BASI DI DATI II – 2 modulo
Parte III: Schemi per XML

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Outline

- The **purpose** of using schemas
- The schema languages **DTD** and **XML Schema**
- **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...

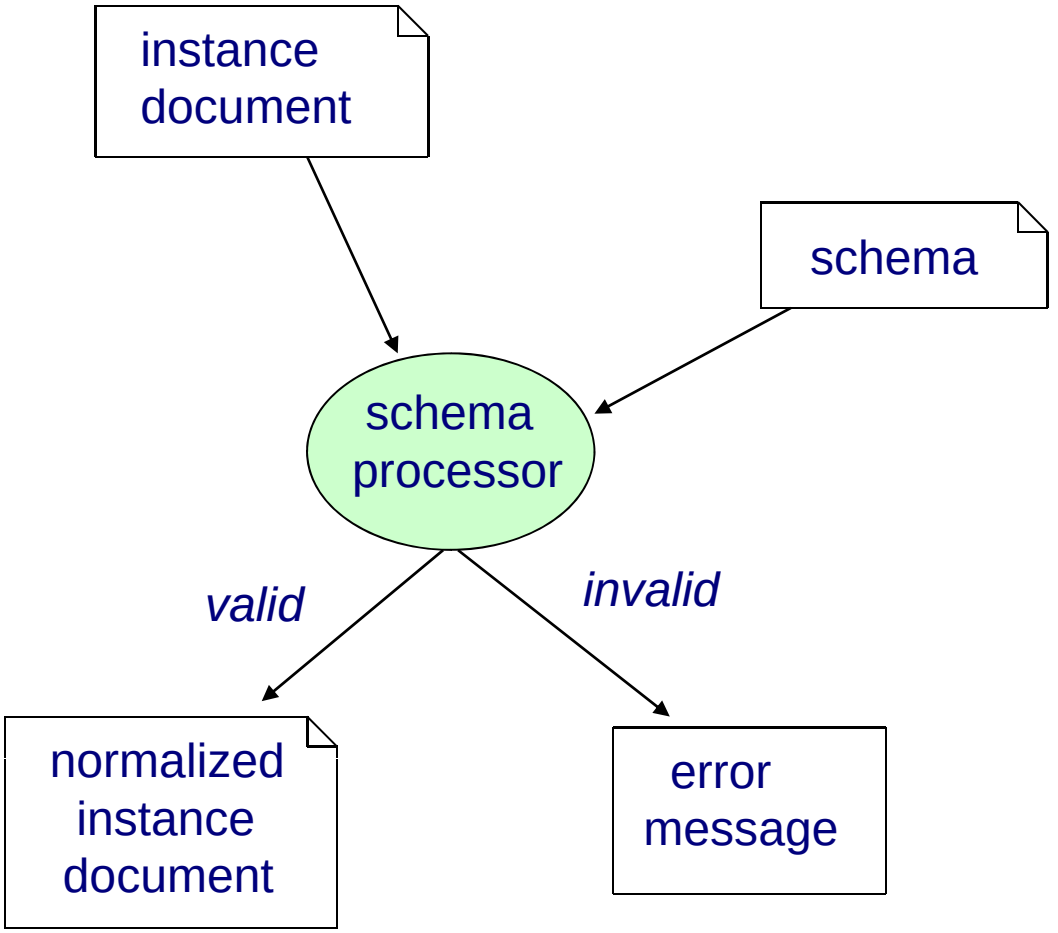
XML Languages

- **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


instance document
schema
schema processor
valid
invalid
normalized instance document
error message

Why use Schemas?

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

General Requirements

- Expressiveness
- Comprehensibility
- Efficiency

Regular Expressions

- Commonly used in schema languages to describe sequences of characters or elements
- Σ: an alphabet (typically Unicode characters or element names)
- A regular expressions (RE) over Σ:
  - Each element in Σ is a regular expression
  - If α and β are regular expressions then:
    - $\alpha?$, α^*, $\alpha+$, $\alpha\ \beta$, $\alpha \mid \beta$, and (α)

    are also regular expressions

Matching

- Matching between a string of elements in Σ and a regular expression over Σ
  - $\sigma \in \Sigma$ matches the string σ
  - α? matches zero or one α
  - α* matches zero or more α's
  - α+ 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
  - (α) matches α

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.uniroma3.it/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|e1|e2|...|en)*`
  - Element content:
    - regular expression over element names (concatenation is written with “,”)
- Example:

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

A valid document

```
<table>
   <caption><em>Great cities of
            the world</em></caption>
   <thead>
       <tr><td>City</td></tr>
   </thead>
   <tbody>
       <tr><td>Copenhagen</td><td>Denmark</td></tr>
       <tr><td>San Francisco</td><td>USA</td></tr>
       <tr><td>Rome</td><td>Italy</td></tr>
   </tbody>
</table>
```

An invalid document

```
<table>
  <thead>
      <tr><td>City</td></tr>
   </thead>
   <tBody>
      <tr><td>Copenhagen</td><td>Denmark</td></tr>
      <tr><td>San Francisco</td><td>USA</td></tr>
      <tr><td>Rome</td><td>Italy</td></tr>
   </tBody>
   <caption><em>Great cities of
            the world</em></caption>
</table>
```

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” (if present 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:

```
<!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.uniroma3.it/widgets.xml">
```

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

  Example:

```
<!ENTITY widget-image
    SYSTEM "http://www.uniroma3.it/widget.gif”
    NDATA gif >
<!NOTATION gif
    SYSTEM "http://www.iana.org/assignments/
                    media-types/image/gif">
```

Conditional Sections

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

  Example:

  - External DTD:

```
<![%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)>
```

  - Internal DTD:

```
<!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

- Cannot constraint character data
- Specification of attribute values is too limited
- Element and attribute declarations are context insensitive
- Character data cannot be combined with the regular expression content model
- The content models lack an “interleaving” operator
- The support for modularity, reuse, and evolution is too primitive
- Lack of element content defaults and proper whitespace control
- Structured embedded self-documentation is not possible
- The ID/IDREF mechanism is too simple
- It does not itself use an XML syntax
- 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

```
<?xml version="1.0“ encoding=“UTF-8”?>
<bc:card xmlns:bc="http://businesscard.org“
  xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
  xsi:schemaLocation="http://businesscard.org
                      business_card.xsd">
  <bc:name>John Doe</bc:name>
  <bc:title>CEO, Widget Inc.</bc:title>
  <bc:email>john.doe@widget.com</bc:email>
  <bc:phone>(202) 555-1414</bc:phone>
  <bc:logo bc:uri="widget.gif"/>
</bc: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

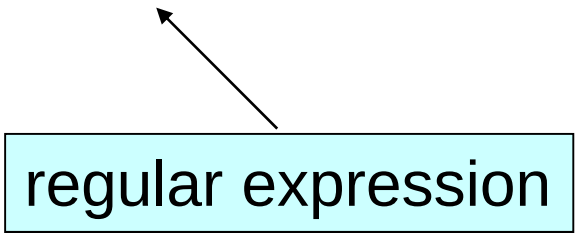
Constraining facets:

- `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>
```



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>
Oppure:
<union memberTypes=“boolean decimal”>
```

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="..."/>`
  - Ordered sequence `<sequence> ... </sequence>`
  - Union `<choice> ... </choice>`
  - Unordered sequence `<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"/>
<attribute name=”id" type=”unsignedInt"/>

<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>
```

Derivation 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 (top-level) 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 (in-lined) style:

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

Global vs. Local Descriptions

- Local type definitions are **anonymous**
- Local element/attribute declarations can be **overloaded** – a simple form of *context sensitivity*
- 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 has no namespace prefix
  - such an attribute or element belongs to the element declared in the surrounding global definition
  - always change the default behaviour using `elementFormDefault="qualified"`

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)

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
- Substitution groups
- Annotations
- Defaults and whitespace
- Modularization

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*

solved

– even XML Schema has insufficient expressiveness!

Limitations of XML Schema

- The details are extremely complicated (and the spec is unreadable)
- Declarations are (mostly) context insensitive
- It is impossible to write an XML Schema description of XML Schema
- With mixed content, character data cannot be constrained
- Cannot require specific root element
- The type system is overly complicated
- xsi:type is problematic
- Simple type definitions are inflexible

Strengths of XML Schema

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

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/