:info/@productid"/>
  </key>
  <keyref name="annotation_references" refer="w:my_widget_key">
    <selector xpath=".//w:annotation"/>
    <field xpath="@manu"/>
    <field xpath="@prod"/>
  </keyref>
</element>
```

in every `widget`, each `part` must have unique (`manufacturer`, `productid`)

only a "downward" subset of XPath is used

in every `widget`, for each `annotation`, (`manu`, `prod`) must match a `my_widget_key`

`unique`: as `key`, but fields may be absent

Other Features in XML Schema

- Groups
- Nil values
- Annotations
- Defaults and whitespace
- Modularization

– read the book chapter

RecipeML with XML Schema (1/5)

```
<schema xmlns="http://www.w3.org/2001/XMLSchema"
        xmlns:r="http://www.brics.dk/ixwt/recipes"
        targetNamespace="http://www.brics.dk/ixwt/recipes"
        elementFormDefault="qualified">

  <element name="collection">
    <complexType>
      <sequence>
        <element name="description" type="string"/>
        <element ref="r:recipe" minOccurs="0" maxOccurs="unbounded"/>
      </sequence>
    </complexType>
    <unique name="recipe-id-uniqueness">
      <selector xpath=".//r:recipe"/>
      <field xpath="@id"/>
    </unique>
    <keyref name="recipe-references" refer="r:recipe-id-uniqueness">
      <selector xpath=".//r:related"/>
      <field xpath="@ref"/>
    </keyref>
  </element>
```


RecipeML with XML Schema (2/5)

```
  <element name="recipe">
    <complexType>
      <sequence>
        <element name="title" type="string"/>
        <element name="date" type="string"/>
        <element ref="r:ingredient" minOccurs="0" maxOccurs="unbounded"/>
        <element ref="r:preparation"/>
        <element name="comment" type="string" minOccurs="0"/>
        <element ref="r:nutrition"/>
        <element ref="r:related" minOccurs="0" maxOccurs="unbounded"/>
      </sequence>
      <attribute name="id" type="NMTOKEN"/>
    </complexType>
  </element>
```


RecipeML with XML Schema (3/5)

```
  <element name="ingredient">
    <complexType>
      <sequence minOccurs="0">
        <element ref="r:ingredient" minOccurs="0" maxOccurs="unbounded"/>
        <element ref="r:preparation"/>
      </sequence>
      <attribute name="name" use="required"/>
      <attribute name="amount" use="optional">
        <simpleType>
          <union>
            <simpleType>
              <restriction base="r:nonNegativeDecimal"/>
            </simpleType>
            <simpleType>
              <restriction base="string">
                <enumeration value="*"/>
              </restriction>
            </simpleType>
          </union>
        </simpleType>
      </attribute>
      <attribute name="unit" use="optional"/>
    </complexType>
  </element>
```

RecipeML with XML Schema (4/5)

```
<element name="preparation">
  <complexType>
    <sequence>
      <element name="step" type="string" minOccurs="0" maxOccurs="unbounded"/>
    </sequence>
  </complexType>
</element>

<element name="nutrition">
  <complexType>
    <attribute name="calories" type="r:nonNegativeDecimal" use="required"/>
    <attribute name="protein" type="r:percentage" use="required"/>
    <attribute name="carbohydrates" type="r:percentage" use="required"/>
    <attribute name="fat" type="r:percentage" use="required"/>
    <attribute name="alcohol" type="r:percentage" use="optional"/>
  </complexType>
</element>

<element name="related">
  <complexType>
    <attribute name="ref" type="NMTOKEN" use="required"/>
  </complexType>
</element>
```


RecipeML with XML Schema (5/5)

```
  <simpleType name="nonNegativeDecimal">
    <restriction base="decimal">
      <minInclusive value="0"/>
    </restriction>
  </simpleType>

  <simpleType name="percentage">
    <restriction base="string">
      <pattern value="([0-9]|[1-9][0-9]|100)%"/>
    </restriction>
  </simpleType>

</schema>
```


Problems with the XML Schema description

- `calories` should contain a non-negative number
- `protein` should contain a value on the form *N*`%` where *N* is between 0 and 100;
- `comment` should be allowed to appear anywhere in the contents of `recipe`
- `unit` should only be allowed in an elements where `amount` is also present
- nested `ingredient` elements should only be allowed when `amount` is absent

– even XML Schema has insufficient expressiveness!

solved

Limitations of XML Schema

1. The details are extremely **complicated** (and the spec is unreadable)
2. Declarations are (mostly) **context insentitive**
3. It is impossible to write an **XML Schema description of XML Schema**
4. With **mixed content**, **character data** cannot be constrained
5. **Unqualified local elements** are bad practice
6. Cannot require specific **root element**
7. **Element defaults** cannot contain markup
8. The **type** system is overly complicated
9. `xsi:type` is problematic
10. **Simple type definitions** are inflexible

Strengths of XML Schema

- Namespace support
- Data types (built-in and derivation)
- Modularization
- Type derivation mechanism

Document Structure Description 2.0

– read the book chapter

RELAX NG

- OASIS + ISO competitor to XML Schema
- Validation only (no normalization)
- Designed for simplicity and expressiveness, solid mathematical foundation

Processing Model

- For a valid instance document, the **root** element must match a designated **pattern**
- A **pattern** may match **elements**, **attributes**, or **character data**
- Element patterns can contain **sub-patterns**, that describe contents and attributes

Patterns – Regular Hedge Expressions

- `<element name="..."> ... </element>`
- `<attribute name="..."> ... </attribute>`
- `<text/>`

- `<group> ... </group>` (concatenation)
- `<optional> ... </optional>`
- `<zeroOrMore> ... </zeroOrMore>`
- `<oneOrMore> ... </oneOrMore>`
- `<choice> ... </choice>` (union)
- `<empty/>`
- `<interleave> ... </interleave>`
- `<mixed> ... </mixed>`

Example

```
<element name="card">
  <element name="name"><text/></element>
  <element name="title"><text/></element>
  <element name="email"><text/></element>
  <optional>
    <element name="phone"><text/></element>
  </optional>
  <optional>
    <element name="logo">
      <attribute name="uri"><text/></attribute>
    </element>
  </optional>
</element>
```


Grammars

- Pattern **definitions** and **references** allow description of *recursive* structures

```
<grammar ...>
  <start>
    ...
  </start>

  <define name="...">
    ...
  </define>
  ...

</grammar>
```


Other Features in RELAX NG

- Name classes
- Datatypes (based on XML Schema's datatypes)
- Modularization
- An alternative compact, non-XML syntax

– read the book chapter

RecipeML with RELAX NG (1/5)

```
<grammar xmlns="http://relaxng.org/ns/structure/1.0"
         ns="http://www.brics.dk/ixwt/recipes"
         datatypeLibrary="http://www.w3.org/2001/XMLSchema-datatypes">
  <start>
    <element name="collection">
      <element name="description"><text/></element>
      <zeroOrMore><ref name="element-recipe"/></zeroOrMore>
    </element>
  </start>

  <define name="element-recipe">
    <element name="recipe">
      <optional><attribute name="id">
          <data datatypeLibrary="http://relaxng.org/..." type="ID"/>
      </attribute></optional>
```


RecipeML with RELAX NG (2/5)

```
      <interleave>
        <group>
          <element name="title"><text/></element>
          <element name="date"><text/></element>
          <zeroOrMore><ref name="element-ingredient"/></zeroOrMore>
          <ref name="element-preparation"/>
          <element name="nutrition">
            <ref name="attributes-nutrition"/>
          </element>
          <zeroOrMore><ref name="element-related"/></zeroOrMore>
        </group>
        <optional><element name="comment"><text/></element></optional>
      </interleave>
    </element>
  </define>
```


RecipeML with RELAX NG (3/5)

```
  <define name="element-ingredient">
    <element name="ingredient">
      <attribute name="name"/>
      <choice>
        <group>
          <attribute name="amount">
            <choice><value>*</value><ref name="NUMBER"/></choice>
          </attribute>
          <optional><attribute name="unit"/></optional>
        </group>
        <group>
          <zeroOrMore><ref name="element-ingredient"/></zeroOrMore>
          <ref name="element-preparation"/>
        </group>
      </choice>
    </element>
  </define>
```


RecipeML with RELAX NG (4/5)

```
  <define name="element-preparation">
    <element name="preparation">
      <zeroOrMore><element name="step"><text/></element></zeroOrMore>
    </element>
  </define>

  <define name="attributes-nutrition">
    <attribute name="calories"><ref name="NUMBER"/></attribute>
    <attribute name="protein"><ref name="PERCENTAGE"/></attribute>
    <attribute name="carbohydrates"><ref name="PERCENTAGE"/></attribute>
    <attribute name="fat"><ref name="PERCENTAGE"/></attribute>
    <optional>
      <attribute name="alcohol"<ref name="PERCENTAGE"/></attribute>
    </optional>
  </define>
```

RecipeML with RELAX NG (5/5)

```
  <define name="element-related">
    <element name="related">
      <attribute name="ref">
        <data datatypeLibrary="http://relaxng.org/..." type="IDREF"/>
      </attribute>
    </element>
  </define>

  <define name="PERCENTAGE">
    <data type="string">
      <param name="pattern">([0-9]|[1-9][0-9]|100)%</param>
    </data>
  </define>

  <define name="NUMBER">
    <data type="decimal"><param name="minInclusive">0</param></data>
  </define>

</grammar>
```


Summary

- **schema**: formal description of the syntax of an XML language
- **DTD**: simple schema language
  - elements, attributes, entities, ...
- **XML Schema**: more advanced schema language
  - element/attribute declarations
  - simple types, complex types, type derivations
  - global vs. local descriptions
  - ...

Essential Online Resources

- http://www.w3.org/TR/xml11/
- http://www.w3.org/TR/xmlschema-1/
- http://www.w3.org/TR/xmlschema-2/