XML Data Management

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Outline

Chapter 1

Introduction

What is XML?

- The eXtensible Markup Language (XML) defines a generic syntax used to mark up data with simple, human-readable tags
- Has been standardized by the World Wide Web Consortium (W3C) as a format for computer documents
- Is flexible enough to be customized for domains as diverse as:
  - Web sites
  - Electronic data interchange
  - News feeds (RSS, e.g., BBC World News)
  - Vector graphics
  - Mathematical expressions
  - Microsoft Word documents
  - Music libraries (e.g., iTunes)
  - ...

What is XML? (2)

- Data in XML documents is represented as strings of text
- This data is surrounded by text markup, in the form of *tags*, that describes the data
- A particular unit of data and markup is called an *element*
- XML specifies the exact syntax of how elements are delimited by tags, what a tag looks like, what names are acceptable, and so on

Which is Easier to Understand?

```
TCP/IP
Stevens
Foundations of Databases
Abiteboul
Hull
Vianu
The C Programming Language
Kernighan
Ritchie
Prentice Hall
...
```

```
<bib>
  <book>
    <title>TCP/IP</title>
    <author>Stevens</author>
  </book>
  <book>
    <title> ... </title>
    ...
  </book>
</bib>
```

XML vs. HTML

- Markup in an XML document looks similar to that in an HTML document
- However, there are some crucial differences:
  - XML is a meta-markup language: it doesn't have a *fixed* set of tags and elements
  - To enhance interoperability, people may agree to use only certain tags (as defined in a DTD or an XML Schema — see later)
  - Although XML is flexible in regard to elements that are allowed, it is strict in many other respects (e.g., closing tags are required)
  - Markup in XML only describes a document's structure; it doesn't say anything about how to display it

Very Brief Review of HTML

- A document structure and hypertext specification language
- Specified by the World Wide Web Consortium (W3C)
- Designed to specify the *logical structure* of information
- Intended for presentation as *Web pages*
- Text is marked up with *tags* defining the document's logical units, e.g.
  - title
  - headings
  - paragraphs
  - lists
  - ...
- The displayed properties of the logical units are determined by the browser (and stylesheet, if present)

HTML Example

- The following is a (very simple) complete HTML document:

```
<html>
  <head>
    <title>A Title</title>
  </head>
  <body>
    <h1>A Heading</h1>
  </body>
</html>
```

- When loaded in a browser
  - "A Title" will be displayed in the title bar of the browser
  - "A Heading" will be displayed big and bold as the page contents

HTML, XHTML and XML

- These days, most web pages use *XHTML* rather than HTML
- XHTML uses the syntax of XML
- XHTML corresponds to a particular XML *vocabulary* or *document type*
- A document type is specified using a *Document Type Definition* (*DTD*) — see later
- HTML is essentially a less strict form of XHTML

Limitations of (X)HTML

So why not use XHTML rather than XML?

- (X)HTML defines a *fixed set* of elements (XHTML is *one* XML vocabulary)
- elements have *document* structuring semantics
- for presentation to human readers
- organisations want to be able to define their own elements
- applications need to exchange structured *data* too
- applications cannot consume (X)HTML easily
- use XML for *data* exchange and (X)HTML for document representation

XML versus Relational Data

- Why not use data from relational databases for exchange?
- XML is more flexible:
  - XML data is *semi-structured* rather than structured
  - Conformance of the data to a schema is not mandatory
  - XML schemas, if used, allow for more varied structures
- Relational data can always be (and often is) wrapped as XML

Motivating Example

- Say we want to store information about a personal CD library
- The CDs are all of classical music
- Some CDs contain simply solo (e.g., piano) works
- Some CDs have orchestral works (with orchestra, conductor)
- Some CDs contain performances of works by different composers
- We want to avoid repeating information in the descriptions
- We have only 4 CDs (see the next few slides)!

Example (1)

```
<CD-library>
   <CD number="724356690424">
      ...
   </CD>

   <CD number="419160-2">
      ...
   </CD>

   <CD number="449719-2">
      ...
   </CD>

   <CD number="430702-2">
      ...
   </CD>
</CD-library>
```

Example (2)

```
<CD number="724356690424">
  <performance>
    <composer>Frederic Chopin</composer>
    <composition>Waltzes</composition>
    <soloist>Dinu Lipatti</soloist>
    <date>1950</date>
  </performance>
</CD>
```

Example (3)

```
<CD number="419160-2">
  <composer>Johannes Brahms</composer>
  <soloist>Emil Gilels</soloist>
  <performance>
    <composition>Piano Concerto No. 2</composition>
    <orchestra>Berlin Philharmonic</orchestra>
    <conductor>Eugen Jochum</conductor>
    <date>1972</date>
  </performance>
  <performance>
    <composition>Fantasias Op. 116</composition>
    <date>1976</date>
  </performance>
</CD>
```

Example (4)

```
<CD number="449719-2">
  <soloist>Martha Argerich</soloist>
  <orchestra>London Symphony Orchestra</orchestra>
  <conductor>Claudio Abbado</conductor>
  <date>1968</date>
  <performance>
    <composer>Frederic Chopin</composer>
    <composition>Piano Concerto No. 1</composition>
  </performance>
  <performance>
    <composer>Franz Liszt</composer>
    <composition>Piano Concerto No. 1</composition>
  </performance>
</CD>
```

Example (5)

```
<CD number="430702-2">
  <composer>Antonin Dvorak</composer>
  <performance>
    <composition>Symphony No. 9</composition>
    <orchestra>Vienna Philharmonic</orchestra>
    <conductor>Kirill Kondrashin</conductor>
    <date>1980</date>
  </performance>
  <performance>
    <composition>American Suite</composition>
    <orchestra>Royal Philharmonic</orchestra>
    <conductor>Antal Dorati</conductor>
    <date>1984</date>
  </performance>
</CD>
```

Future of XML

- XML offers the possibility of truly cross-platform, long-term data formats:
  - Much of the data from the original moon landings is now effectively lost
  - Even reading an older Word file might already be problematic
- XML is a very simple, well-documented data format
- Any tool that can read text files can read an XML document
- XML may be the most portable and flexible document format since the ASCII text file

Overview

- In these lectures we are going to look at
  - some basic notions of XML
  - how to define XML vocabularies (DTDs, XML schemas)
  - how to query XML documents (XPath, XQuery)
  - how to process these queries (very little, indeed)

Literature

- A. Møller and M. Schwartzbach. *An Introduction to XML and Web Technologies*. Addison Wesley, 2006.
- S. Abiteboul, I. Manolescu, P. Rigaux, M-C. Rousset and P. Senellart. *Web Data Management*. Cambridge University Press, 2012.
- E.R. Harold, W.S. Means. *XML in a Nutshell.* O'Reilly, 2004
- H. Katz (editor). *XQuery from the Experts.* Addison Wesley, 2004
- These slides . . .

Chapter 2

XML Fundamentals

Elements, Tags, and Data

- A very simple fragment of an XML document:

```
<person>
   Alan Turing
</person>
```

- Composed of a single *element* whose name is `person`
- Element is delimited by the *start tag* `<person>` and the *end tag* `</person>`
- Everything between the start tag and end tag (exclusive) is the element's *content*

Elements, Tags, and Data (2)

- Content of the above element is the text string `Alan Turing`
- Whitespace is part of the content (although many applications choose to ignore it)
- `<person>` and `</person>` are *markup*,
- The string `Alan Turing` and surrounding whitespace are *character data*

Elements, Tags, and Data (3)

- Special syntax for *empty elements*, elements without content
  - Each can be represented by a *single* tag that begins with `<` but ends with `/>`
  - e.g., `<person/>` instead of `<person></person>`
- XML is case sensitive, i.e. `<Person>` is not the same as `<PERSON>` (or `<person>`)

XML Documents and Trees

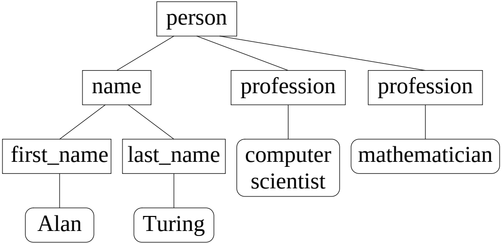
XML documents can be represented as trees

```
<person>
  <name>
    <first_name>Alan</first_name>
    <last_name>Turing</last_name>
  </name>
  <profession>
    computer scientist
  </profession>
  <profession>
    mathematician
  </profession>
</person>
```

XML Documents and Trees

XML documents can be represented as trees

```
<person>
  <name>
    <first_name>Alan</first_name>
    <last_name>Turing</last_name>
  </name>
  <profession>
    computer scientist
  </profession>
  <profession>
    mathematician
  </profession>
</person>
```



XML Documents and Trees (2)

- The `person` element contains three *child* elements: one `name` and two `profession` elements
- The `person` element is called the *parent* element of these three elements
- An element can have an arbitrary number of child elements and the elements may be nested arbitrarily deeply
- Children of the same parent are called *siblings*
- Overlapping tags are prohibited, so the following is not possible:

```
<strong>
    <em>
        example from HTML
    </strong>
</em>
```

XML Documents and Trees (3)

- Every XML document has one element without a parent
- This element is called the document's *root element* (sometimes called *document element*)
- The root element contains all other elements of a document

Attributes

- XML elements can have *attributes*
- An attribute is name-value pair attached to an element's start tag
- Names are separated from values by an equals sign
- Values are enclosed in single or double quotation marks
- An element cannot have two attributes with the same name
- Example:

```
<person born='1912/06/23' died='1954/06/07'>
   Alan Turing
</person>
```

- The order in which attributes appear is not significant

Attributes (2)

- We could model the contents of the original document as attributes:

```
<person>
  <name first='Alan' last='Turing'/>
  <profession value='computer scientist'/>
  <profession value='mathematician'/>
</person>
```

- This raises the question of when to use child elements and when to use attributes
- There is no simple answer

Attributes vs. Child Elements

- Some people argue that attributes should be used for metadata (about the element) and elements for the information itself
  - It's not always easy to distinguish between the two
- Attributes are limited in structure (their value is simply a string)
- There can also be no more than one attribute with a given name
- Consequently, an element-based structure is more flexible and extensible

Entities and Entity References

- Character data inside an element may not contain, e.g., a raw unescaped opening angle bracket <
- If this character is needed in the text, it has to be escaped by using the < *entity reference*
- lt is the *name* of the entity; & and ; delimit the reference
- XML predefines five entities:

lt	<
amp	&
gt	>
quot	"
apos	'

- We will cover entities in more detail when discussing DTDs later

CDATA Sections

- When an XML document includes samples of XML or HTML source code, all <, >, and & characters must be encoded using entity references
- This replacement can become quite tedious
- To facilitate the process, literal code can be enclosed in a *CDATA section*
- Everything between `<![CDATA[` and `]]>` is treated as raw character data
- The only thing that cannot appear in a CDATA section is the end delimiter `]]>`

Comments

- XML documents can also be commented
- Similar to HTML comments, they begin with `<!--` and end with `-->`
- Comments may appear
  - anywhere in character data
  - before or after the root element
  - However, NOT inside a tag or another comment
- XML parsers may or may not pass along information found in comments

Processing Instructions

- In HTML, comments are sometimes abused to support nonstandard extensions (e.g., server-side includes)
- Unfortunately,
  - comments may not survive being passed through several different HTML editors and/or processors
  - innocent comments may end up as input to an application
- XML uses a special construct to pass information on to applications: a *processing instruction*
- It begins with `<?` and ends with `?>`
- Immediately following the `<?` is the target (possibly the name of the application)

Processing Instructions (2)

Examples:

- Associating a stylesheet with an XML document:

```
<?xml-stylesheet type="text/xsl" href="style.xsl"?>
```

- Embedded PHP in (X)HTML:

```
<?php
  mysql_connect("database...",
                "user",
                "password");
  ...
  mysql_close();
?>
```

XML Declaration

- The *XML declaration* looks like a processing instruction, but only gives some information about the document:

```
<?xml version='1.0'
      encoding='US-ASCII'
      standalone='yes'?>
```

- *version*: at the moment 1.0 and 1.1 are available (we focus on 1.0)
- *encoding*: defines the character set used (e.g. ASCII, Latin-1, Unicode UTF-8)
- *standalone*: determines if some other file (e.g. DTD) has to be read to determine proper values for parts of the document

Well-Formedness

A *well-formed* document observes the syntax rules of XML:

- Every start tag must have a matching end tag
- Elements may not overlap
- There must be exactly one root element
- Attribute values must be quoted
- An element may not have two attributes with the same name
- Comments and processing instructions may not appear inside tags
- No unescaped `<` or `&` signs may occur in character data

Well-Formedness (2)

- XML names must be formed in certain ways:
  - May contain standard letters and digits 0 through 9
  - May include the punctuation characters underscore (_), hyphen (-), and period (.)
  - May only start with letters or the underscore character
  - There is no limit to the length
- The above list is not exhaustive; for a complete list look at the W3C specification
- A parser encountering a non-well-formed document will stop its parsing with an error message

XML Namespaces

- MathML is an XML vocabulary for mathematical expressions
- SVG (Scalable Vector Graphics) is an XML vocabulary for diagrams
- say we want to use XHTML, MathML and SVG in a single XML document
- how does a browser know which element is from which vocabulary?
- e.g., both SVG and MathML define a `set` element
- we shouldn't have to worry about potential name clashes
- we should be able to specify different *namespaces*, one for each of XHTML, MathML and SVG

The namespaces solution

- The solution is to *qualify* element names with *URIs*
- A URI (Universal Resource Identifier) is usually used for *identifying* a resource on the Web
- (A Uniform Resource Locator (URL) is a special type of URI)
- A *qualified name* then consists of two parts: `namespace:local-name`
- e.g., `<http://www.w3.org/2000/svg:circle ... />`
- where `http://www.w3.org/2000/svg` is a URI and namespace
- The URI does *not* have to reference a real Web resource
- URIs only disambiguate names; they don't have to define them
- In this case, the browser knows the SVG namespace and behaves accordingly

Namespace declarations

- using URIs everywhere is very cumbersome
- so namespaces are used indirectly using
  - namespace *declarations* and
  - associated *prefixes* (user-specified)

```
<... xmlns:svg="http://www.w3.org/2000/svg">
    <p>A circle looks like this
    ...
        <svg:circle ... />
    ...
</...>
```

- The `xmlns:svg` attribute
  - declares the namespace `http://www.w3.org/2000/svg`
  - associates it with prefix `svg`

Scope of namespace declarations

- the *scope* of a namespace declaration is
  - the element containing the declaration
  - and all its *descendants* (those elements nested inside the element)
  - can be overridden by *nested* declarations
- both elements and attributes can be qualified with namespaces
- unprefixed element names are assigned a *default* namespace
- default namespace declaration: `xmlns="URI"`

Namespaces example

```
<html xmlns="http://www.w3.org/1999/xhtml"
      xmlns:svg="http://www.w3.org/2000/svg">
   ...
   <p>A circle looks like this
      <svg:svg ...  >
         ...
         <svg:circle ...  />
         ...
      </svg:svg>
       and has
      ...
   </p>
</html>
```

- `html` and `p` are in the *default* namespace (`http://www.w3.org/1999/xhtml`)

Namespaces example (2)

```
<html xmlns="http://www.w3.org/1999/xhtml"
      xmlns:svg="http://www.w3.org/2000/svg">
   ...
   <p>A circle looks like this
      <svg:svg ...  >
         ...
         <svg:circle ...  />
         ...
      </svg:svg>
       and has
      ...
   </p>
</html>
```

- namespace for `svg` and `circle` is `http://www.w3.org/2000/svg`
- note that `svg` is used both as a prefix and as an element name

Summary

- This chapter gave a brief summary of XML
- Only the most important aspects (which are needed later on) were covered
- More details can be found
  - in the books listed in the Introduction
  - on numerous websites, e.g., World Wide Web Consortium or w3schools.com

Chapter 3

Document Type Definitions

Document Types

- A *document type* is defined by specifying the constraints which any document which is an *instance* of the type must satisfy
- For example,
  - in an HTML document, one paragraph cannot be nested inside another
  - in an SVG document, every `circle` element must have an `r` (radius) attribute
- Document types are
  - useful for restricting authors to use particular representations
  - important for correct processing of documents by software

Languages for Defining Document Types

- There are many languages for *defining* document types on the Web, e.g.,
  - document type definitions (DTDs)
  - XML schema definition language (XSDL)
  - relaxNG
  - schematron
- We will consider the first two of these

Document Type Definitions (DTDs)

- A DTD defines a *class* of documents
- The structural constraints are specified using an *extended context-free grammar*
- This defines
  - *element* names and their allowed contents
  - *attribute* names and their allowed values
  - *entity* names and their allowed values

Valid XML

- A *valid* XML document
  - is well-formed and
  - has been validated against a DTD
  - (the DTD is specified in the document — see later)

DTD syntax

- The syntax for an element declaration in a DTD is:

  `<!ELEMENT` *name* (*model*) `>`

  where
  - `ELEMENT` is a keyword
  - *name* is the element name being declared
  - *model* is the element *content model* (the allowed contents of the element)
- The content model is specified using a *regular expression* over element names
- The regular expression specifies the permitted *sequences* of element names

Examples of DTD element declarations

- An `html` element must contain a `head` element followed by a `body` element:

  ```
  <!ELEMENT html (head, body) >
  ```

  where "," is the *sequence* (or concatenation) operator

Examples of DTD element declarations

- An `html` element must contain a `head` element followed by a `body` element:

  ```
  <!ELEMENT html (head, body) >
  ```

  where "," is the *sequence* (or concatenation) operator

- A `list` element (not in HTML) must contain either a `ul` element or an `ol` element (but not both):

  ```
  <!ELEMENT list (ul | ol) >
  ```

  where "|" is the *alternation* (or "exclusive or") operator

Examples of DTD element declarations

- An `html` element must contain a `head` element followed by a `body` element:

  `<!ELEMENT html (head, body) >`

  where "," is the *sequence* (or concatenation) operator
- A `list` element (not in HTML) must contain either a `ul` element or an `ol` element (but not both):

  `<!ELEMENT list (ul | ol) >`

  where "|" is the *alternation* (or "exclusive or") operator
- A `ul` element must contain zero or more `li` elements:

  `<!ELEMENT ul (li)* >`

  where "*" is the *repetition* (or "Kleene star") operator

DTD syntax (1)

In the table below:

- e denotes any element name, the simplest regular expression
- α and β denote regular expressions

DTD Syntax	Meaning
e	element e must occur
α	elements must match α
(α)	elements must match α
α , β	elements must match α followed by β
α | β	elements must match either α or β (not both)
α*	elements must match zero or more occurrences of α

DTD syntax (2)

DTD Syntax	Meaning
α+	one or more sequences matching α must occur
α?	zero or one sequences matching α must occur
EMPTY	no element content is allowed
ANY	any content (of declared elements and text) is allowed
#PCDATA	content is text rather than elements

- α+ is short for (α,α*)
- α? is short for (α|EMPTY)
- #PCDATA stands for "parsed character data," meaning an XML parser should parse the text to resolve character and entity references

RSS

- RSS is a simple XML vocabulary for use in news feeds
- RSS stands for *Really Simple Syndication*, among other things
- The root (document) element is `rss`
- `rss` has a single child called `channel`
- `channel` has a `title` child, any number of `item` children (and others)
- Each `item` (news story) has a `title`, `description`, `link`, `pubDate`, ...

RSS Example Outline

```
<rss version="2.0">
  <channel>
    <title> BBC News - World </title>
      ...
    <item>
      <title> Hollande becomes French president </title>
        ...
    </item>
    <item>
      <title> New Greece poll due as talks fail </title>
        ...
    </item>
    <item>
      <title> EU forces attack Somalia pirates </title>
    </item>
      ...
  </channel>
</rss>
```

RSS Example Fragment (channel)

```
<channel>
  <title> BBC News - World </title>
  <link>http://www.bbc.co.uk/news/world/...</link>
  <description>The latest stories from the World section of
             the BBC News web site.</description>
  <lastBuildDate>Tue, 15 May 2012 13:42:05 GMT</lastBuildDate>
  <ttl>15</ttl>
  ...
</channel>
```

RSS Example Fragment (first item)

```
<item>
  <title>Hollande becomes French president</title>
  <description>Francois Hollande says he is fully aware
    of the challenges facing France after being sworn
    in as the country's new president.</description>
  <link>http://www.bbc.co.uk/news/world-europe-...</link>
  <pubDate>Tue, 15 May 2012 11:44:17 GMT</pubDate>
  ...
</item>
```

RSS Example Fragment (second item)

```
<item>
  <title>New Greece poll due as talks fail</title>
  <description>Greece is set to go to the polls again
    after parties failed to agree on a government for
    the debt-stricken country, says Socialist leader
    Evangelos Venizelos.</description>
  <link>http://www.bbc.co.uk/news/world-europe-...</link>
  <pubDate>Tue, 15 May 2012 13:52:38 GMT</pubDate>
  ...
</item>
```

RSS Example Fragment (third item)

```
<item>
  <title>EU forces attack Somalia pirates</title>
  <description>EU naval forces conduct their first raid
    on pirate bases on the Somali mainland, saying they
    have destroyed several boats.</description>
  <link>http://www.bbc.co.uk/news/world-africa-...</link>
  <pubDate>Tue, 15 May 2012 13:19:51 GMT</pubDate>
  ...
</item>
```

Simplified DTD for RSS

```
<!ELEMENT rss         (channel)>
<!ELEMENT channel     (title, link, description,
                       lastBuildDate?, ttl?, item+)>
<!ELEMENT item        (title, description, link?, pubDate?)>
<!ELEMENT title       (#PCDATA)>
<!ELEMENT link        (#PCDATA)>
<!ELEMENT description (#PCDATA)>
<!ELEMENT lastBuildDate (#PCDATA)>
<!ELEMENT ttl         (#PCDATA)>
<!ELEMENT pubDate     (#PCDATA)>
```

Validation of XML Documents

- Recall that an XML document is called *valid* if it is well-formed and has been validated against a DTD
- Validation is essentially checking that the XML document, viewed as a tree, is a *parse tree* in the language specified by the DTD
- We can use the W3C validator service (suggestion, pass the URI; use two files, one for the XML document and the other for the DTD)
- Each of the following files has the same DTD specified (as on the previous slide):
  - `rss-invalid.xml` giving results
  - `rss-valid.xml` giving results

Referencing a DTD

- The DTD to be used to validate a document can be specified
  - internally (as part of the document)
  - externally (in another file)
- done using a *document type declaration*
- *declare* document to be of type given in DTD
- e.g., `<!DOCTYPE rss ... >`

Declaring an Internal DTD

```
<?xml version="1.0"?>
<!DOCTYPE rss [
      <!-- all declarations for rss DTD go here -->
      ...
      <!ELEMENT rss ...  >
      ...
]>
<rss>
      <!-- This is an instance of a document of type rss -->
      ...
</rss>
```

- element `rss` must be defined in the DTD
- name after `DOCTYPE` (i.e., `rss`) must match root element of document

Declaring an External DTD (1)

```
<?xml version="1.0"?>
<!DOCTYPE rss SYSTEM "rss.dtd">
<rss>
   <!-- This is an instance of a document of type rss -->
   ...
</rss>
```

- what follows `SYSTEM` is a *URI*
- `rss.dtd` is a relative URI, assumed to be in same directory as source document

Declaring an External DTD (2)

```
<?xml version="1.0"?>
<!DOCTYPE math PUBLIC "-//W3C//DTD MathML 2.0//EN"
     "http://www.w3.org/TR/MathML2/dtd/mathml2.dtd">
<math>
   <!-- This is an instance of a mathML document type -->
   ...
</math>
```

- `PUBLIC` means what follows is a *formal public identifier* with 4 fields:
  1. `ISO` for ISO standard, `+` for approval by other standards body, and `-` for everything else
  2. *owner* of the DTD: e.g., `W3C`
  3. *title* of the DTD: e.g., `DTD MathML 2.0`
  4. *language* abbreviation: e.g., `EN`
- URI gives location of DTD

More on RSS

- The RSS 2.0 specification actually states that, for each `item`, *at least one of* `title` or `description` must be present
- How can we modify our previous DTD to specify this?

More on RSS

- The RSS 2.0 specification actually states that, for each `item`, *at least one of* `title` or `description` must be present
- How can we modify our previous DTD to specify this?
- The allowed sequences are:
  1. `title`
  2. `title description`
  3. `description`

More on RSS

- The RSS 2.0 specification actually states that, for each `item`, *at least one of* `title` or `description` must be present
- How can we modify our previous DTD to specify this?
- The allowed sequences are:
  1. `title`
  2. `title description`
  3. `description`
- So what about the following regular expression?

```
title | (title, description) | description
```

Non-Deterministic Regular Expressions

- The regular expression

  `title | (title, description) | description`

  is non-deterministic
- This means that a parser must read ahead to find out which part of the regular expression to match
- e.g., given a `title` element in the input, which of the following expressions should a parser try to match?
  - `title` or
  - `title description`

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- e.g., given a `title` element in the input, which of the following expressions should a parser try to match?
  - `title` or
  - `title description`
- It needs to read the next element to check whether or not it is `description`

Non-Deterministic vs Deterministic Regular Expressions

- Non-deterministic regular expressions are *forbidden* by DTDs and XSDL
- They are allowed by RelaxNG
- A non-deterministic regular expression can always be rewritten to be deterministic

Non-Deterministic vs Deterministic Regular Expressions

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- A non-deterministic regular expression can always be rewritten to be deterministic
- e.g.,

  ```
  title | (title, description) | description
  ```

  can be rewritten as

  ```
  (title, description?)  | description
  ```

Non-Deterministic vs Deterministic Regular Expressions

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- They are allowed by RelaxNG
- A non-deterministic regular expression can always be rewritten to be deterministic
- e.g.,

  ```
  title | (title, description) | description
  ```

  can be rewritten as

  ```
  (title, description?)  | description
  ```
- The rewriting may cause an exponential increase in size

Attributes

- Recall that attribute name-value pairs are allowed in start tags, e.g., `version="2.0"` in the `rss` start tag
- Allowed attributes for an element are defined in an *attribute list declaration*: e.g., for `rss` and `guid` elements

```
<!ATTLIST rss
  version CDATA #FIXED "2.0" >
<!ATTLIST guid
  isPermaLink (true|false) "true" >
```

- attribute definition comprises
  - *attribute name*, e.g., `version`
  - *type*, e.g., `CDATA`
  - *default*, e.g., `"true"`

Some Attribute Types

- `CDATA`: any valid character data
- `ID`: an identifier unique within the document
- `IDREF`: a reference to a unique identifier
- `IDREFS`: a reference to several unique identifiers (separated by white-space)
- `(a|b|c)`, e.g.: (*enumerated attribute type*) possible values are one of `a`, `b` or `c`
- ...

Attribute Defaults

- `#IMPLIED`: attribute may be omitted (optional)
- `#REQUIRED`: attribute must be present
- `#FIXED "x"`, e.g.: attribute optional; if present, value must be `x`
- `"x"`, e.g.: value will be `x` if attribute is omitted

Mixed Content

- In `rss`, the content of each element comprised either only other elements or only text
- In HTML, on the other hand, paragraph elements allow text interleaved with various in-line elements, such as `em`, `img`, `b`, etc.
- Elements like HTML paragraphs are said to have *mixed content*
- How do we define mixed content models in a DTD?

Mixed Content Models

- Say we want to mix text with elements `em`, `img` and `b` as the allowed contents of a `p` element
- The DTD content model would be as follows:

```
<!ELEMENT p (#PCDATA | em | img | b)* >
```

  - `#PCDATA` must be first (in the definition)
  - It must be followed by the other elements separated by |
  - The subexpression must have ∗ applied to it
- These restrictions limit our ability to constrain the content model (see XSDL later)

Entities

- An *entity* is a physical unit such as a character, string or file — essentially, they are “macros”
- Entities allow
  - references to non-keyboard characters
  - abbreviations for frequently used strings
  - documents to be broken up into multiple parts
- An *entity declaration* in a DTD associates a name with an entity, e.g.,
  `<!ENTITY BBK "Birkbeck, University of London">`
- An *entity reference*, e.g., `&BBK;` substitutes value of entity for its name in document
- An entity must be declared before it is referenced

General Entities

- BBK is an example of a *general entity*
- In XML, only 5 general entity declarations are built-in
  - & (&), < (<), > (>), " ("), ' (’),
- All other entities must be declared in a DTD
- The values of *internal* entities are defined in the same document as references to them
- The values of *external* entities are defined elsewhere, e.g.,
  <!ENTITY HTML-chapter SYSTEM "html.xml" >
  - then &HTML-chapter; includes the contents of file html.xml at the point of reference
  - standalone="no" must be included in the XML declaration

Parameter Entities

- *Parameter entities* are
  - used only within XML markup declarations
  - declared by inserting % between `ENTITY` and name, e.g.,

```
<!ENTITY % list     "OL | UL" >
<!ENTITY % heading  "H1 | H2 | H3 | H4 | H5 | H6" >
```

  - referenced using % and ; delimiters, e.g.,

```
<!ENTITY % block  "P | %list; | %heading; | ..." >
```

- As an example. see the HTML 4.01 DTD

Limitations of DTDs

- There is no data typing, especially for element content
- They are only marginally compatible with namespaces
- We cannot use mixed content *and* enforce the order and number of child elements
- It is clumsy to enforce the presence of child elements without also enforcing an order for them (i.e. no & operator from SGML)
- Element names in a DTD are *global* (see later)
- They use non-XML syntax
- The XML Schema Definition Language, e.g., addresses these limitations

Chapter 4

XML Schema Definition Language (XSDL)

XML Schema

- XML Schema is a W3C Recommendation
  - XML Schema Part 0: Primer
  - XML Schema Part 1: Structures
  - XML Schema Part 2: Datatypes
- describes permissible contents of XML documents
- uses XML syntax
- sometimes referred to as *XSDL: XML Schema Definition Language*
- addresses a number of limitations of DTDs

Simple example

- file `greeting.xml` contains:

```
<?xml version="1.0"?>
<greet>Hello World!</greet>
```

- file `greeting.xsd` contains:

```
<xsd:schema xmlns:xsd="http://www.w3.org/2001/XMLSchema">
   <xsd:element name="greet" type="xsd:string"/>
</xsd:schema>
```

- declares element with name `greet` to be of built-in type `string`
- `xsd` is prefix for the namespace for the "schema of schemas"

DTDs vs. schemas

DTD	Schema
`<!ELEMENT>` declaration	`xsd:element` element
`<!ATTLIST>` declaration	`xsd:attribute` element
`<!ENTITY>` declaration	(not available)
`#PCDATA` content	`xsd:string` type
(not available)	other data types

Schemas and namespaces

- schemas are designed to be compatible with namespaces
- a schema can define structures for a particular namespace
  - this is called the *target* namespace
- a document using this namespace can refer to the schema for validation
- schemas can also be defined for document types which do not use namespaces
  - in this case, there is no target namespace

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- a document using this namespace can refer to the schema for validation
- schemas can also be defined for document types which do not use namespaces
  - in this case, there is no target namespace
- we will consider only the case without namespaces

Linking a schema to a document (no namespaces)

- `xsi:noNamespaceSchemaLocation` attribute on root element
- this says no target namespace is declared in the schema
- `xsi` prefix is mapped to the URI:
  `http://www.w3.org/2001/XMLSchema-instance`
- this namespace defines global attributes that relate to schemas and can occur in instance documents
- for example:

```
<greet xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
   xsi:noNamespaceSchemaLocation="greeting.xsd">
   Hello World!
</greet>
```

Validating a document

- a validator (found yesterday — it seems ok):
  - http://www.freeformatter.com/xml-validator-xsd.html

More complex document example

```
<cd xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
      xsi:noNamespaceSchemaLocation="cd.xsd">
  <composer>Johannes Brahms</composer>
  <performance>
    <composition>Piano Concerto No. 2</composition>
    <soloist>Emil Gilels</soloist>
    <orchestra>Berlin Philharmonic</orchestra>
    <conductor>Eugen Jochum</conductor>
    <recorded>1972</recorded>
  </performance>
  <performance>
    <composition>Fantasias Op. 116</composition>
    <soloist>Emil Gilels</soloist>
    <recorded>1976</recorded>
  </performance>
  <length>PT1H13M37S</length>
</cd>
```

Simple and complex data types

- XSDL allows the definition of *data types* as well as declarations of elements and attributes
- simple data types can contain only text (i.e., no markup)
  - e.g., values of attributes
  - e.g., elements without children or attributes
- complex data types can contain
  - child elements (i.e., markup) or
  - attributes

More complex schema example

```
<xsd:schema xmlns:xsd="http://www.w3.org/2001/XMLSchema">
   <xsd:element name="cd" type="CDType"/>









</xsd:schema>
```

More complex schema example

```
<xsd:schema xmlns:xsd="http://www.w3.org/2001/XMLSchema">
   <xsd:element name="cd" type="CDType"/>
   <xsd:complexType name="CDType">







   </xsd:complexType>

</xsd:schema>
```

More complex schema example

```
<xsd:schema xmlns:xsd="http://www.w3.org/2001/XMLSchema">
   <xsd:element name="cd" type="CDType"/>
   <xsd:complexType name="CDType">
      <xsd:sequence>






      </xsd:sequence>
   </xsd:complexType>

</xsd:schema>
```

More complex schema example

```
<xsd:schema xmlns:xsd="http://www.w3.org/2001/XMLSchema">
   <xsd:element name="cd" type="CDType"/>
   <xsd:complexType name="CDType">
      <xsd:sequence>
         <xsd:element name="composer" type="xsd:string"/>
         <xsd:element name="performance" type="PerfType"
                      maxOccurs="unbounded"/>
         <xsd:element name="length" type="xsd:duration"
                      minOccurs="0"/>
      </xsd:sequence>
   </xsd:complexType>

</xsd:schema>
```

More complex schema example

```
<xsd:schema xmlns:xsd="http://www.w3.org/2001/XMLSchema">
   <xsd:element name="cd" type="CDType"/>
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      </xsd:sequence>
   </xsd:complexType>
   ...
</xsd:schema>
```

Main schema components

- `xsd:element` *declares* an element and assigns it a type, e.g.,

  ```
  <xsd:element name="composer"  type="xsd:string"/>
  ```

  using a built-in, simple data type, or

  ```
  <xsd:element name="cd" type="CDType"/>
  ```

  using a user-defined, complex data type

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  <xsd:element name="cd" type="CDType"/>
  ```

  using a user-defined, complex data type
- `xsd:complexType` *defines* a new type, e.g.,

  ```
  <xsd:complexType name="CDType">
  ...
  </xsd:complexType>
  ```

- defining named types allows reuse (and may help readability)

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```
<xsd:element name="cd" type="CDType"/>
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  using a user-defined, complex data type
- `xsd:complexType` *defines* a new type, e.g.,

```
<xsd:complexType name="CDType">
...
</xsd:complexType>
```

- defining named types allows reuse (and may help readability)
- `xsd:attribute` *declares* an attribute and assigns it a type (see later)

Structuring element declarations

- `xsd:sequence`
  - requires elements to occur in order given
  - analogous to `,` in DTDs
- `xsd:choice`
  - allows only one of the given elements to occur
  - analogous to `|` in DTDs
- `xsd:all`
  - all elements must occur, but in any order
  - analogous to `&` in *SGML* DTDs

Defining number of element occurrences

- `minOccurs` and `maxOccurs` attributes control the number of occurrences of an element, sequence or choice
- `minOccurs` must be a non-negative integer
- `maxOccurs` must be a non-negative integer or `unbounded`
- default value for each of `minOccurs` and `maxOccurs` is 1

Another complex type example

```
<xsd:complexType name="PerfType">
  <xsd:sequence>
    <xsd:element name="composition" type="xsd:string"/>
    <xsd:element name="soloist"     type="xsd:string"
                                    minOccurs="0"/>
    <xsd:sequence minOccurs="0">
      <xsd:element name="orchestra" type="xsd:string"/>
      <xsd:element name="conductor" type="xsd:string"/>
    </xsd:sequence>
    <xsd:element name="recorded"    type="xsd:gYear"/>
  </xsd:sequence>
</xsd:complexType>
```

An equivalent DTD

```
<!ELEMENT CD          (composer, (performance)+, (length)?)>
<!ELEMENT performance (composition, (soloist)?,
                       (orchestra, conductor)?, recorded)>
<!ELEMENT composer    (#PCDATA)>
<!ELEMENT length      (#PCDATA)> <!-- duration -->
<!ELEMENT composition (#PCDATA)>
<!ELEMENT soloist     (#PCDATA)>
<!ELEMENT orchestra   (#PCDATA)>
<!ELEMENT conductor   (#PCDATA)>
<!ELEMENT recorded    (#PCDATA)> <!-- gYear -->
```

Declaring attributes

- use `xsd:attribute` element inside an `xsd:complexType`
- has attributes `name`, `type`, e.g.,

```
<xsd:attribute name="version" type="xsd:number"/>
```

- attribute `use` is optional
  - if omitted means attribute is optional (like `#IMPLIED`)
  - for required attributes, say `use="required"` (like `#REQUIRED`)
- for fixed attributes, say `fixed="..."` (like `#FIXED`), e.g.,

```
<xs:attribute name="version" type="xs:number" fixed="2.0"/>
```

- for attributes with default value, say `default="..."`
- for enumeration, use `xsd:simpleType`
- attributes must be declared at the *end* of an `xsd:complexType`

Locally-scoped element names

- in DTDs, all element names are *global*
- XML schema allows element types to be local to a context, e.g.,

```
<xsd:element name="book">
      <xsd:element name="title"> ... </xsd:element>
    ...
</xsd:element>

<xsd:element name="employee">
      <xsd:element name="title"> ... </xsd:element>
    ...
</xsd:element>
```

- content models for two occurrences of `title` can be different

Simple data types

- form a type hierarchy; the root is called *anyType*
  - all complex types
  - *anySimpleType*
    - `string`
    - `boolean`, e.g., `true`
    - `anyUri`, e.g., `http://www.dcs.bbk.ac.uk/~ptw/home.html`
    - `duration`, e.g., `P1Y2M3DT10H5M49.3S`
    - `gYear`, e.g., `1972`
    - `float`, e.g., `123E99`
    - `decimal`, e.g., `123456.789`
    - ...
- lowest level above are the *primitive data types*
- for a full list, see Simple Types in the Primer

Primitive date and time types

- `date`, e.g., `1994-04-27`
- `time`, e.g., `16:50:00+01:00` or `15:50:00Z` if in Co-ordinated Universal Time (UTC)
- `dateTime`, e.g., `1918-11-11T11:00:00.000+01:00`
- `duration`, e.g., `P2Y1M3DT20H30M31.4159S`
- "Gregorian" calendar dates (introduced in 1582 by Pope Gregory XIII):
  - `gYear`, e.g., `2001`
  - `gYearMonth`, e.g., `2001-01`
  - `gMonthDay`, e.g., `--12-25` (note hyphen for missing year)
  - `gMonth`, e.g., `--12--` (note hyphens for missing year and day)
  - `gDay`, e.g., `---25` (note only 3 hyphens)

Built-in derived string types

Derived from `string`:

- `normalizedString` (newline, tab, carriage-return are converted to spaces)
  - `token` (adjacent spaces collapsed to a single space; leading and trailing spaces removed)
    - `language`, e.g., `en`
    - `name`, e.g., `my:name`

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    - `language`, e.g., `en`
    - `name`, e.g., `my:name`

Derived from `name`:

- `NCNAME` ("non-colonized" name), e.g., `myName`
  - `ID`
  - `IDREF`
  - `ENTITY`

Built-in derived numeric types

Derived from `decimal`:

- `integer` (decimal with no fractional part), e.g., -123456
  - `nonPositiveInteger`, e.g., 0, -1
    - `negativeInteger`, e.g., -1
  - `nonNegativeInteger`, e.g., 0, 1
    - `positiveInteger`, e.g., 1
    - ...
  - ...

User-derived simple data types

- complex data types can be created "from scratch"
- new simple data types must be *derived* from existing simple data types

User-derived simple data types

- complex data types can be created "from scratch"
- new simple data types must be *derived* from existing simple data types
- derivation can be by one of
  - *extension*
    - *list*: a list of values of an existing data type
    - *union*: allows values from two or more data types
  - *restriction*: limits the values allowed using, e.g.,
    - maximum value (e.g., 100)
    - minimum value (e.g., 50)
    - length (e.g., of string or list)
    - number of digits
    - enumeration (list of values)
    - pattern

  above constraints are known as *facets*

Restriction by enumeration

```
<xsd:element name="MScResult">
  <xsd:simpleType>
    <xsd:restriction base="xsd:string">
      <xsd:enumeration value="distinction"/>
      <xsd:enumeration value="merit"/>
      <xsd:enumeration value="pass"/>
      <xsd:enumeration value="fail"/>
    </xsd:restriction>
  </xsd:simpleType>
</xsd:element>
```

- contents of `MScResult` element is a restriction of the `xsd:string` type
- must be one of the 4 values given
- e.g., `<MScResult>pass</MScResult>`

Restriction by values

- examMark can be from 0 to 100

```
<xsd:element name="examMark">
  <xsd:simpleType>
    <xsd:restriction base="xsd:nonNegativeInteger">
      <xsd:maxInclusive value="100"/>
    </xsd:restriction>
  </xsd:simpleType>
</xsd:element>
```

Restriction by values

- examMark can be from 0 to 100

```
<xsd:element name="examMark">
  <xsd:simpleType>
    <xsd:restriction base="xsd:nonNegativeInteger">
      <xsd:maxInclusive value="100"/>
    </xsd:restriction>
  </xsd:simpleType>
</xsd:element>
```

- or, equivalently

```
    <xsd:restriction base="xsd:integer">
      <xsd:minInclusive value="0"/>
      <xsd:maxInclusive value="100"/>
    </xsd:restriction>
```

Restriction by pattern

```
<xsd:element name="zipcode">
  <xsd:simpleType>
    <xsd:restriction base="xsd:string">
      <xsd:pattern value="\d{5}(-\d{4})?"/>
    </xsd:restriction>
  </xsd:simpleType>
</xsd:element>
```

- `value` attribute contains a *regular expression*
- `\d` means any digit
- `()` used for grouping
- `x{5}` means exactly 5 `x`'s (in a row)
- `x?` indicates zero or one `x`
- zipcode examples: 90720-1314 and 22043

Document with mixed content

- We may want to mix elements and text, e.g.:

```
<letter>
  Dear Mr <name>Smith</name>,
  Your order of <quantity>1</quantity>
  <product>Baby Monitor</product> was shipped
  on <date>1999-05-21</date>. ....
</letter>
```

- A DTD would have to contain:

```
<!ELEMENT letter (#PCDATA|name|quantity|product|date)*>
```

which cannot enforce the order of subelements

Schema fragment declaring mixed content

```
<xsd:schema xmlns:xsd="http://www.w3.org/2001/XMLSchema">
  <xsd:element name="letter">
   <xsd:complexType mixed="true">
    <xsd:sequence>
     <xsd:element name="name" type="xsd:string"/>
     <xsd:element name="quantity" type="xsd:positiveInteger"/>
     <xsd:element name="product"  type="xsd:string"/>
     <xsd:element name="date" type="xsd:date" minOccurs="0"/>
     <!-- etc. -->
    </xsd:sequence>
   </xsd:complexType>
  </xsd:element>
</xsd:schema>
```

Summary

XSDL provides, e.g.:

- compatibility with namespaces
- many built-in data types
- user-defined (derived) data types
- locally-scoped element declarations
- more control over mixed content models

Chapter 6

XPath

Introduction

- XPath is a language that lets you identify particular parts of XML documents
- XPath interprets XML documents as nodes (with content) organised in a tree structure
- XPath indicates nodes by (relative) position, type, content, and several other criteria
- Basic syntax is somewhat similar to that used for navigating file hierarchies
- XPath 1.0 (1999) and 2.0 (2010) are W3C recommendations

Some Tools for XPath

- Saxon (specifically Saxon-HE which implements XPath 2.0, XQuery 1.0 and XSLT 2.0)
- eXist-db (a native XML database system supporting XPath 2.0, most of XQuery 1.0 and 3.0, and XSLT 1.0)
- XPath Checker (add-on for Firefox)
- XPath Expression Testbed (available online)
- http://videlibri.sourceforge.net/cgi-bin/xidelcgi (also available online)

Data Model

XPath's data model has some non-obvious features:

- The tree's root node is not the same as the document's root (document) element
- The tree's root node contains the entire document including the root element (and comments and processing instructions that appear before it)
- XPath's data model does not include everything in the document: XML declaration and DTD are not addressable
- `xmlns` attributes are reported as namespace nodes

Data Model (2)

- There are 6 types of *node*:
  - *root*
  - *element*
  - *attribute*
  - *text*
  - *comment*
  - *processing instruction*
- Element nodes have an associated set of attribute nodes
- Attribute nodes are *not* children of element nodes
- The order of child element nodes is *significant*
- We will only consider the first 4 types of node

Example (1)

Recall our CD library example

```
<CD-library>
  <CD number="724356690424">
    <performance>
      <composer>Frederic Chopin</composer>
      <composition>Waltzes</composition>
      <soloist>Dinu Lipatti</soloist>
      <date>1950</date>
    </performance>
  </CD>
  ...
```

Example (2)

```
...
<CD number="419160-2">
  <composer>Johannes Brahms</composer>
  <soloist>Emil Gilels</soloist>
  <performance>
    <composition>Piano Concerto No. 2</composition>
    <orchestra>Berlin Philharmonic</orchestra>
    <conductor>Eugen Jochum</conductor>
    <date>1972</date>
  </performance>
  <performance>
    <composition>Fantasias Op. 116</composition>
    <date>1976</date>
  </performance>
</CD>
...
```

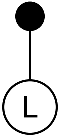
Example (3)

```
...
<CD number="449719-2">
  <soloist>Martha Argerich</soloist>
  <orchestra>London Symphony Orchestra</orchestra>
  <conductor>Claudio Abbado</conductor>
  <date>1968</date>
  <performance>
    <composer>Frederic Chopin</composer>
    <composition>Piano Concerto No. 1</composition>
  </performance>
  <performance>
    <composer>Franz Liszt</composer>
    <composition>Piano Concerto No. 1</composition>
  </performance>
</CD>
...
```

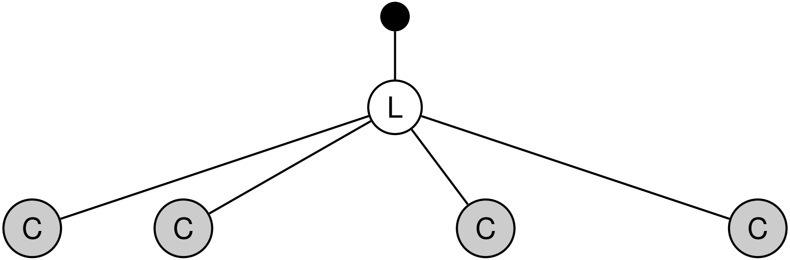
Example (4)

```
  ...
  <CD number="430702-2">
    <composer>Antonin Dvorak</composer>
    <performance>
      <composition>Symphony No. 9</composition>
      <orchestra>Vienna Philharmonic</orchestra>
      <conductor>Kirill Kondrashin</conductor>
      <date>1980</date>
    </performance>
    <performance>
      <composition>American Suite</composition>
      <orchestra>Royal Philharmonic</orchestra>
      <conductor>Antal Dorati</conductor>
      <date>1984</date>
    </performance>
  </CD>
</CD-library>
```

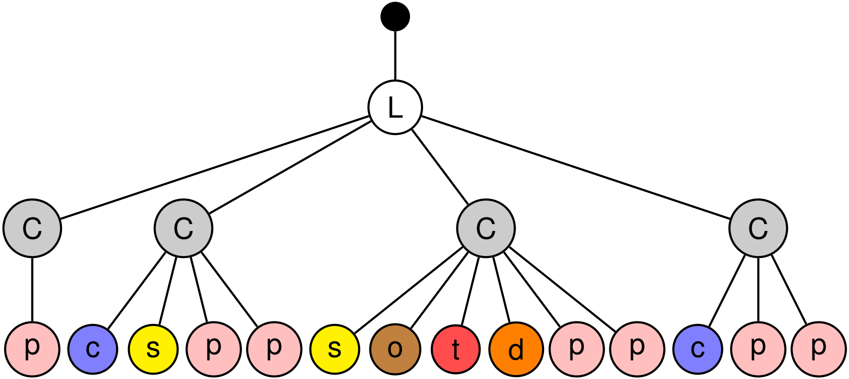
Example — Tree Structure



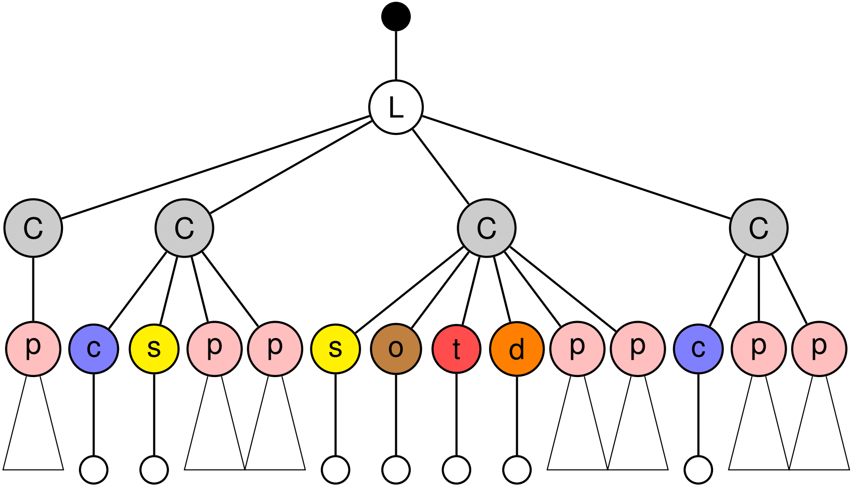
Example — Tree Structure



Example — Tree Structure



Example — Tree Structure



Comments on example tree structure

- *attribute* nodes are not shown (for `number` attribute)
- the *root* node is shown as solid black
- all nodes with labels (C, p, . . .) are *element* nodes
- white nodes without labels are *text* nodes
- not all of the tree is shown

Location Path

- The most useful XPath expression is a *location path*:
  e.g., `/CD-library/CD/performance`
- A location path consists of at least one *location step*:
  e.g., `CD-library`, `CD` and `performance` are location steps
- A location step takes as input a set of nodes, also called the *context* (to be defined more precisely later)
- The location step expression is applied to this node set and results in an output node set
- This output node set is used as input for the next location step

Location Path (2)

- There are two different kinds of location paths:
  - *Absolute* location paths
  - *Relative* location paths

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- An absolute location path
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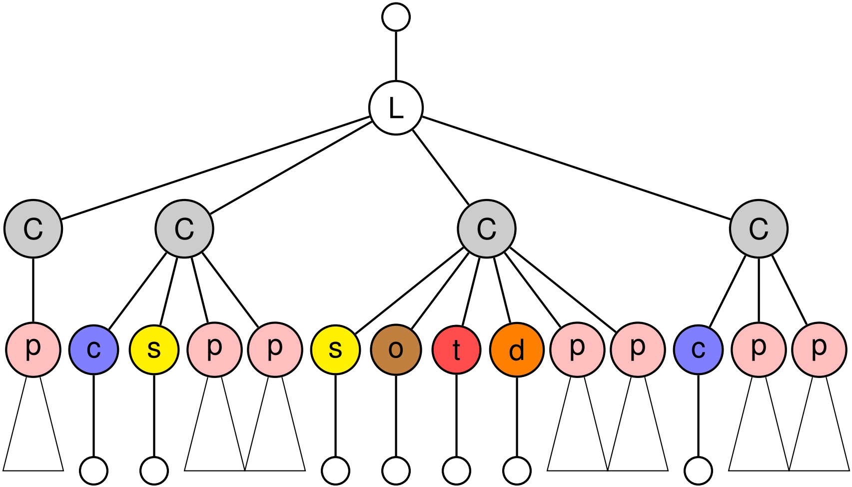
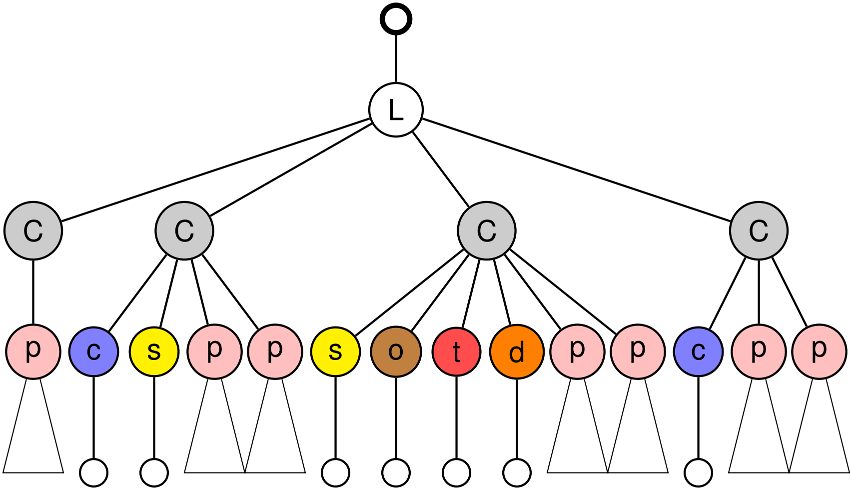
  - is followed by a relative location path
  - is evaluated at the root (context) node of a document
  - e.g., `/CD-library/CD/performance`
- A relative location path
  - is a sequence of location steps
  - each separated by `/`
  - evaluated with respect to some other context nodes
  - e.g., `CD/performance`

Evaluation of absolute location path



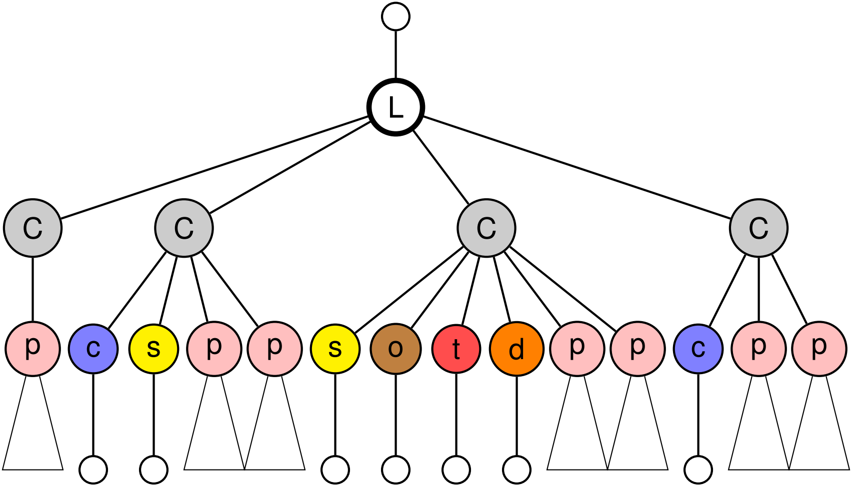
Evaluation of absolute location path

/



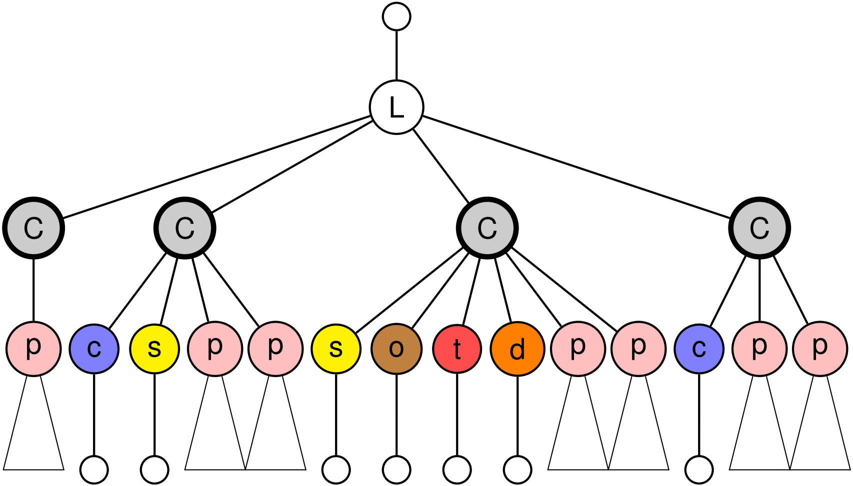
Evaluation of absolute location path

`/CD-library`



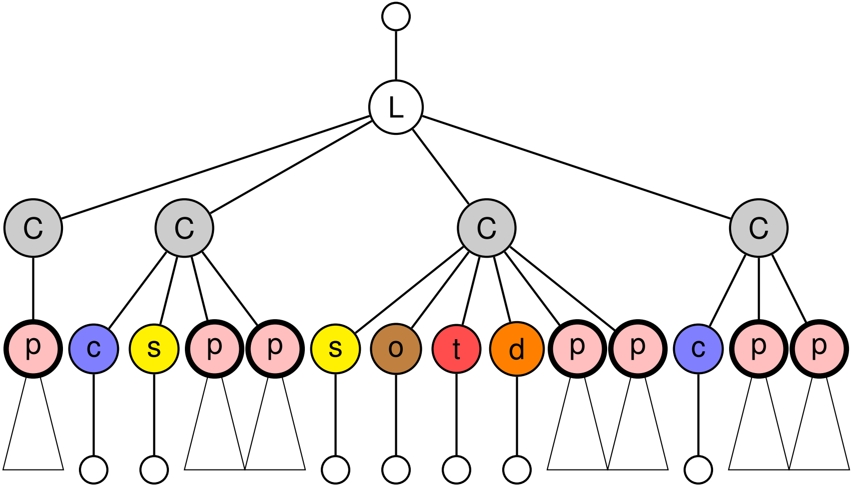
Evaluation of absolute location path

`/CD-library/CD`



Evaluation of absolute location path

/CD-library/CD/performance



Location Step

- In general, a location step consists of 3 parts:
  - (navigation) axis
  - node test
  - (optional) predicate(s)
- Full syntax is *axis* `::` *node test* `[` *predicate* `]` ... `[` *predicate* `]`
- (We used the *abbreviated* syntax in previous examples)

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- Full syntax is *axis* `::` *node test* `[` *predicate* `]` . . . `[` *predicate* `]`
- (We used the *abbreviated* syntax in previous examples)
- e.g., `child::CD[composer='Johannes Brahms']`
  - `child` is the axis
  - `CD` is the node test
  - `composer='Johannes Brahms'` is the predicate

Location Step

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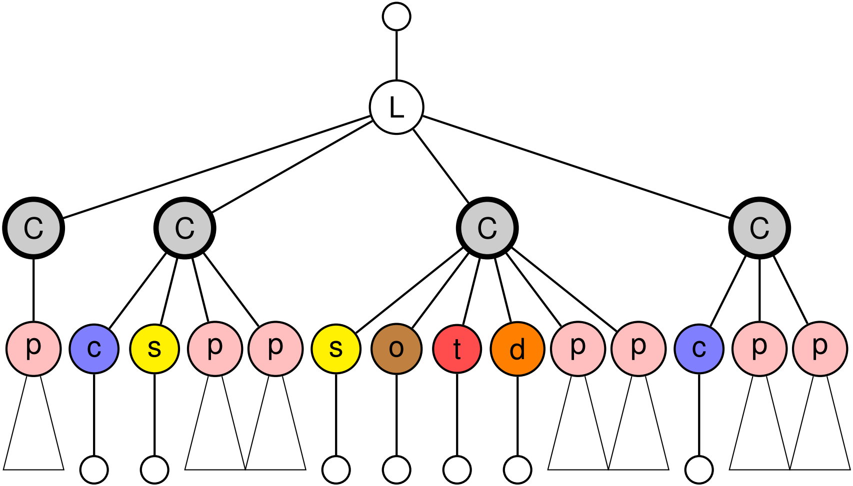
- (We used the *abbreviated* syntax in previous examples)
- e.g., `child::CD[composer='Johannes Brahms']`
  - `child` is the axis
  - `CD` is the node test
  - `composer='Johannes Brahms'` is the predicate
- A location step is applied to each node in the context (i.e., each node becomes the context node)
- All resulting nodes are added to the output set of this location step

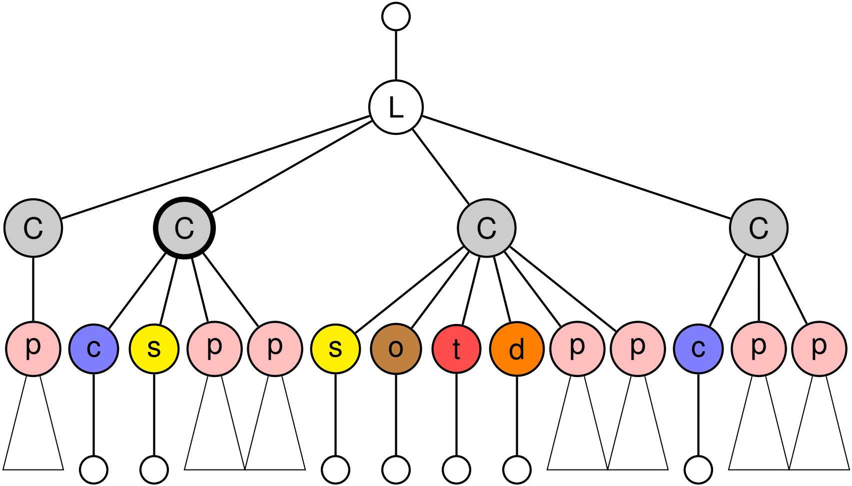
Evaluation of predicate

`/child::CD-library/child::CD`



Evaluation of predicate

`/child::CD-library/child::CD[composer='Johannes Brahms']`

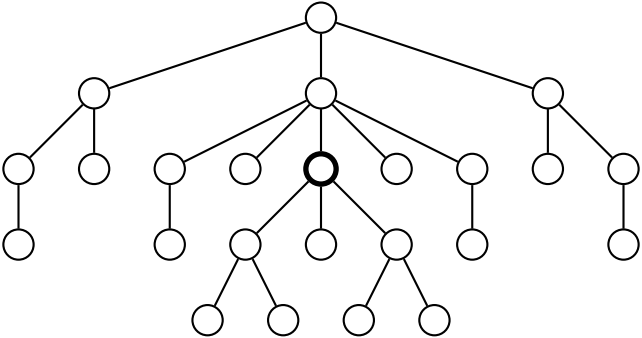


Axes

- An axis specifies what nodes, relative to the current context node, to consider
- There are 13 different axes (some can be abbreviated)
  - `self`, abbreviated by `.`
  - `child`, abbreviated by *empty axis*
  - `parent`, abbreviated by `..`
  - `descendant-or-self`, abbreviated by *empty location step*
  - `descendant`, `ancestor`, `ancestor-or-self`
  - `following`, `following-sibling`, `preceding`, `preceding-sibling`
  - `attribute`, abbreviated by `@`
  - `namespace`

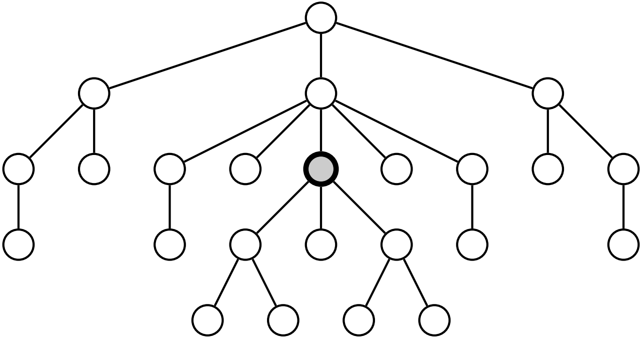
Axes

- The following slides show (graphical) examples of the axes, assuming the node in bold typeface is the context node



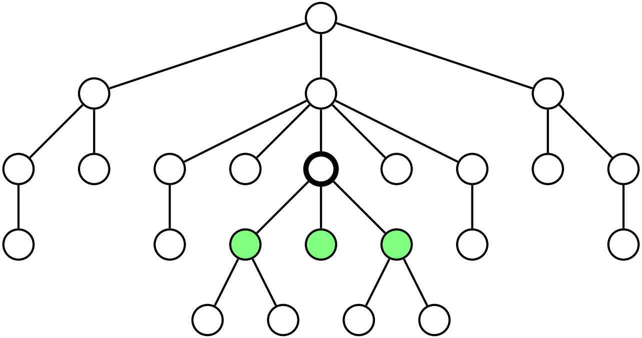
Self-Axis

- The self-axis just contains the context node itself



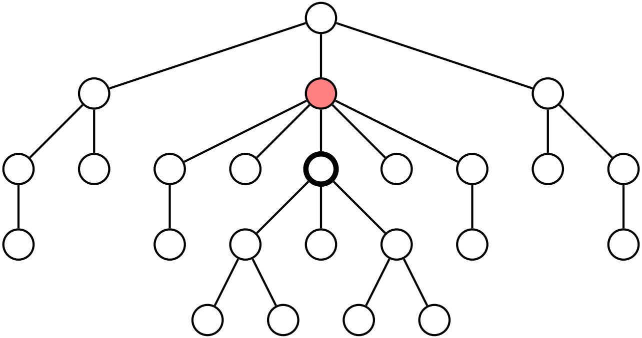
Child-Axis

- The child-axis contains the children (direct descendants) of the context node



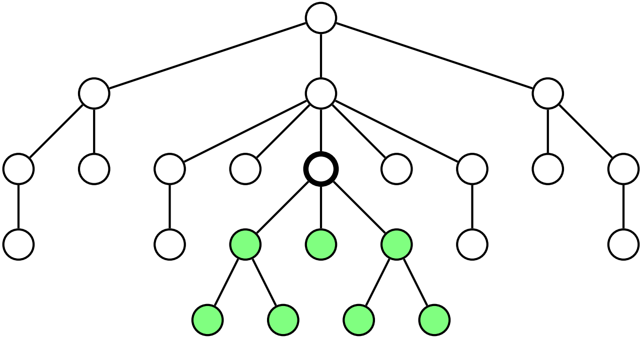
Parent-Axis

- The parent-axis contains the parent (direct ancestor) of the context node



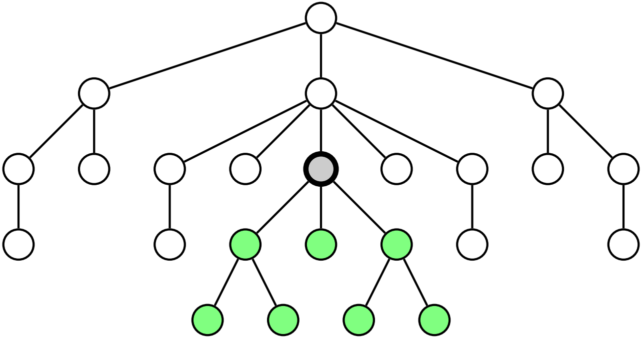
Descendant-Axis

- The descendant-axis contains all direct and indirect descendants of the context node



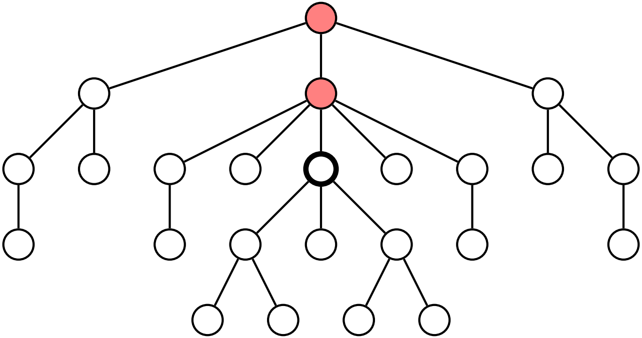
Descendant-Or-Self-Axis

- The descendant-or-self-axis contains all direct and indirect descendants of the context node + the context node itself



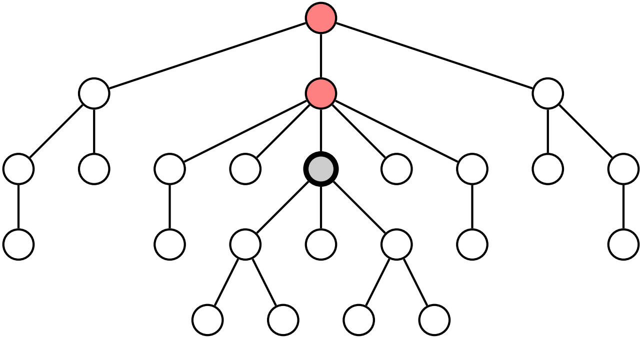
Ancestor-Axis

- The ancestor-axis contains all direct and indirect ancestors of the context node



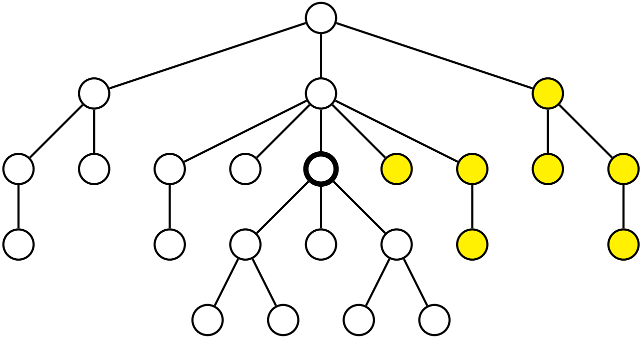
Ancestor-Or-Self-Axis

- The ancestor-or-self-axis contains all direct and indirect ancestors of the context node + the context node itself



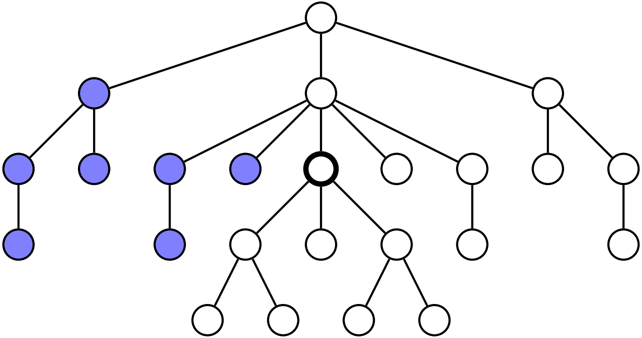
Following-Axis

- The following-axis contains all nodes that begin after the context node ends



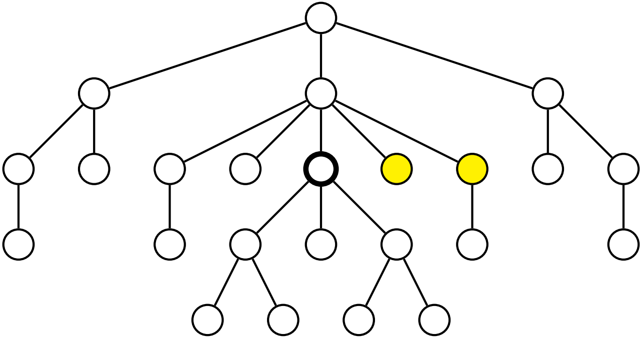
Preceding-Axis

- The preceding-axis contains all nodes that end before the context node begins



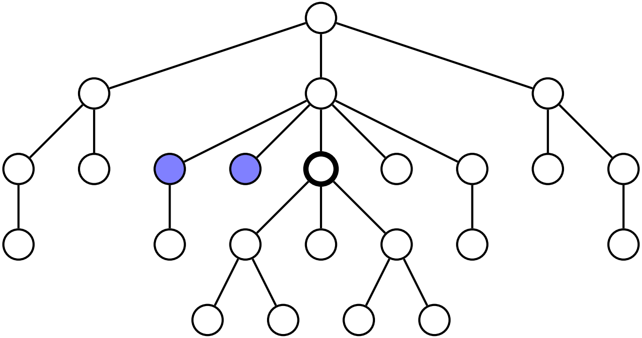
Following-Sibling-Axes

- The following-sibling-axis contains all following nodes that have the same parent as the context node



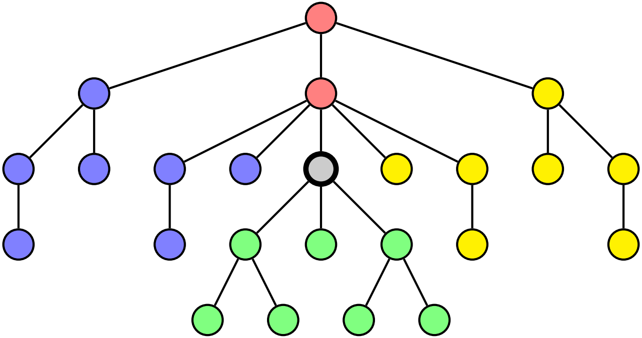
Preceding-Sibling-Axis

- The preceding-sibling-axis contains all preceding nodes that have the same parent as the context node



Partitioning

- The axes self, ancestor, descendant, following and preceding partition a document into five disjoint subtrees:



Attribute-Axis

- Attributes are handled in a special way in XPath
- The attribute-axis contains all the attribute nodes of the context node
- This axis is empty if the context node is not an element node
- Does not contain `xmlns` attributes used to declare namespaces

Namespace-Axis

- The namespace-axis contains all namespaces in scope of the context node
- This axis is empty if the context node is not an element node

Node Tests

- Once the correct relative position of a node has been identified the type of a node can be tested
- A *node test* further refines the nodes selected by the location step
- A double colon `::` separates the axis from the node test
- There are seven different kinds of node tests

name
prefix`:*`
`node()`
`text()`
`comment()`
`processing-instruction()`
`*`

Name

- The *name* node test selects all elements with a matching name
  - e.g., if our context is a set of 4 `CD` elements and the location step uses the `child` axis, then we get element nodes with different names
  - we can use the *name* node test to return, e.g., only `soloist` elements
- Along the attribute-axis it matches all attributes with the same name

Prefix:*

- Along an element axis, all nodes whose namespace URIs are the same as the prefix are matched
- This node test is also available for attribute nodes

Comment, Text, Processing-Instruction

- `comment()` matches all comment nodes
- `text()` matches all text nodes
- `processing-instruction()` matches all processing instructions

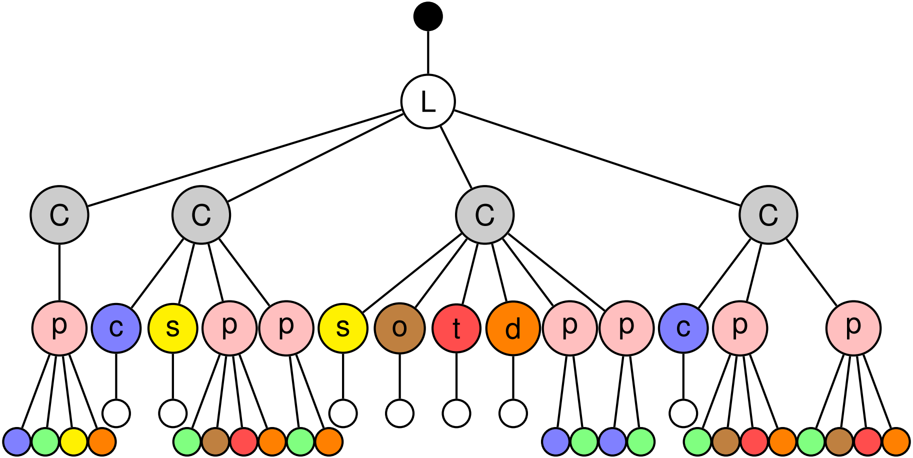
Node and *

- `node()` selects all nodes, regardless of type: attribute, element, text, comment, namespace, processing instruction, and root
- usually `*` selects all *element* nodes, regardless of name
  - If the axis is the attribute axis, then it selects all attribute nodes
  - If the axis is the namespace axis, then is selects all namespace nodes

Key for full CD library example

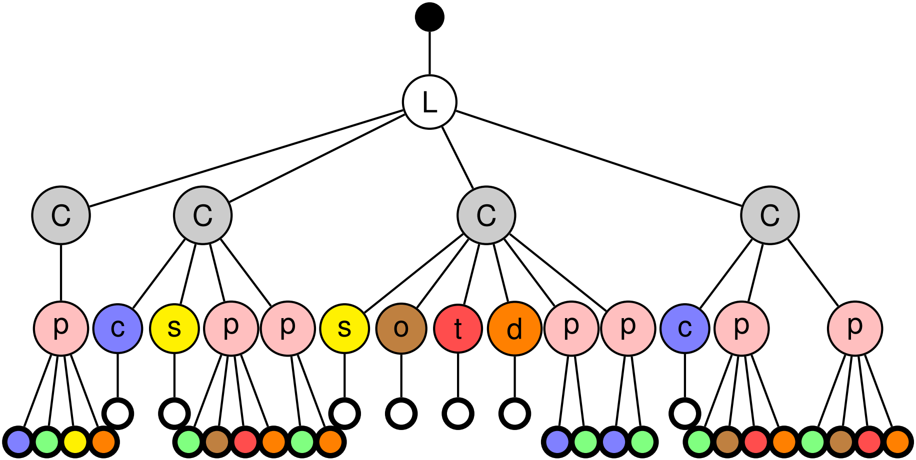
Element name	Abbreviation	Colour
root		black
library	L	white
cd	C	grey
performance	p	pink
composer	c	blue
composition		green
soloist	s	yellow
conductor	t	red
orchestra	o	brown
date	d	orange

Full CD library example



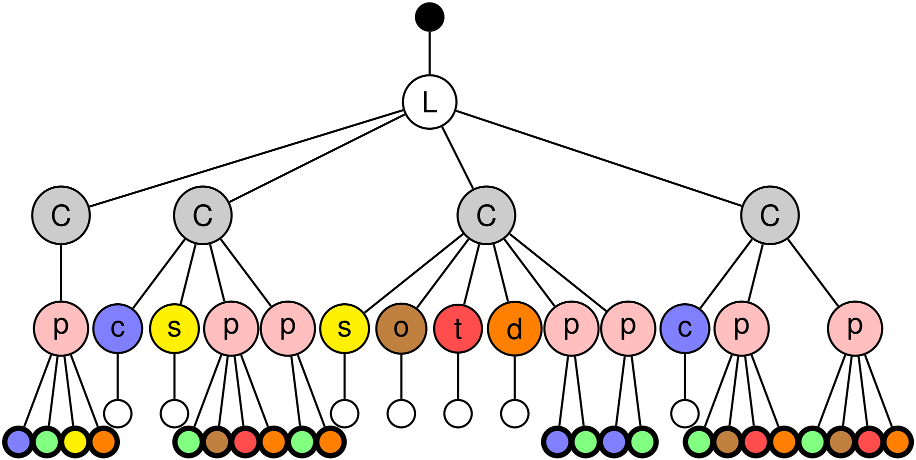
Example using * and node()

`/CD-library/CD/*/node()`



Example showing difference between * and node()

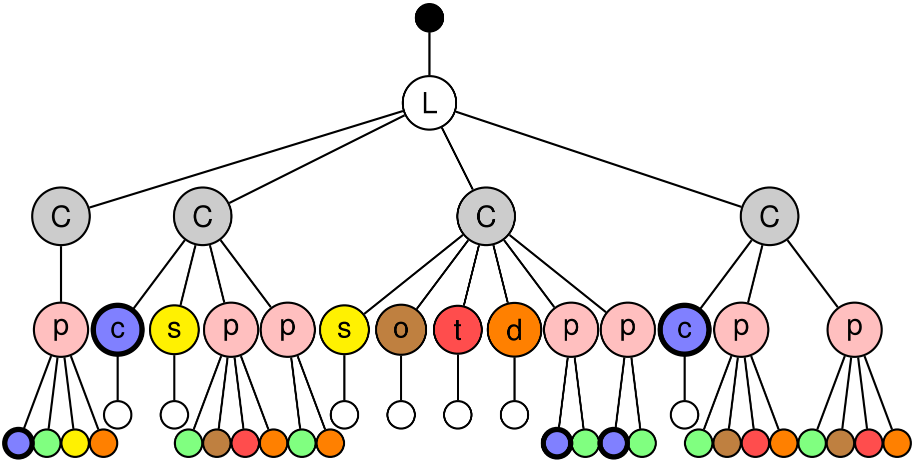
`/CD-library/CD/*/*`



Example using descendant

`//composer` (abbreviated syntax) or

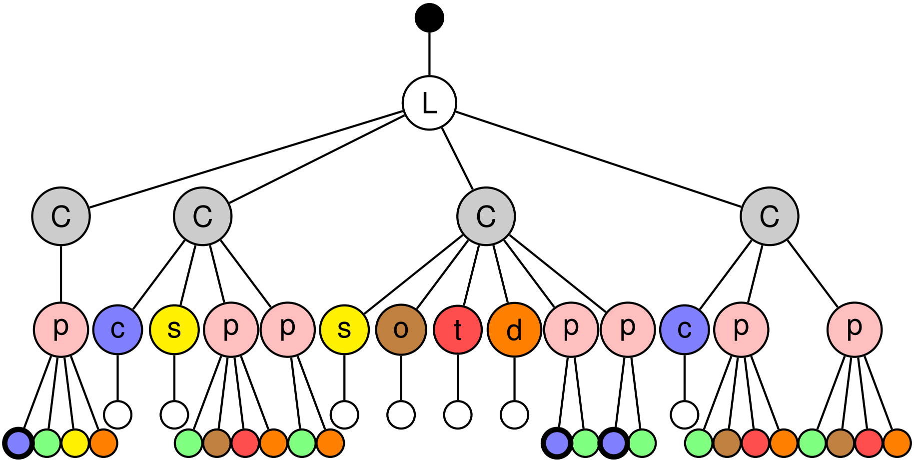
`/descendant-or-self::node()/child::composer` (full syntax)



Another example using descendant

`//performance/composer` or

`/descendant-or-self::performance/child::composer`



Predicates

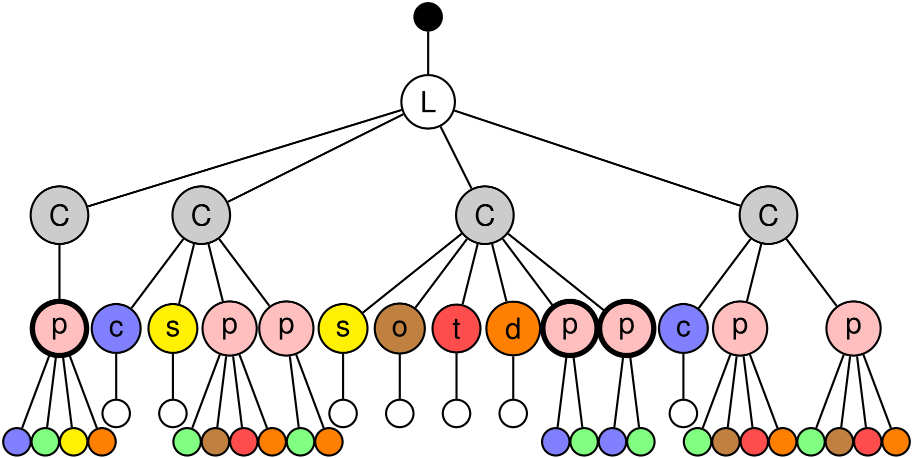
- A node set can be reduced further with *predicates*
- While each location step must have an axis and a node test (which may be empty), a predicate is optional
- A predicate contains a Boolean expression which is tested for each node in the resulting node set
- A predicate is enclosed in square brackets `[ ]`

Predicates (2)

- XPath supports a full complement of relational operators, including `=`, `>`, `<`, `>=`, `<=`, `!=`
- XPath also provides Boolean `and` and `or` operators to combine expressions logically
- In some cases a predicate may not be a Boolean; then XPath will convert it to one implicitly (if that is possible):
  - an empty node set is interpreted as false
  - a non-empty node set is interpreted as true

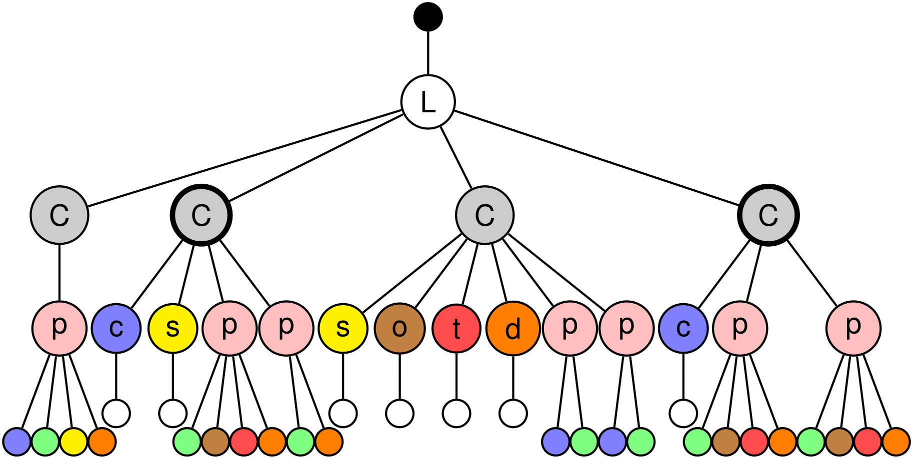
Example using a predicate

`//performance[composer]`



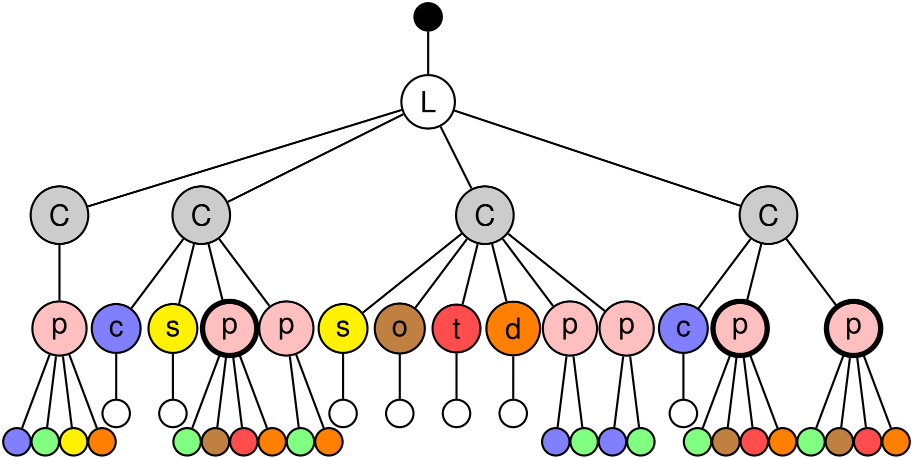
Another example using a predicate

`//CD[performance/orchestra]`



Example using multiple predicates

```
//performance[conductor][date]
```



Further examples with predicates

- `//performance[composer='Frederic Chopin']/composition` returns
  1. `<composition>Waltzes</composition>`
  2. `<composition>Piano Concerto No. 1</composition>`

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- `//performance[composer='Frederic Chopin']/composition` returns
  1. `<composition>Waltzes</composition>`
  2. `<composition>Piano Concerto No. 1</composition>`
- `//CD[@number="449719-2"]//composition` returns
  1. `<composition>Piano Concerto No. 1</composition>`
  2. `<composition>Piano Concerto No. 1</composition>`

  The two composition nodes have the same value, but they are different nodes

Functions

- XPath provides many functions that may be useful in predicates
- Each XPath function takes as input or returns one of these four types:
  - node set
  - string
  - Boolean
  - number

More about Context

- Each location step and predicate is evaluated with respect to a given *context*
- A specific context is defined as $(\langle N_1, N_2, \ldots N_m \rangle, N_c)$ with
  - a *context list* $\langle N_1, N_2, \ldots N_m \rangle$ of nodes in the tree
  - a *context node* N_c belonging to the list
- The *context length* m is the size of the context list
- The *context node position* $c \in [1, m]$ gives the position of the context node in the list

More about XPath Evaluation

- Each step s_i is interpreted with respect to a context; its result is a node list
- A step s_i is evaluated with respect to the context of step s_{i-1}
- More precisely:
  - for $i = 1$ (first step)
    if the path is absolute, the context is the root of the XML tree;
    else (relative paths) the context is defined by the environment;
  - For $i > 1$
    if $\mathcal{N} = \langle N_1, N_2, \ldots N_m \rangle$ is the result of step s_{i-1},
    step s_i is successively evaluated with respect to the context $(\mathcal{N}, N_j)$,
    for each $j \in [1, m]$
- The result of the path expression is the node list obtained after evaluating the last step

Node-set Functions

- *Node-set functions* operate on or return information about node sets
- Examples:
  - `position()`: returns a number equal to the position of the current node in the context list
    - `[position()=i]` can be abbreviated as `[i]`
  - `last()`: returns the size (i.e. the number of nodes in) the context list
  - `count(`*set*`)`: returns the size of the argument node *set*
  - `id(`*idrefs*`)`: returns a node set containing all elements in the document with any of the IDs specified by *idrefs*

Example about context

- The expression `//CD/performance[2]` returns the second performance *of each* CD, not the second of all performances
- The result of the step `CD` is the list of the 4 CD nodes
- The step `performance[2]` is evaluated once for each of 4 CD nodes in the context

Example about context (2)

- The result is the list comprising the second performance element child of each CD:

1.
```
<performance>
  <composition>Fantasias Op. 116</composition>
  <date>1976</date>
</performance>
```
2.
```
<performance>
  <composer>Franz Liszt</composer>
  <composition>Piano Concerto No. 1</composition>
</performance>
```
3.
```
<performance>
  <composition>American Suite</composition>
  <orchestra>Royal Philharmonic</orchestra>
  <conductor>Antal Dorati</conductor>
  <date>1984</date>
</performance>
```

Problems with XPath processors

- Say we want those `performance` children of `CD` elements that are both the second `performance` and have a `date`
- The following 4 expressions should all be equivalent
  - `//CD/performance[2][date]`
  - `//CD/performance[date][2]`
  - `//CD/performance[date and position()=2]`
  - `//CD/performance[position()=2 and date]`
- But different processors give different results!

Problems with XPath processors

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- But, for `//CD/performance[date][2]`, eXist seems to return the second of all `performance` elements with a `date`

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- Saxon and Safari, e.g., correctly give the answer as (1) and (3) from the previous slide for all 4 expressions
- But, for `//CD/performance[date][2]`, eXist seems to return the second of all `performance` elements with a `date`
- An earlier tool returned, for each `CD`, the second of its `performance` elements that had a `date` (if any)

More about the position() function

- `position()` is a function that returns the position of the current node in the context node set
- For most axes it counts forward from the context node
- For the “backward” axes it counts backwards from the context node
- The “backward” axes are: ancestor, ancestor-or-self, preceding, and preceding-sibling

Examples using position()

- To get the CD immediately before the one where the composer was Dvorak:
  `//CD[composer='Antonin Dvorak']/preceding::CD[1]`
- This selects the third CD

Examples using position()

- To get the CD immediately before the one where the composer was Dvorak:
  `//CD[composer='Antonin Dvorak']/preceding::CD[1]`
- This selects the third CD
- To get the last CD (without having to know how many there are), use `//CD[position()=last()]`

Example using a different axis

- `//date/following-sibling::*` returns the following:
  1.
```
<performance>
  <composer>Frederic Chopin</composer>
  <composition>Piano Concerto No. 1</composition>
</performance>
```
  2.
```
<performance>
  <composer>Franz Liszt</composer>
  <composition>Piano Concerto No. 1</composition>
</performance>
```
- only one date element in the document has any following siblings

Examples using count

- `//CD[count(performance)=2]` returns CD elements with exactly two `performance` elements as children: the last 3 CDs

Examples using count

- `//CD[count(performance)=2]` returns CD elements with exactly two `performance` elements as children: the last 3 CDs
- `//CD[performance][performance]` of course does *not* do this:
  - it is equivalent to `//CD[performance]`
  - which returns CD elements with at least one `performance` child

More examples using count

- Assume we want the CDs containing only one `orchestra` element
- `//CD[count(orchestra)=1]` returns only one CD, where the orchestra is “London Symphony Orchestra”
- This is because we are counting the orchestra *children* of `CD` elements
- But orchestras are also represented below `performance` elements

More examples using count

- Assume we want the CDs containing only one `orchestra` element
- `//CD[count(orchestra)=1]` returns only one CD, where the orchestra is “London Symphony Orchestra”
- This is because we are counting the orchestra *children* of `CD` elements
- But orchestras are also represented below `performance` elements
- What about `//CD[count(//orchestra)=1]`?
  - But `//orchestra` is an absolute expression evaluated at the root
  - So the answer to `count(//orchestra)` is 4, not 1

More examples using count

- Assume we want the CDs containing only one `orchestra` element
- `//CD[count(orchestra)=1]` returns only one CD, where the orchestra is "London Symphony Orchestra"
- This is because we are counting the orchestra *children* of `CD` elements
- But orchestras are also represented below `performance` elements
- What about `//CD[count(//orchestra)=1]`?
  - But `//orchestra` is an absolute expression evaluated at the root
  - So the answer to `count(//orchestra)` is 4, not 1
- What we need is `/CD[count(.//orchestra)=1]`, where "`.`" represents the current context node
  - This gives us the CDs with the "Berlin Philharmonic" and "London Symphony Orchestra"

String Functions

- *String functions* include basic string operations
- Examples:
  - `string-length()`: returns the length of a string
  - `concat()`: concatenates its arguments in order from left to right and returns the combined string
  - `contains(`*s1, s2*`)`: returns true if *s2* is a substring of *s1*
  - `normalize-space()`: strips all leading and trailing whitespace from its argument

Boolean Functions

- *Boolean functions* always return a Boolean with the value true or false:
  - `true()`: simply returns true (makes up for the lack of Boolean literals in XPath)
  - `false()`: returns false
  - `not()`: inverts its argument (i.e., true becomes false and vice versa)

Boolean Functions

- *Boolean functions* always return a Boolean with the value true or false:
  - `true()`: simply returns true (makes up for the lack of Boolean literals in XPath)
  - `false()`: returns false
  - `not()`: inverts its argument (i.e., true becomes false and vice versa)
- Examples:
  - `//performance[orchestra][not(conductor)]` returns `performance` elements which have an `orchestra` child but no `conductor` child
  - `//CD[not(.//soloist)]` returns CDs containing no soloists

Boolean Functions (2)

- `boolean()`: converts its argument to a Boolean and returns the result
  - Numbers are false if they are zero or NaN (not a number)
  - Node sets are false if they are empty
  - Strings are false if they have zero length

Number Functions

- *Number functions* include a few simple numeric functions
- Examples:
  - `sum(`*set*`)`: converts each node in a node set to a number and returns the sum of these numbers
  - `round()`, `floor()`, `ceiling()`: round numbers to integer values

Summary

- XPath is used to navigate through elements and attributes in an XML document
- XPath is a major element in many W3C standards: XQuery, XSLT, XLink, XPointer
- It is also used to navigate XML trees represented in Java or JavaScript, e.g.
- So an understanding of XPath is fundamental to much advanced XML usage

Chapter 9

XQuery

Motivation

- Now that we have XPath, what do we need XQuery for?
- XPath was designed for addressing parts of existing XML documents
- XPath cannot
    - create new XML nodes
    - perform joins between parts of a document (or many documents)
    - re-order the output it produces
    - ...
- Furthermore, XPath
    - has a very simple type system
    - can be hard to read and understand (due to its conciseness)

Data Model

- XQuery closely follows the XML Schema data model
- The most general data type is an *item*
- An item is either a (single) node or an atomic value

Data Model (2)

- XQuery works on *sequences*, which are series of items
- In XQuery every value is a sequence
  - There is no distinction between a single item and a sequence of length one
- Sequences can only contain items; they cannot contain other sequences

Document Representation

- Every document is represented as a tree of nodes
- Every node has a unique node identity that distinguishes it from other nodes (independent of any ID attributes)
- The first node in any document is the document node (which contains the whole document)
- The order in which the nodes occur in an XML document is called the *document order* (which corresponds to the pre-order traversal of the nodes)

Document Representation (2)

- Attributes are not considered children of an element
  - They occur after their element and before its first child
  - The relative order within the attributes of an element is implementation-dependent

Query Language

- We are now going to look at the query language itself
  - Basics
  - Creating nodes/documents
  - FLWOR expressions
  - Advanced topics

Comments

- XQuery uses “smileys” to begin and end comments:
  `(:  This is a comment :)`
- These are comments found in a query (to comment the query)
  - Not to be confused with comments in XML documents

Literals

- XQuery supports numeric and string literals
- There are three kinds of numeric literals
  - Integers (e.g. 3)
  - Decimals (e.g. -1.23)
  - Doubles (e.g. 1.2e5)
- String literals are delimited by quotation marks or apostrophes
  - “a string”
  - ’a string’
  - ’This is a “string”’

Input Functions

- XQuery uses input functions to identify the data to be queried
- There are two different input functions, each taking a single argument
  - `doc()`
    - ★ Returns an entire document (i.e. the document node)
    - ★ Document is identified by a Universal Resource Identifier (URI)
  - `collection()`
    - ★ Returns any sequence of nodes that is associated with a URI
    - ★ How the sequence is identified is implementation-dependant
    - ★ For example, eXist allows a database administrator to define collections, each containing a number of documents

Sample Data

- In order to illustrate XQuery queries, we use a sample data file `books.xml` which is based on bibliography data

```
<bib>

  <book year='1994'>
    <title>TCP/IP Illustrated</title>
    <author>
      <last>Stevens</last>
      <first>W.</first>
    </author>
    <publisher>Addison Wesley</publisher>
    <price>65.95</price>
  </book>
```

Sample Data (cont'd)

```
<book year='1992'>
  <title>
    Advanced Programming in the UNIX environment
  </title>
  <author>
    <last>Stevens</last>
    <first>W.</first>
  </author>
  <publisher>Addison Wesley</publisher>
  <price>65.95</price>
</book>
```

Sample Data (cont'd)

```
<book year='2000'>
  <title>Data on the Web</title>
  <author>
    <last>Abiteboul</last> <first>Serge</first>
  </author>
  <author>
    <last>Buneman</last> <first>Peter</first>
  </author>
  <author>
    <last>Suciu</last> <first>Dan</first>
  </author>
  <publisher>Morgan Kaufmann</publisher>
  <price>39.95</price>
</book>
```

Sample Data (cont'd)

```
  <book year='1999'>
    <title>
      The Economics of Technology and Content for Digital TV
    </title>
    <editor>
      <last>Gerbarg</last>
      <first>Darcy</first>
      <affiliation>CITI</affiliation>
    </editor>
    <publisher>Kluwer Academic</publisher>
    <price>129.95</price>
  </book>

</bib>
```

Input Functions (2)

- `doc("books.xml")` returns the entire document
- A run-time error is raised if the `doc` function is unable to locate the document

Input Functions (3)

- XQuery uses XPath to locate nodes in XML data
- An XPath expression can be appended to a `doc` (or `collection`) function to select specific nodes
- For example, `doc("books.xml")//book` returns all book nodes of `books.xml`

Creating Nodes

- So far, XQuery does not look much more powerful than XPath
- We only located nodes in XML documents
- Now we take a look at how to create nodes
- Note that this creates nodes in the *output* of a query; it does *not* update the document being queried

Creating Nodes (2)

- Elements, attributes, text nodes, processing instructions, and comment nodes can all be created using the same syntax as XML
- The following element constructor creates a book element:

```
<book year='1977'>
  <title>Harold and the Purple Crayon</title>
  <author>
    <last>Johnson</last>
    <first>Crockett</first>
  </author>
  <publisher>
    Harper Collins Juvenile Books
  </publisher>
  <price>14.95</price>
</book>
```

Creating Nodes (3)

- Document nodes do not have an explicit syntax in XML
- XQuery provides a special document node constructor
- The query

  ```
  document {}
  ```

  creates an empty document node

Creating Nodes (4)

- Document node constructor can be combined with other constructors to create entire documents

```
document {
  <?xml-stylesheet type='text/xsl' href='trans.xslt'?>
  <!-- I love this book -->
  <book year='1977'>
    <title>Harold and the Purple Crayon</title>
    <author>
      <last>Johnson</last>
      <first>Crockett</first>
    </author>
    <publisher>
      Harper Collins Juvenile Books
    </publisher>
    <price>14.95</price>
  </book>
}
```

Creating Nodes (5)

- Constructors can be combined with other XQuery expressions to generate content dynamically
- In element constructors, curly braces `{ }` delimit enclosed expressions which are evaluated to create content
- Enclosed expressions may occur in the content of an element or the value of an attribute

Creating Nodes (6)

- This query creates a list of book titles from `books.xml`

```
<titles count =
 '{ count(doc("books.xml")//title) }'>
 {
  doc("books.xml")//title
 }
</titles>
```

Creating Nodes (6)

- This query creates a list of book titles from `books.xml`

```
<titles count =
 '{ count(doc("books.xml")//title) }'>
 {
  doc("books.xml")//title
 }
</titles>
```

- The result is:

```
<titles count="4">
    <title>TCP/IP Illustrated</title>
    <title>Advanced Programming ...</title>
    <title>Data on the Web</title>
    <title>The Economics of ...</title>
</titles>
```

Whitespace

- Implementations may discard boundary whitespace (whitespace between tags with no intervening non-whitespace)
- This whitespace can be preserved by an `boundary-space` declaration in the *prolog* of a query
- The prolog of a query is an optional section setting up the compile-time context for the rest of the query

Whitespace (2)

- The following query declares that all whitespace in element constructors must be preserved (which will output the element in exactly the same format)

```
declare boundary-space preserve;

<author>
  <last>Stevens</last>
  <first>W.</first>
</author>
```

- Omitting this declaration (or setting the mode to `strip`) will give:

```
<author><last>Stevens</last><first>W.</first></author>
```

Combining and Restructuring

- The expressiveness of XQuery goes beyond just creating nodes
- Information from one or more sources can be combined and restructured to create new results
- We are going to have a look at the most important expressions and functions

FLWOR

- FLWOR expressions (pronounced “flower”) are one of the most powerful and common expressions in XQuery
- Syntactically, they show similarity to the select-from-where statements in SQL
- However, FLWOR expressions do not operate on tables, rows, and columns

FLWOR (2)

- The name FLWOR is an acronym standing for the first letter of the clauses that may appear
  - For
  - Let
  - Where
  - Order by
  - Return

FLWOR (3)

- The acronym FLWOR roughly follows the order in which the clauses occur
- A FLWOR expression
  - starts with one or more `for` or `let` clauses (in any order)
  - followed by an optional `where` clause,
  - an optional `order by` clause,
  - and a required `return` clause

For and Let Clauses

- Every clause in a FLWOR expression is defined in terms of tuples
- The `for` and `let` clauses produce these tuples
- Therefore, every FLWOR expression must have at least one `for` or `let` clause
- We will start with artificial-looking queries to illustrate the inner workings of `for` and `let` clauses

For and Let Clauses (2)

- The following query creates an element named `tuple` in its return clause

```
for $i in (1, 2, 3)
return
  <tuple><i> { $i } </i></tuple>
```

- We bind the variable `$i` to the expression `(1, 2, 3)`, which constructs a sequence of integers

For and Let Clauses (2)

- The following query creates an element named `tuple` in its return clause

```
for $i in (1, 2, 3)
return
  <tuple><i> { $i } </i></tuple>
```

- We bind the variable `$i` to the expression `(1, 2, 3)`, which constructs a sequence of integers
- The above query results in:

```
<tuple><i> 1 </i></tuple>
<tuple><i> 2 </i></tuple>
<tuple><i> 3 </i></tuple>
```

(a `for` clause preserves order when it creates tuples)

For and Let Clauses (3)

- A `let` clause binds a variable to the entire result of an expression
- If there are no `for` clauses, then a single tuple is created
- So the query:

```
let $i := (1, 2, 3)
return
  <tuple><i> { $i } </i></tuple>
```

For and Let Clauses (3)

- A `let` clause binds a variable to the entire result of an expression
- If there are no `for` clauses, then a single tuple is created
- So the query:

```
let $i := (1, 2, 3)
return
  <tuple><i> { $i } </i></tuple>
```

- gives the answer:

```
<tuple><i> 1 2 3 </i></tuple>
```

For and Let Clauses (4)

- Variable bindings of `let` clauses are added to the tuples generated by `for` clauses
- So the query:

```
for $i in (1, 2, 3)
let $j := ('a', 'b', 'c')
return
  <tuple><i>{ $i }</i><j>{ $j }</j></tuple>
```

For and Let Clauses (4)

- Variable bindings of `let` clauses are added to the tuples generated by `for` clauses
- So the query:

```
for $i in (1, 2, 3)
let $j := ('a', 'b', 'c')
return
  <tuple><i>{ $i }</i><j>{ $j }</j></tuple>
```

- gives the answer:

```
<tuple><i>1</i><j>a b c</j></tuple>
<tuple><i>2</i><j>a b c</j></tuple>
<tuple><i>3</i><j>a b c</j></tuple>
```

For and Let Clauses (5)

- `for` and `let` clauses can be bound to any XQuery expression
- Let us do a more realistic example
- List the title of each book in `books.xml` together with the numbers of authors:

```
for $b in doc("books.xml")//book
let $a := $b/author
return
  <book> { $b/title,
    <count> { count($a) } </count> }
  </book>
```

For and Let Clauses (6)

- This results in:

```
<book>
  <title>TCP/IP Illustrated</title>
  <count> 1 </count>
</book>
<book>
  <title>Advanced Programming ...</title>
  <count> 1 </count>
</book>
<book>
  <title>Data on the Web</title>
  <count> 3 </count>
</book>
<book>
  <title>The Economics of Technology ...</title>
  <count> 0 </count>
</book>
```

Where Clauses

- A `where` clause eliminates tuples that do not satisfy a particular condition
- A `return` clause is only evaluated for tuples that “survive” the `where` clause
- The following query returns only books whose prices are less than 50.00:

```
for $b in doc("books.xml")//book
where $b/price < 50.00
return $b/title
```

Where Clauses

- A `where` clause eliminates tuples that do not satisfy a particular condition
- A `return` clause is only evaluated for tuples that “survive” the `where` clause
- The following query returns only books whose prices are less than 50.00:

```
for $b in doc("books.xml")//book
where $b/price < 50.00
return $b/title
```

- The answer is

```
<title>Data on the Web</title>
```

Order By Clauses

- An `order by` clause sorts the tuples before the return clause is evaluated
- If there is no `order by` clause, then the results are returned in document order
- The following example lists the titles of books in alphabetical order:

```
for $t in doc("books.xml")//title
order by $t
return $t
```

- An order spec may also specify whether to sort in ascending or descending order (using `ascending` or `descending`)

Return Clauses

- Any XQuery expression may occur in a `return` clause
- Element constructors are very common in `return` clauses
- The following query represents an author's name as a string in a single element

```
for $a in doc("books.xml")//author
return
  <author> { string($a/first),
             string($a/last) } </author>
```

Return Clauses

- Any XQuery expression may occur in a `return` clause
- Element constructors are very common in `return` clauses
- The following query represents an author's name as a string in a single element

```
for $a in doc("books.xml")//author
return
  <author> { string($a/first),
             string($a/last) } </author>
```

- The result is

```
<author> W. Stevens </author>
<author> W. Stevens </author>
<author> Serge Abiteboul </author>
<author> Peter Buneman </author>
<author> Dan Suciu </author>
```

Return Clauses (2)

- The following query adds another level to the hierarchy:

```
for $a in doc("books.xml")//author
return
  <author>
    <name> { $a/first, $a/last } </name>
  </author>
```

Return Clauses (2)

- The following query adds another level to the hierarchy:

```
for $a in doc("books.xml")//author
return
  <author>
    <name> { $a/first, $a/last } </name>
  </author>
```

- The result is

```
<author>
    <name>
        <first>W.</first>
        <last>Stevens</last>
    </name>
</author>
...
```

Formatting XQuery Output

- Standard XQuery parameters can be set to
  - omit the XML declaration in the output (`omit-xml-declaration`)
  - have nested elements in the out put indented (`indent`)
- However, it seems that new lines have to be added to the output explicitly using the new line character obtained through the entity reference `
`
- As an example, see the query on the next slide

Nested Expressions

- This query outputs book titles and authors, each on a new line:

```
declare namespace saxon="http://saxon.sf.net/";
declare option saxon:output "omit-xml-declaration=yes";
declare option saxon:output "indent=yes";

let $nl := "&#10;"
for $b in doc("books.xml")//book
return ($b/title,
        for $a in $b/author return ($a, $nl),
        $nl)
```

Nested Expressions

- This query outputs book titles and authors, each on a new line:

```
declare namespace saxon="http://saxon.sf.net/";
declare option saxon:output "omit-xml-declaration=yes";
declare option saxon:output "indent=yes";

let $nl := "&#10;"
for $b in doc("books.xml")//book
return ($b/title,
        for $a in $b/author return ($a, $nl),
        $nl)
```

- Note the:
  - use of the namespace declaration for the software tool Saxon
  - character entity reference for the new line character
  - `for` clause nested in the `return` clause
  - sequences returned by using `(` and `)`

Operators

- We have seen a few examples of operators in queries
- Let's consider operators in more detail now
- XQuery has three different kinds of operators
    - Arithmetic operators
    - Comparison operators
    - Sequence operators

Arithmetic Operators

- XQuery supports the arithmetic operators `+`, `-`, `*`, `div`, `idiv`, and `mod`
- The `idiv` and `mod` operators require integer arguments, returning the quotient and the remainder, respectively
- If an operand is a node, atomization is applied (casting the content to an atomic type)
- If an operand is an empty sequence, the result is an empty sequence
- If an operand is untyped, it is cast to a double (raising an error if the cast fails)

Comparison Operators

- XQuery has different sets of comparison operators: value comparisons, general comparisons and node (order) comparisons
- *Value* comparison operators compare atomic values:

eq	equals
ne	not equals
lt	less than
le	less than or equal to
gt	greater than
ge	greater than or equal to

General Comparisons

- The following query raises an error

```
for $b in doc("books.xml")//book
where $b/author/last eq 'Stevens'
return $b/title
```

  because we try to compare several author names to `'Stevens'` (books may have more than one author)
- We need a *general* comparison operator for this to work
- A general comparison returns true if **any** value in a sequence of atomic values matches

General Comparisons (2)

- The following table shows the corresponding general comparison operator for each value comparison operator

value comparison	general comparison
eq	=
ne	!=
lt	$<$
le	$<=$
gt	$>$
ge	$>=$

Node (Order) Comparisons

- These operators expect each of their operands to be a single node
- If not, an error is raised
- The operator `is` tests whether two expressions return the same node
- The operators « and » test whether one node precedes («) or succeeds (») another, in document order

Built-in Functions

- XQuery also offers a set of built-in functions and operators
- We focus only on the most common ones here
- SQL users will be familiar with the `min()`, `max()`, `count()`, `sum()`, and `avg()` functions
- Other familiar functions include
  - Numeric functions like `round()`, `floor()`, and `ceiling()`
  - String functions like `concat()`, `string-length()`, `substring()`, `upper-case()`, `lower-case()`
  - Cast functions for the various atomic types

User-Defined Functions and Library Modules

- When a query becomes large and complex, it becomes easier to understand if it is split up into functions
- A function is declared in the XQuery prolog
- Functions can be put into library modules, which can be imported by any query
- Every module in XQuery is either a main module (which contains a query body) or a library module (which has no query body)
- We will not cover the details of user-defined functions or library modules

Positional Variables

- The `for` clause supports positional variables using `at`
- This identifies the position of a given item in the sequence generated by an expression
- The following query returns the titles of books with an attribute that numbers the books:

```
for $t at $i in doc("books.xml")//title
return
  <title pos=' { $i } '>
    { string($t) }
  </title>
```

Positional Variables (2)

- The output of the previous query is as follows:

```
<title pos=" 1 ">
  TCP/IP Illustrated
</title>
<title pos=" 2 ">
  Advanced Programming in ...
</title>
<title pos=" 3 ">
  Data on the Web
</title>
<title pos=" 4 ">
  The Economics of Technology ...
</title>
```

Combining Data Sources

- A query may bind multiple variables in a `for` clause to combine data from different expressions
- Suppose we have a file named `reviews.xml` that contains book reviews:

```
<reviews>
  <entry>
    <title>Data on the Web</title>
    <price>34.95</price>
    <review>
      A very good discussion of
      semi-structured databases ...
    </review>
  </entry>
    ...
```

Combining Data Sources (2)

- A FLWOR expression can bind one variable to the bibliography data and another to the review data
- In the following query we join data from the two files:

```
for $t in doc("books.xml")//title,
    $e in doc("reviews.xml")//entry
where $t = $e/title
return
  <review>
    { $t, $e/review }
  </review>
```

Combining Data Sources (3)

- This returns the following answer:

```
<review>
  <title>TCP/IP Illustrated</title>
  <review>
    One of the best books on TCP/IP.
  </review>
</review>
<review>
  <title>Advanced Programming in the ...</title>
  <review>
    A clear and detailed discussion of ...
  </review>
</review>
...
```

Eliminating Duplicates

- Data (or intermediate query results) often contain duplicate values
- Consider a query returning the last names of authors:

```
doc("books.xml")//author/last
```

Eliminating Duplicates

- Data (or intermediate query results) often contain duplicate values
- Consider a query returning the last names of authors:

```
doc("books.xml")//author/last
```

- This returns one of the authors twice:

```
<last>Stevens</last>
<last>Stevens</last>
<last>Abiteboul</last>
<last>Buneman</last>
<last>Suciu</last>
```

Eliminating Duplicates (2)

- The `distinct-values()` function is used to remove duplicate values
- It extracts values from a sequence of nodes and creates a sequence of unique values
- Example:

```
distinct-values(doc("books.xml")//author/last)
```

which outputs

```
Stevens Abiteboul Buneman Suciu
```

Inverting Hierarchies

- XQuery can be used to do general transformations
- In the `books.xml` file, books are sorted by title
- If we want to group books by publisher, we have to “pull up” the publisher element (i.e., invert the hierarchy of the document)
- The next slide shows a query to do this

Inverting Hierarchies — Example Query

```
<listings> {
  for $p in
    distinct-values(doc("books.xml")//publisher)
  order by $p
  return
    <result>
      <publisher>{ $p }</publisher>
      { for $b in doc("books.xml")//book
        where $b/publisher = $p
        order by $b/title
        return $b/title
      }
    </result>
  }
</listings>
```

Inverting Hierarchies — Query Result

```
<listings>
  <result>
    <publisher>Addison-Wesley</publisher>
    <title>Advanced Programming ...</title>
    <title>TCP/IP Illustrated</title>
  </result>
  <result>
    <publisher>Kluwer Academic Publishers</publisher>
    <title>The Economics of ...</title>
  </result>
  <result>
    <publisher>Morgan Kaufmann Publishers</publisher>
    <title>Data on the Web</title>
  </result>
</listings>
```

Quantifiers

- Some queries need to determine whether
  - at least one item in a sequence satisfies a condition
  - every item in sequence satisfies a condition
- This is done using quantifiers:
  - `some` is an existential quantifier
  - `every` is a universal quantifier

Quantifiers (2)

- The following query shows an existential quantifier
- We are looking for a book where *at least one* of the authors has the last name ‘Buneman’:

```
for $b in doc("books.xml")//book
where some $a in $b/author
      satisfies ($a/last = 'Buneman')
return $b/title
```

which returns:

```
<title>Data on the Web</title>
```

Quantifiers (3)

- The following query shows a universal quantifier
- We are looking for a book where *all* of the authors have the last name ‘Stevens’:

```
for $b in doc("books.xml")//book
where every $a in $b/author
      satisfies ($a/last = 'Stevens')
return $b/title
```

which returns:

```
<title>TCP/IP Illustrated</title>
<title>Advanced Programming ...</title>
<title>The Economics of Technology ...</title>
```

Quantifiers (4)

- A universal quantifier applied to an empty sequence always yields true (there is no item violating the condition)
- An existential quantifier applied to an empty sequence always yields false (there is no item satisfying the condition)

Conditional Expressions

- XQuery's conditional expressions (`if - then - else`) are used in the same way as in other languages
- In XQuery, both the `then` and the `else` clause are required
- The empty sequence `()` can be used to specify that a clause should return nothing
- The following query returns all authors for books with up to two authors and "et al." for any remaining authors

Conditional Expressions — Example Query

```
for $b in doc("books.xml")//book
return
  <book> { $b/title } {
    for $a at $i in $b/author
    where $i <= 2
    return <author> { string($a/last), ", ",
                      string($a/first) }
           </author>
    }
    { if (count($b/author) > 2)
      then <author> et al. </author>
      else ()
    }
  </book>
```

Conditional Expressions — Query Result

```
<book>
    <title>TCP/IP Illustrated</title>
    <author>Stevens, W.</author>
</book>
 <book>
    <title>Advanced Programming in ...</title>
    <author>Stevens, W.</author>
</book>
 <book>
    <title>Data on the Web</title>
    <author>Abiteboul, Serge</author>
    <author>Buneman, Peter</author>
    <author>et al. </author>
</book>
 <book>
    <title>The Economics of Technology ...</title>
</book>
```

Summary

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- It is a powerful declarative language
- It is well-suited to XML-processing tasks like data integration and data transformation (including tasks for which XSLT might be used)

Summary

- XQuery was designed to be compact and compositional
- It is a powerful declarative language
- It is well-suited to XML-processing tasks like data integration and data transformation (including tasks for which XSLT might be used)
- But what if most of your data is stored in a relational database?