Compilers and Language Processing Tools

Summer Term 2011

Prof. Dr. Arnd Poetzsch-Heffter

Software Technology Group
TU Kaiserslautern

Content of Lecture

6. XML Processing

Chapter Outline

6.1 Introduction

XML- eXtensibleMarkup Language

XML is a standard for structuring and storing and information.
(XML is not a programming language).

Characteristics of XML:

- XML documents are text files with Unicode character encoding.
- XML separates data from its representation.
- XML structures data in a tree-like way by markup.
- XML does not define a semantics of the data itself.
- XML is extensible in order to create new languages.

Example XML Document

```
<?xml version="1.0"?>
<!-- file people.xml -->
<people>
      <person>
            <name>Alan Turing</name>
            <profession>computer scientist</profession>
      </person>
      <person>
            <name>Richard M. Feynman</name>
            <profession>physicist</profession>
      </person>
</people>
```

Why XML ...?

- Widely used and universally available
- Simplifies exchanging information between incompatible systems and via the internet
- Standardized format
- Platform-independent
- Many tools are available for XML processing.

Examples of XML-based Languages

- MathML(Mathematical Markup Language)
- WAP (Wireless Application Protocol)
- RDF (Resource Description Framework)
- SVG (Scaleable Vector Graphics)
- HTML (Hypertext Markup Language)
- SOAP (Simple Object Access Protocoll)
- WSDL (Web Services Description Language)
- ODF (Open Document Format)
- RSS (RDF Site Summary)

6.2 Specification of XML Documents

XML Documents

- XML documents may have an XML declaration (optional)
  `<?xml version="1.0" encoding="UTF-8"?>`
- There is exactly one root element.
- Each element has a matching start and end tag.
- Elements can be nested.
- Empty elements use a special notation.
- Elements can be repeated (distinguished by position).
- Elements can have attributes (zero to any number).
- Attributes can only occur once in elements.
- Comments cannot be placed inside tags.

XML Elements

- Element names consist of letters, numbers, ".", "_", "-", ":" and start with letter or "_".
- Element names are case-sensitive:
  <firstname> and <FirstName> are different
- Start tag encloses element name in < >, e.g., <firstname>
- Matching end tag: </firstname>
- Empty element: <firstname/>

Attributes

- Attributes carry additional information of elements that is not considered content (e.g., metadata).
- Attributes are specified in tags:
  `<name language=“DE”> Chris </name>`
- Attribute values are enclosed in quotes and may not contain "<"

Grammar for XML documents (Part)

According to http://www.w3.org/TR/xml11/

```
document ::=  ( prolog element Misc* )
prolog ::=  XMLDecl Misc* (doctypedecl Misc*)?
XMLDecl ::=  '<?xml' VersionInfo EncodingDecl? '?>'
Misc  ::=  Comment | PI | S

element  ::= EmptyElemTag
           | STag content ETag

EmptyElemTag ::=  '<' Name (S Attribute)* S? '/>'
STag ::=  '<' Name (S Attribute)* S? '>'
Attribute ::=  Name Eq AttValue
ETag ::=  '</' Name S? '>'

PI processing instructions; S whitespace
```

XML Document Example

```
<?xml version="1.0" encoding="UTF-8"?>
<section id="xml" author="bob">
      <title> Extensible Markup Language (XML)</title>
      <p> XML is based on SGML (Section <ref name="sgml"/>) </p>
      <p type="example">XML can be used ... </p>
      <section id="xml-syntax">
            <title> XML Syntax</title>
            <p>Section <ref name="sgml-syntax"/> ...</p>
      </section>
</section>
```

Mixed Content

Mixed content refers to elements which have text content mixed with elements.

Example:

```
<p>The term <em>Mixed content</em> in XML refers to elements
<a href="http://www.w3.org/TR/xml/#sec-mixed-content">
which have text content mixed with elements</a>. The elements
are on the same level as the text nodes of the
mixed content.</p>
```

Well-formed and Valid XML Documents

- Well-formed documents satisfy all basic constraints of the XML specification:
  - they can be parsed according to the XML grammar
  - they satisfy the additional constraints (e.g., matching start and end tags)
  - this means they can be translated into a tree
- Valid documents must satisfy additional constraints (e.g., of an DTD, XSD, ...)
  - a document must be well-formed before it can be validated
  - all used elements and attributes in the document have been defined and are used according to their definition.

Specifying Valid XML Documents

- Document Type Definitions (DTD)
  - Part of SGML, developed before XML
  - Not itself in XML syntax, but included in XML definition
  - No type system
- XML Schemas (XSD)
  - Developed after XML
  - More complicated than DTD
  - In XML syntax
  - Support namespaces to resolve conflicts between element and attribute names
  - Elaborated and extensible type system

6.2.1 DTD

DTD by Example

Example DTD

```
<!ELEMENT address (name, phone*)>
<!ELEMENT name (#PCDATA)>

<!ELEMENT phone (#PCDATA)>
<!ATTLIST phone type ( voice | fax ) #REQUIRED>
```

Example Document

```
<address>
      <name> MaxMuster </name>
      <phone type ="voice"> 4711 </phone>
      <phone type ="fax"> 4712 </phone>
</address>
```

6.2.2 XSD

XML Namespaces

- Namespaces are used to resolve conflicts between element and attribute names if two XML formats are merged.
- A namespace is defined by a Uniform Resource Identifier (URI):
  - Default Namespace:
    ```
    html xmlns="http://www.w3.org/1999/xhtml"
    ```
  - Prefix Namespace:
    ```
    xhtml:html xmlns:xhtml="http://www.w3.org/1999/xhtml"
    ```
- If an element name has no prefix, it is in the default namespace.
- If a name has a prefix, the prefix must be bound to a namespace (qualified names).
- A prefix is only valid inside of the element defining the prefix.

Uniform Resource Identifier

URIs identify resources and are typically hierarchically structured.

Commonly used URIs:

- Uniform Resource Locators (URLs): define resource location and access protocol, e.g., `http://www.w3.org/1999/xhtml`
- Uniform Resource Names (URNs): an identifying (existing) name, e.g., `urn:ietf:rfc:2648`

List of possible URI schemes:
`http://www.iana.org/assignments/uri-schemes.html`

Namespaces by Example

```
<catalog xmlns:dc="http://purl.org/dc"
            xmlns:pt="http://vangoghgallery.com/pt" >
      <dc:description>
            <dc:title>Impressionist Paintings</dc:title>
            <dc:creator>Elliotte Rusty Harold</dc:creator>
      </dc:description>
      <pt:painting>
            <pt:title>Memory of the Garden at Etten</pt:title>
            <pt:artist>Vincent van Gogh</pt:artist>
      </pt:painting>
</catalog>
```

XML Schema - XSD

- is an XML dialect itself
- supports namespaces
- sophisticated extensible type system
- allows rigorous automated checking of document content
- enables automated conversion of XML documents, e.g., to Java Objects and vice versa

Structure of XSD

A schema defines

- which elements a document may contain
- which attributes theses elements have
- the relationship between parent and child elements
- the ordering of elements
- the number of child elements
- if elements are empty or may contain text
- data types for elements and attributes
- default values and constants for elements and attributes

Types in XSD

- Atomic types: integer, boolean, string, ... (more built-in types)
- Simple types : derived from atomic types by list and union operators
- Complex types
  - can contain elements and attributes themselves
  - ordered and unordered sequences of elements
  - selection of elements
  - constraints on values of elements and attributes
  - constraints on occurrences of elements and attributes

Selected XSD Language Elements

- Simple elements:

```
<xs:element name="lastName" type="xs:string"/>
<xs:element name="age" type="xs:integer"/>
```

  Instance:

```
<lastName> Schmid </lastName>
<age> 34 </age>
```

Selected XSD Language Elements (2)

- Elements with attributes:

```
<xs:element name ="shoeSize">
<xs:complexType>
  <xs:simpleContent>
    <xs:extension base="xs:positiveInteger">
     <xs:attribute name="country" type="xs:string"/>
    </xs:extension>
  </xs:simpleContent>
 </xs:complexType>
 </xs:element>
```

Instance:

```
<shoeSize country="france">35</shoeSize>
```

Selected XSD Language Elements (3)

- Empty elements:

```
<xs:element name="product">
  <xs:complexType>
    <xs:attribute name="prodId" type="xs:positiveInteger"/>
  </xs:complexType>
</xs:element>
```

Instance:

```
<product prodId="1345"/>
```

Selected XSD Language Elements (4)

- Elements with a sequence of child elements:

```
<xs:element name="person>
  <xs:complexType>
    <xs:sequence>
      <xs:element name="firstName"type="xs:string"
              minOccurs="0" maxOccurs="2" />
      <xs:element name="lastName" type="xs:string"
              minOccurs="0"/>
   </xs:sequence>
  </xs:complexType>
</xs:element>
```

Instance:

```
<person>
  <firstName>John</firstName>
  <lastName>Smith</lastName>
</person>
```

Selected XSD Language Elements (5)

- Elements with an unordered sequence of child elements: (maxOccurs = 1 for each child element)

```
<xs:element name="person>
  <xs:complexType>
   <xs:all>
     <xs:element name="firstName"type="xs:string"/>
     <xs:element name="lastName"type="xs:string"/>
   </xs:all>
</xs:complexType>
</xs:element>
```

Selected XSD Language Elements (6)

- Elements with a selection of child elements:

```
<xs:element name="person>
  <xs:complexType>
   <xs:choice>
    <xs:element name="employee" type="employeeType"/>
    <xs:element name="member" type="memberType"/>
   </xs:choice>
 </xs:complexType>
</xs:element>
```

Each person is either an employee or a member, but not both.

XSD Example

```
<?xml version="1.0"?>
<xs:schema
  xmlns:xs="http://www.w3.org/2001/XMLSchema"
        targetNamespace="http://www.note.org">
   <xs:element name="note">
     <xs:complexType>
       <xs:sequence>
         <xs:element name="to" type="xs:string"/>
         <xs:element name="from" type="xs:string"/>
         <xs:element name="heading" type="xs:string"/>
         <xs:element name="body" type="xs:string"/>
       </xs:sequence>
       <xs:attribute name="id" type="xs:id"/>
     </xs:complexType>
   </xs:element>
</xs:schema>
```

XSD Example (2)

Instance:

```
<?xml version="1.0"?>
<note xmlns="http://www.note.org" id = "4711" >
  <to> Bill </to>
  <from> Jani </from>
  <heading> Reminder </heading>
  <body>
   Don’t forget the book!
  </body>
</note>
```

Validation of XML Documents

- Lexical and context-free analysis
- Well-formedness checks (wrt. XML grammar)
  (matching tags, unique attribute names, ...)
- Validation checks for structural integrity
  (is the document schema-valid?)
  - checking elements and attributes for correct application
  - checking element contents and attribute values for compliance to constraints

XSD: Unordered List with Multiple Occurrences

```
<xs:element name="root">
   <xs:complexType>
     <xs:sequence>
        <xs:choice maxOccurs="unbounded">
           <xs:element name="A"/>
           <xs:element name="B"/>
       </xs:choice>
     </xs:sequence>
  </xs:complexType>
</xs:element>
```

XSD: Unordered List with Multiple Occurrences (2)

Instances:

```
<root>
  <A/>
  <B/>
  <B/>
</root>
```

or

```
<root>
  <B/>
  <A/>
  <A/>
  <B/>
</root>
```

6.3 Processing of XML Documents

Processing XML Documents

1. Map XML documents to programming language data types (XML Data Binding, e.g., JAXB)
2. Function libraries providing XML processing facilities
   - SAX (Simple API for XML) as an event-based API
   - DOM (Document Object Model) as a tree-based API
3. XML processing languages (XSLT, XPATH, XQuery, ...)

6.3.1 SAX

SAX

- an event-based API for accessing XML documents
- use event handlers for parsing-related events
- the parser reads a document and raises events when markup is recognized
- for each recognized structure, an event triggers a user-supplied function

SAX (2)

- Pros:
  - requires little memory and can handle very large documents
- Cons:
  - does not allow random access or backward movement
  - context and history has to be managed by the application
  - at a certain complexity, SAX parsing requires a lot of additional code

SAX Parsing

Observers of a SAX Parser must implement the `org.xml.sax.ContentHandler` interface.

The class `org.sax.xml.helpers.DefaultHandler` contains a default implementation for the methods of `ContentHandler` such that observers only have to implement the used methods.

SAX Parsing (2)

Example for Observer:

```
class mySaxApp extends DefaultHandler{

public void startDocument ()
  { System.out.println("Start document"); }

public void endDocument ()
  { System.out.println("End document"); }

public void startElement (String uri, String name,
            String qName, Attributes atts) { ... }

public void endElement (String uri, String name, String qName){...}

public void characters (char ch[], int start, int length){...}
}
```

SAX Parsing (3)

Example application of SAX parser:

```
public static void main (String args[])
  { // create XML Reader
      XMLReader xr = XMLReaderFactory.createXMLReader();

    // create observer
    MySAXApp handler = new MySAXApp();

    // register observer
    xr.setContentHandler(handler);

    // parse document
    InputSource r = new InputSource(FileReader(args[0]);
    xr.parse(r);
  }
```

6.3.2 DOM

DOM

- a tree-based API for accessing XML documents
- based on an in-memory representation of an XML document
- access to tree structure by special methods

- Pros:
  - random document access
  - more specific tasks possible, e.g., getting an element's attribute by name
- Cons:
  - very large documents may not fit into memory
  - for isolated tasks, the parsing overhead is prohibitive

DOM Parsing

For representing XML documents as trees, a general data structure is used. Central data type is `Node`:

```
interface Node {
Node appendChild(Node newChild) ;
Node cloneNode(boolean deep);
NamedNodeMap getAttributes();
NodeList getChildNodes();
Node getFirstChild();
Node getLastChild();
String getLocalName();
String getNamespaceURI();
Node getNextSibling();
String getNodeName();
short getNodeType();
String getNodeValue();
... // und viele Methoden mehr
}
```

DOM Parsing (2)

The type `Document` represents complete XML documents:

```
interface Document extends Node { ...  }
```

DOM Parsing (3)

Example application of DOM Parser:

```
public static void main(String[] args) {
InputSource src = new InputSource(new FileInputStream(args[0]));

// create parser
DOMParser prsr = new DOMParser();

// start parsing
 prsr.parse( src );

// access to DOM tree
Document doc = prsr.getDocument();

// further processing, e.g.
 System.out.print(doc.getFirstChild.getNextSibling.getNodeName());
}
```

6.4 Transforming XML Documents

XSL - eXtensible Stylesheet Language

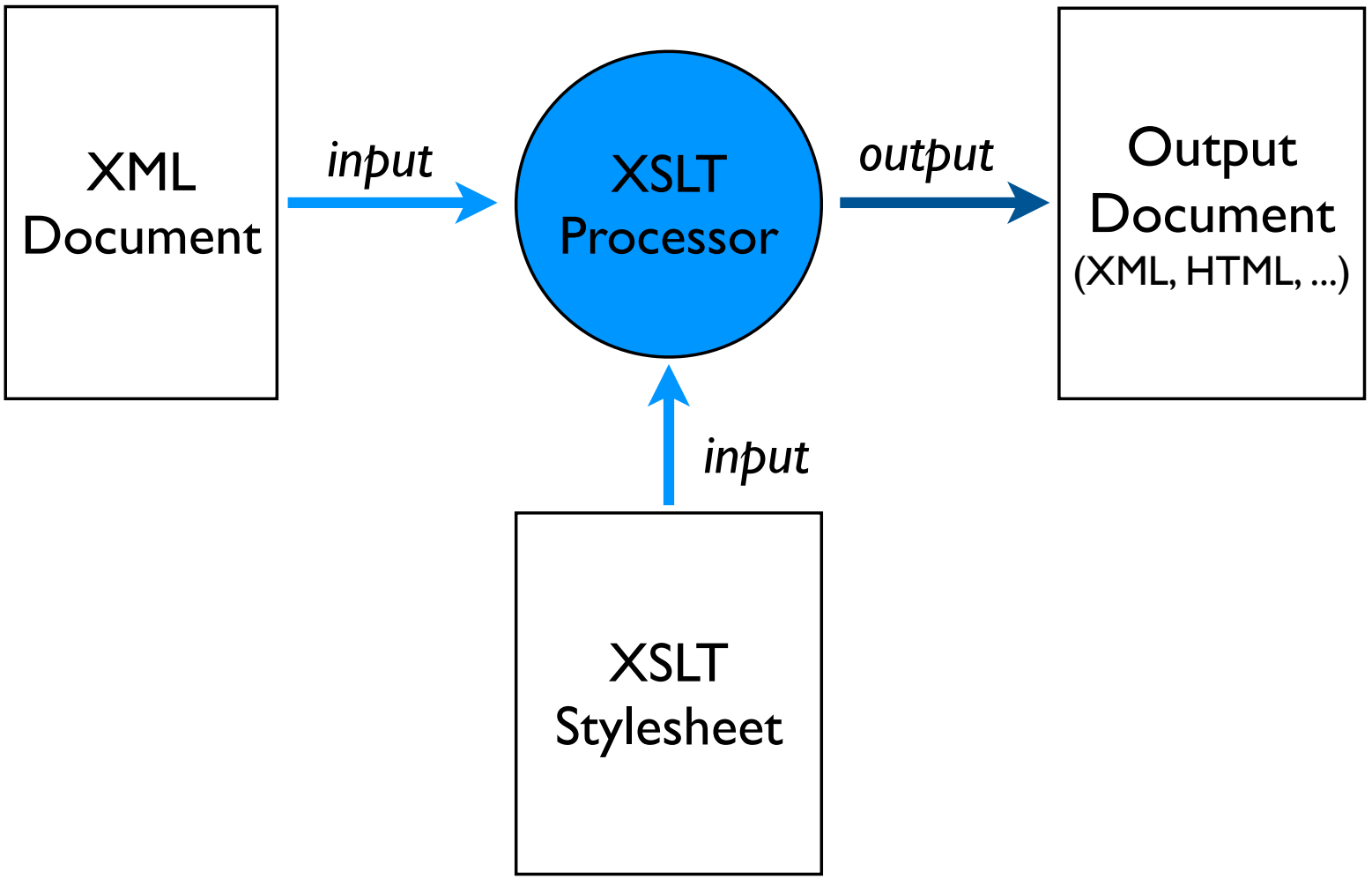
- XSLT: Language for transforming XML
- XPath: Language for selecting XML nodes in an XML document
- XSL-FO (Formatting Objects): Language for describing formatted output

6.4.1 XSLT

XSLT

- XML-based processing language
- not designed for large programming tasks
- standard language for XML-to-XML/text transformations
- based on XPath (navigation and computation)
- needs XSLT processor,
  e.g., `xsltproc -o outputfile xslt_script input.xml`

XSLT processing



Examples of XSLT Applications

- Transforming XML to (X)HTML for web servers
- Add content to XML documents, e.g., table of contents
- Transform one XML format to another, e.g., DocBook to ODF/ODT

Main concepts of XSLT

- XSLT is a functional processing/programming language
- XSLT has built-in behavior for tree traversal
- XSLT defines a set of templates
- A template consists of:
  1. a pattern which selects a set of nodes
  2. a set of actions to perform on these nodes
  3. further processing instructions

Structure of XSLT stylesheet

```
<?xml version="1.0" encoding="UTF-8"?>
<xsl:stylesheet version="1.0"
  xmlns:xsl="http://www.w3.org/1999/XSL/Transform">
  <xsl:output method="html"/> // Alternatives are "xml" or "text"

 <xsl:template match = [Set of Nodes] >
     [Actions]
     // recursively apply matching templates of children
     <xsl:apply-templates/>
 </xsl:template>

</xsl:stylesheet>
```

Execution of XSLT Stylesheet

Execution starts with root node of input document.
For each node:

1. Find matching templates
2. If matching template exists:
   - execute actions of template and/or
   - execute <xsl:apply-templates/> recursively
3. If no matching template exists, apply default rules, if applicable

XSLT default rules

- Root and Element Nodes: recurse on children

```
<xsl:template match="*|/">
  <xsl:apply-templates>
</xsl:template>
```

- Text Node and Attributes: copy text content to output tree

```
<xsl:template match="@*|text()">
  <xsl:value-of select="."> // returns text content
</xsl:template>
```

- Comments and Processing Instructions are removed from output.

XSLT default rules (2)

Stop default behavior by introducing matching rule overriding the default behavior, e.g.,

```
<xsl:template match="text()" />
```

or by qualifying nodes to which templates are applied by

```
<xsl:apply-templates select= [Set of Nodes] />
```

XSLT by Example

Transform XML to HTML

Input document:

```
<?xml version="1.0"?>
 <people>
  <person>
     Alan Turing
</person>
 <person>
     Kurt Goedel
</person>
<person>
     John von Neumann
</person>
</people>
```

XSLT by Example (2)

XSLT Stylesheet:

```
<?xml version="1.0" encoding="UTF-8"?>
<xsl:stylesheet version="1.0"
      xmlns:xsl="http://www.w3.org/1999/XSL/Transform">
<xsl:output method="html"/>

<xsl:template match="people">
      <html> <head> People List </head> <body>
        <ul> <xsl:apply-templates/> </ul>
        </body> </html>
</xsl:template>

<xsl:template match="person">
      <li> <xsl:apply-templates /></li>
</xsl:template>
</xsl:stylesheet>
```

XSLT by Example (3)

Output document:

```
<html>
<head> People List </head>
<body><ul>
  <li>
     Alan Turing
</li>
 <li>
     Kurt Goedel
</li>
<li>
     John von Neumann
</li>
</ul></body>
</html>
```

6.4.2 XPath

XPath

- Language for selecting nodes in an XML document
- Syntax is similar to file system addressing.
- XPath expressions define patterns matching a set of document nodes.
- Matching depends on current evaluation context wrt current node.

XPath Examples

- `name`: all <name> children of current node
- `name/firstName`: all <firstName> children of all <name> children of current node
- / : the root node of the document
- .: the current node
- ..: the parent of the current node
- //name: all <name> elements in the document
- .//name: all <name> successors (direct or indirect) of the current node

More XPath Expressions

- An XPath is absolut, if it starts with "/",
  e.g., `/person`
- A path can contain a number of steps separated by "/",
  e.g., `people/person/born`
- Attributes are marked by "@",
  e.g., `born/@addressRef`
- XPaths can be combined by "|" denoting alternatives,
  e.g., `name/firstName| profession | hobby`

Wildcards

XPaths can contain wildcards:

- * - selects all elements
- @* - selects all attributes
- node() - selects all nodes
- text() - selects text nodes

Examples:

- //* - all elements in the document
- /* - all children of root
- str/*/title- all <title> grand-children of str elements
- //*/@id - all attributes with name id

XPath Predicates

Predicates can be used to define additional constraints on the values of attributes and elements.

Examples:

- person[name/firstName!='Alan'] - all person children where the first name in the name element is not 'Alan'
- died[@addressRef] - all <died> children with addressRef attribute
- born[@addressRef = 'gbc'] - all <born> children with addressRef attribute with value 'gbc'
- person [born/@date > 1900] - all persons born later then 1900

XPath Axes

Instead of the abbreviated notation, axes denoting the access direction can be denoted explicitly.

Some examples:

- self::node() - the current node itself
- child::name - all <name> children
- parent::node() - the parent node of the current node
- descendant::name - all descendants of <name> node
- ancestor-or-self::name - all prececessors of <name> node including the <name> node itself
- following::name - all nodes following a <name> node in the document text
- preceding-sibling::name - the sibling before a <name> node

XPath functions

XPath has a large set of built-in functions (even more in XPath 2.0) that can be used in XPath predicates and in XSLT scripts for computing values from document nodes.

Some examples:

- Arithmetic, relational and logical operators,
  e.g., +, -, =, !=, <, and, ...
- String operations,
  e.g., concat, substring, normalize-space, ...
- count(//person) - counts number of person nodes in the document
- sum(//number) - computes the sum of the values in <number> nodes
- person[1] - the first person element
- person[last()] - the last person element

6.4.3 More Complex XSLT

Selected XSLT language constructs

- `<xsl:apply-templates ... >` applies templates in style sheet to further nodes.

  The next nodes to be processed can be explicitly selected by XPath expression:
  `<xsl:apply-templates select=[XPath expression]/>`

  `<xsl:apply-templates/>` applies templates to all children of current node.

Selected XSLT language constructs (2)

- `<xsl:for-each ... >` processes template for each node with matching expression:

```
<xsl:template match="people">
  <xsl:for-each select=[XPath expression]>
    [Action]
  </xsl:for-each>
</xsl:template>
```

Selected XSLT language constructs (3)

- `<xsl-value-of ... ">` selects (and processes) particular nodes in an XML document:

```
<xsl:value-of select="lastName"/>

<xsl:value-of select="born/@date"/>
            // outputs data attribute

<xsl:value-of select="sum(//number)"/>
            // sum of all number values

<xsl:value-of select="count(//person)"/>
            // number of person nodes in document
```

Selected XSLT language constructs (4)

- `<xsl:call-template ... >` calls a template by its name:

```
<xsl:template match="people" >
  <xsl:call-template name="templ1"/>
</xsl:template>

<xsl:template name=" templ1">
  <xsl:apply-templates select="person"/>
</xsl:template>
```

Selected XSLT language constructs (5)

- Templates with modes allow context-dependent execution of templates:

```
<xsl:template match="people">
  <h4>Table of Contents</h4>
  <xsl:apply-templates select="person" mode="toc"/>
  <xsl:apply-templates select="person"/>
</xsl:template>

<xsl:template match="person" mode="toc">
  <xsl:value-of select="name/lastName"/>
</xsl:template>

<xsl:template match="person">
  <xsl:apply-templates select="name"/>
</xsl:template>
```

Conditional Processing

- `<xsl:if test = [condition]>` allows processing nodes differently:

```
<xsl:template match="person">
  <xsl:if test="born/@date > 1900
              and name/firstName != 'Alan'">
    <xsl:apply-templates select="name"/>
  </xsl:if>
</xsl:template>
```

Conditional Processing (2)

- `<xsl:choose>` can be used as an if-then-else or as a switch construct:

```
<xsl:choose>
  <xsl:when test="...">
    [Actions if condition is true]
  </xsl:when>
  <xsl:when test="...">
    [Actions if condition is true]
  </xsl:when>
  <xsl:otherwise>
    [Default actions]
  </xsl:otherwise>
</xsl:choose>
```

Conditional Processing (3)

- `<xsl:sort ...>` allows sorting of nodes during transformation inside `<xsl:apply-templates ..>` or `<xsl:for-each ...>` elements:

```
<xsl:apply-templates select="person">
  <xsl:sort select="name/lastName" order="ascending"/>
</xsl:apply-templates>
```

Variables and Parameters

In XSLT, also variables can be defined by

```
<xsl:variable name="variablename">
  [Definition of value_of_variable] // can be complex content
</xsl:variable>
```

Value of variable can be read by `$variablename` in `<xsl:value-of select="$variablename"/>`.

The value cannot be changed after definition of a variable.

Variables and Parameters (2)

Example: Computation of a weighed sum

```
<xsl:variable name="tmp">
  <tmpPrice>
  <xsl:for-each select="book">
    <item>
      <xsl:value-of select="price * quantity"/>
    </item>
   </xsl:for-each>
  </tmpPrice>
</xsl:variable>

<xsl:value-of select="sum($tmp/tmpPrice/item)"/>
```

Variables and Parameters (3)

Declaration of template with parameter:

```
<xsl:template name="myTemplate">
  <xsl:param name="p1"/> // formal parameter declaration
    [Actions using $p1]
</xsl:template>
```

Calling a template with a parameter:

```
<xsl:template match="person">
 <xsl:call-template name="myTemplate">
  <xsl:with-param name="p1"> // current parameter
    <xsl:value-of select="someValue"/>
  </xsl:with-param>
 </xsl:call-template>
</xsl:template>
```

6.5 Concluding Remarks

What is not covered

- XQuery: Querying XML documents
- XSL-FO: Formatting Objects
- Other Schema Languges: RELAX NG, Schematron
- XML Data Binding: JAXB, Castor

Literature

- Recommendations of the W3C `http://www.w3c.org`
- Many other XML-related resources are available on the web.
- There are many XML books available.
  Make sure you get the newest edition!