XML, DTD, and XML Schema

CompSci 316

Introduction to Database Systems

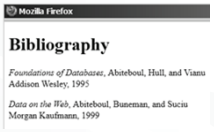
Announcements (Thu. Oct. 18)

- Project milestone #1 due today!
- Midterm being graded; sample solution available next Tuesday
- Homework #3 available next Thursday

From HTML to XML (eXtensible Markup Language)

- HTML describes presentation of content

```
<h1>Bibliography</h1>
<p><i>Foundations of Databases</i>,
Abiteboul, Hull, and Vianu
<br>Addison Wesley, 1995
<p>…
```



- XML describes only the content

```
<bibliography>
  <book>
    <title>Foundations of Databases</title>
    <author>Abiteboul</author>
    <author>Hull</author>
    <author>Vianu</author>
    <publisher>Addison Wesley</publisher>
    <year>1995</year>
  </book>
  <book>…</book>
</bibliography>
```

- ☞ Separation of content from presentation simplifies content extraction and allows the same content to be presented easily in different looks

Other nice features of XML

- Portability: Just like HTML, you can ship XML data across platforms
  - Relational data requires heavy-weight protocols, e.g., JDBC
- Flexibility: You can represent any information (structured, semi-structured, documents, …)
  - Relational data is best suited for structured data
- Extensibility: Since data describes itself, you can change the schema easily
  - Relational schema is rigid and difficult to change

XML terminology


```
<bibliography>
  <book ISBN="ISBN-10" price="80.00">
    <title>Foundations of Databases</title>
    <is_textbook/>
    <author>Abiteboul</author>
    <author>Hull</author>
    <author>Vianu</author>
    <publisher>Addison Wesley</publisher>
    <year>1995</year>
  </book>…
</bibliography>
```

- Tag names: `book`, `title`, …
- Start tags: `<book>`, `<title>`, …
- End tags: `</book>`, `</title>`, …
- An element is enclosed by a pair of start and end tags: `<book>…</book>`
  - Elements can be nested: `<book>…<title>…</title>…</book>`
  - Empty elements: `<is_textbook></is_textbook>`
    - Can be abbreviated: `<is_textbook/>`
- Elements can also have attributes: `<book ISBN="…" price="80.00">`

- ☞ Ordering generally matters, except for attributes

Well-formed XML documents

A well-formed XML document

- Follows XML lexical conventions
  - Wrong: `<section>We show that x < 0…</section>`
  - Right: `<section>We show that x &lt; 0…</section>`
    - Other special entities: `>` becomes `&gt;` and `&` becomes `&amp;`
- Contains a single root element
- Has properly matched tags and properly nested elements
  - Right: `<section>…<subsection>…</subsection>…</section>`
  - Wrong: `<section>…<subsection>…</section>…</subsection>`

A tree representation

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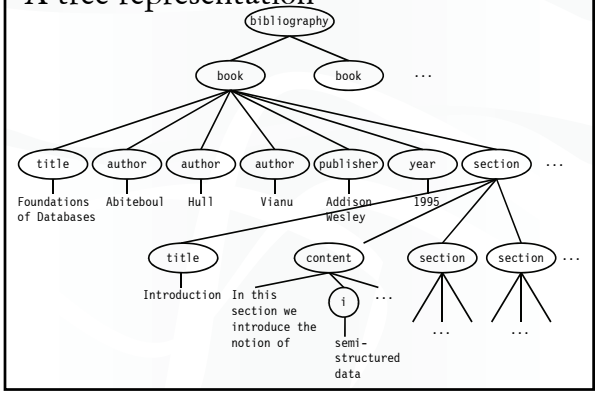

More XML features

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- Processing instructions for apps: `<? … ?>`
  - An XML file typically starts with a version declaration using this syntax: `<?xml version="1.0"?>`
- Comments: `<!-- Comments here -->`
- CDATA section: `<![CDATA[Tags: <book>,…]]>`
- ID's and references

```
<person id="o12"><name>Homer</name>…</person>
<person id="o34"><name>Marge</name>…</person>
<person id="o56" father="o12" mother="o34"><name>Bart</name>…</person>…
```

- Namespaces allow external schemas and qualified names

```
<book xmlns:myCitationStyle="http://…/mySchema">
  <myCitationStyle:title>…</myCitationStyle:title>
  <myCitationStyle:author>…</myCitationStyle:author>…
</book>
```

- And more…

Valid XML documents

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- A valid XML document conforms to a Document Type Definition (DTD)
  - A DTD is optional
  - A DTD specifies a grammar for the document
    - Constraints on structures and values of elements, attributes, etc.
- Example

```
<!DOCTYPE bibliography [
      <!ELEMENT bibliography (book+)>
      <!ELEMENT book (title, author*, publisher?, year?, section*)>
      <!ATTLIST book ISBN CDATA #REQUIRED>
      <!ATTLIST book price CDATA #IMPLIED>
      <!ELEMENT title (#PCDATA)>
      <!ELEMENT author (#PCDATA)>
      <!ELEMENT publisher (#PCDATA)>
      <!ELEMENT year (#PCDATA)>
      <!ELEMENT i (#PCDATA)>
      <!ELEMENT content (#PCDATA|i)*>
      <!ELEMENT section (title, content?, section*)>
]>
```

DTD explained

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```
<!DOCTYPE bibliography [
```
→ `bibliography` is the root element of the document

```
<!ELEMENT bibliography (book+)>
```
→ One or more

→ `bibliography` consists of a sequence of one or more `book` elements

```
<!ELEMENT book (title, author*, publisher?, year?, section*)>
```
→ Zero or one

→ Zero or more

→ `book` consists of a `title`, zero or more `author`s, an optional `publisher`, and zero or more `section`s, in sequence

```
<!ATTLIST book ISBN ID #REQUIRED>
```
→ `book` has a required `ISBN` attribute which is a unique identifier

```
<!ATTLIST book price CDATA #IMPLIED>
```
→ `book` has an optional (`#IMPLIED`) `price` attribute which contains character data

Other attribute types include `IDREF` (reference to an `ID`), `IDREFS` (space-separated list of references), enumerated list, etc.

```
<bibliography>
  <book ISBN="ISBN-10" price="80.00">
    <title>Foundations of Databases</title>
    <author>Abiteboul</author>
    <author>Hull</author>
    <author>Vianu</author>
    <publisher>Addison Wesley</publisher>
    <year>1995</year>
  </book>…
</bibliography>
```

DTD explained (cont'd)

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```
<!ELEMENT title (#PCDATA)>
<!ELEMENT author (#PCDATA)>
<!ELEMENT publisher (#PCDATA)>
<!ELEMENT year (#PCDATA)>
<!ELEMENT i (#PCDATA)>
```
→ `author`, `publisher`, `year`, and `i` contain parsed character data

`PCDATA` is text that will be parsed
- `<` etc. will be parsed as entities
- Use a CDATA section to include text verbatim

```
<!ELEMENT content (#PCDATA|i)*>
```
→ `content` contains mixed content: text optionally interspersed with `i` elements

```
<!ELEMENT section (title, content?, section*)>
```
→ Recursive declaration: Each `section` begins with a `title`, followed by an optional `content`, and then zero or more (sub) `section`s

```
]>
```

```
<section><title>Introduction</title>
  <content>In this section we introduce
    the notion of <i>semi-structured data</i>…
  </content>
  <section><title>XML</title>
    <content>XML stands for…</content>
  </section>
  <section><title>DTD</title>
    <section><title>Definition</title>
      <content>DTD stands for…</content>
    </section>
    <section><title>Usage</title>
      <content>You can use DTD to…</content>
    </section>
  </section>
</section>
```

Using DTD

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- DTD can be included in the XML source file

```
<?xml version="1.0"?>
<!DOCTYPE bibliography [
  … …
]>
<bibliography>
… …
</bibliography>
```

- DTD can be external

```
<?xml version="1.0"?>
<!DOCTYPE bibliography SYSTEM "../dtds/bib.dtd">
<bibliography>
… …
</bibliography>
```

```
<?xml version="1.0"?>
<!DOCTYPE html PUBLIC "-//W3C//DTD XHTML 1.0 Strict//EN"
                      "http://www.w3.org/TR/xhtml1/DTD/xhtml1-strict.dtd">
<html>
… …
</html>
```

Annoyances: element type declarations

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- Consider this element content (children) declaration:

```
<!ELEMENT pub-venue
  ( (name, address, month, year) |
    (name, volume, number, year) )>
```

  - "|" means "or"
- Syntactically legal, but won't work
  - Because of SGML compatibility issues
  - When looking at `name`, a parser would not know which way to go without looking further ahead
  - Requirement: content declaration must be "deterministic" (i.e., no look-ahead required)
  - Can we rewrite it into an equivalent, deterministic one?
- Also, you cannot nest mixed content declarations
  - Illegal: `<!ELEMENT Section (title, (#PCDATA|i)*, section*)>`

Annoyances: element name clash

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- Suppose we want to represent book titles and section titles differently
  - Book titles are pure text: `(#PCDATA)`
  - Section titles can have formatting tags: `(#PCDATA|i|b|math)*`
- But DTD only allows one `title` declaration!
- Workaround: rename as `book-title` and `section-title`?
  - Not nice—why can't one infer title's contexts from data?

Annoyances: lack of type support

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- Too few attribute types: string (`CDATA`), token (e.g., `ID`, `IDREF`), enumeration (e.g., `(red|green|blue)`)
  - What about integer, float, date, etc.?
- ID not typed
  - No two elements can have the same ID value, even if they are different types of elements (e.g., `book` vs. `section`)
- Difficult to reuse complex structure definitions
  - E.g.: already defined element `E1` as `(blah, bleh, foo?, bar*, …)`; want to define `E2` to have the same structure
  - Parameter entities in DTD provide a workaround
    - `<!ENTITY % E.struct '(blah, bleh, foo?, bar*, …)'>`
    - `<!ELEMENT E1 %E.struct;>`
    - `<!ELEMENT E2 %E.struct;>`
  - Something less "hacky"?

XML Schema

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- A more powerful way of defining the structure and constraining the contents of XML documents
- An XML Schema definition is itself an XML document
  - Typically stored as a standalone .xsd file
  - XML (data) documents refer to external .xsd files
- W3C recommendation
  - Unlike DTD, XML Schema is separate from the XML specification

XML Schema definition (XSD)

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```
<?xml version="1.0"?>
<xs:schema xmlns:xs="http://www.w3.org/2001/XMLSchema">
  … …
  … …
</xs:schema>
```

`xmlns:xs="http://www.w3.org/2001/XMLSchema"` → Defines `xs` to be the namespace described in the URL

Uses of `xs:` within the `xs:schema` element now refer to tags from this namespace

XSD example

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```
<xs:element name="book">
  <xs:complexType>
    <xs:sequence>
      <xs:element name="title" type="xs:string"/>
      <xs:element name="author" type="xs:string"
                  minOccurs="0" maxOccurs="unbounded"/>
      <xs:element name="publisher" type="xs:string"
                  minOccurs="0" maxOccurs="1"/>
      <xs:element name="year" type="xs:integer"
                  minOccurs="0" maxOccurs="1"/>
      <xs:element ref="section"
                  minOccurs="0" maxOccurs="unbounded"/>
    </xs:sequence>
    <xs:attribute name="ISBN" type="xs:string" use="required"/>
    <xs:attribute name="price" type="xs:decimal" use="optional"/>
  </xs:complexType>
</xs:element>
```

`<xs:complexType>` Declares a structure with child elements/attributes as opposed to just text)

`<xs:sequence>` Declares a sequence of child elements, like "(…, …, …)" in DTD

`<xs:element name="title" type="xs:string"/>` A leaf element with string content

`<xs:element name="author" …>` Like `author*` in DTD

`<xs:element name="publisher" …>` Like `publisher?` in DTD

`<xs:element name="year" type="xs:integer" …>` A leaf element with integer content

`<xs:element ref="section" …>` Reference to element `section` defined elsewhere

`<xs:attribute name="ISBN" type="xs:string" use="required"/>` Declares an attribute under `book`… and this attribute is required

`<xs:attribute name="price" type="xs:decimal" use="optional"/>` This attribute has a decimal value, and it is optional

XSD example cont'd


```
<xs:element name="section">
  <xs:complexType>
   <xs:sequence>
      <xs:element name="title" type="xs:string"/>
      <xs:element name="content" minOccurs="0" maxOccurs="1">
        <xs:complexType mixed="true">
          <xs:choice minOccurs="0" maxOccurs="unbounded">
            <xs:element name="i" type="xs:string"/>
            <xs:element name="b" type="xs:string"/>
          </xs:choice>
        </xs:complexType>
      </xs:element>
      <xs:element ref="section" minOccurs="0" maxOccurs="unbounded"/>
   </xs:sequence>
  </xs:complexType>
</xs:element>
```

Another `title` definition; can be different from `book/title`

Declares mixed content (text interspersed with structure below)

A compositor like `xs:sequence`; this one declares a list of alternatives, like "(…|…|…)" in DTD

`minOccurs` can be attached to compositors too

Like (#PCDATA|i|b)* in DTD

Recursive definition

XSD example cont'd

- To complete `bib.xsd`:

```
<xs:element name="bibliography">
  <xs:complexType>
    <xs:sequence>
      <xs:element ref="book" minOccurs="0" maxOccurs="unbounded"/>
    </xs:sequence>
  </xs:complexType>
</xs:element>
```

- To use `bib.xsd` in an XML document:

```
<?xml version="1.0"?>
<bibliography xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
              xsi:noNamespaceSchemaLocation="file:bib.xsd">
  <book>… …</book>
  <book>… …</book>
  … …
</bibliography>
```

Named types

- Define once:

```
<xs:complexType name="formattedTextType" mixed="true">
  <xs:choice minOccurs="0" maxOccurs="unbounded">
    <xs:element name="i" type="xs:string"/>
    <xs:element name="b" type="xs:string"/>
  </xs:choice>
</xs:complexType>
```

- Use elsewhere in XSD:

```
… …
<xs:element name="title" type="formattedTextType"/>
<xs:element name="content" type="formattedTextType"
            minOccurs="0" maxOccurs="1"/>
… …
```

Restrictions


```
<xs:simpleType name="priceType">
  <xs:restriction base="xs:decimal">
    <xs:minInclusive value="0.00"/>
  </xs:restriction>
</xs:simpleType>

<xs:simpleType name="statusType">
  <xs:restriction base="xs:string">
    <xs:enumeration value="in stock"/>
    <xs:enumeration value="out of stock"/>
    <xs:enumeration value="out of print"/>
  </xs:restriction>
</xs:simpleType>
```

Keys


```
<xs:element name="bibliography">
  <xs:complexType>… …</xs:complexType>
  <xs:key name="bookKey">
    <xs:selector xpath="./book"/>
    <xs:field xpath="@ISBN"/>
  </xs:key>
</xs:element>
```

- Under any `bibliography` element, elements reachable by selector "`./book`" (i.e., `book` child elements) must have unique values for field "`@ISBN`" (i.e., `ISBN` attributes)
  - In general, a key can consist of multiple fields (multiple `<xs:field>` elements under `<xs:key>`)
  - More on XPath in next lecture

Foreign keys

- Suppose content can reference books

```
<xs:element name="content">
  <xs:complexType mixed="true">
    <xs:choice minOccurs="0" maxOccurs="unbounded">
      <xs:element name="i" type="xs:string"/>
      <xs:element name="b" type="xs:string"/>
      <xs:element name="book-ref">
        <xs:complexType>
          <xs:attribute name="ISBN"
                        type="xs:string"/>
        </xs:complexType>
      </xs:element>
    </xs:choice>
  </xs:complexType>
</xs:element>
```

```
<xs:element name="bibliography">
  <xs:complexType>… …</xs:complexType>
  <xs:key name="bookKey">
    <xs:selector xpath="./book"/>
    <xs:field xpath="@ISBN"/>
  </xs:key>
  <xs:keyref name="bookForeignKey"
             refer="bookKey">
    <xs:selector xpath=".//book-ref"/>
    <xs:field xpath="@ISBN"/>
  </xs:keyref>
</xs:element>
```

- Under any `bibliography` element, for elements reachable by selector "`.//book-ref`" (i.e., any `book-ref` element underneath), values for field "`@ISBN`" (i.e., `ISBN` attributes) must appear as values of `bookKey`, the key being referred
  - Make sure `keyref` is declared in the same scope as the key it refers to

Why use DTD or XML Schema?

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- Benefits of not using them
  - Unstructured data is easy to represent
  - Overhead of validation is avoided
- Benefits of using them
  - Serve as schema for the XML data
    - Guards against errors
    - Helps with processing
  - Facilitate information exchange
    - People can agree to use a common DTD or XML Schema to exchange data (e.g., XHTML)

XML versus relational data

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Relational data

- Schema is always fixed in advance and difficult to change
- Simple, flat table structures
- Ordering of rows and columns is unimportant
- Data exchange is problematic
- "Native" support in all serious commercial DBMS

XML data

- Well-formed XML does not require predefined, fixed schema
- Nested structure; `ID`/`IDREF(S)` permit arbitrary graphs
- Ordering forced by document format; may or may not be important
- Designed for easy exchange
- Often implemented as an "add-on" on top of relations

Case study

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- Design an XML document representing cities, counties, and states
  - For states, record name and capital (city)
  - For counties, record name, area, and location (state)
  - For cities, record name, population, and location (county and state)
- Assume the following:
  - Names of states are unique
  - Names of counties are only unique within a state
  - Names of cities are only unique within a county
  - A city is always located in a single county
  - A county is always located in a single state

A possible design

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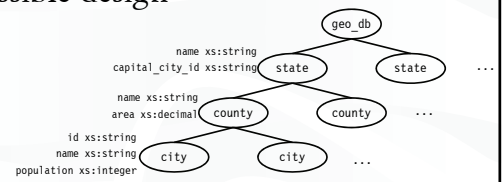

Declare `stateKey` in `geo_db` with
- Selector `./state`
- Field `@name`

Declare `countyInStateKey` in `state` with
- Selector `./county`
- Field `@name`

Declare `cityInCountyKey` in `county` with
- Selector `./city`
- Field `@name`

Declare `cityIdKey` in `geo_db` with
- Selector `./state/county/city`
- Field `@id`

Declare `capitalCityIdKeyRef` in `geo_db` referencing `cityIdKey`, with
- Selector `./state`
- Field `@capital_city_id`