XML, DTD, and XML Schema

Introduction to Databases

CompSci 316 Fall 2016

DUKE
COMPUTER SCIENCE

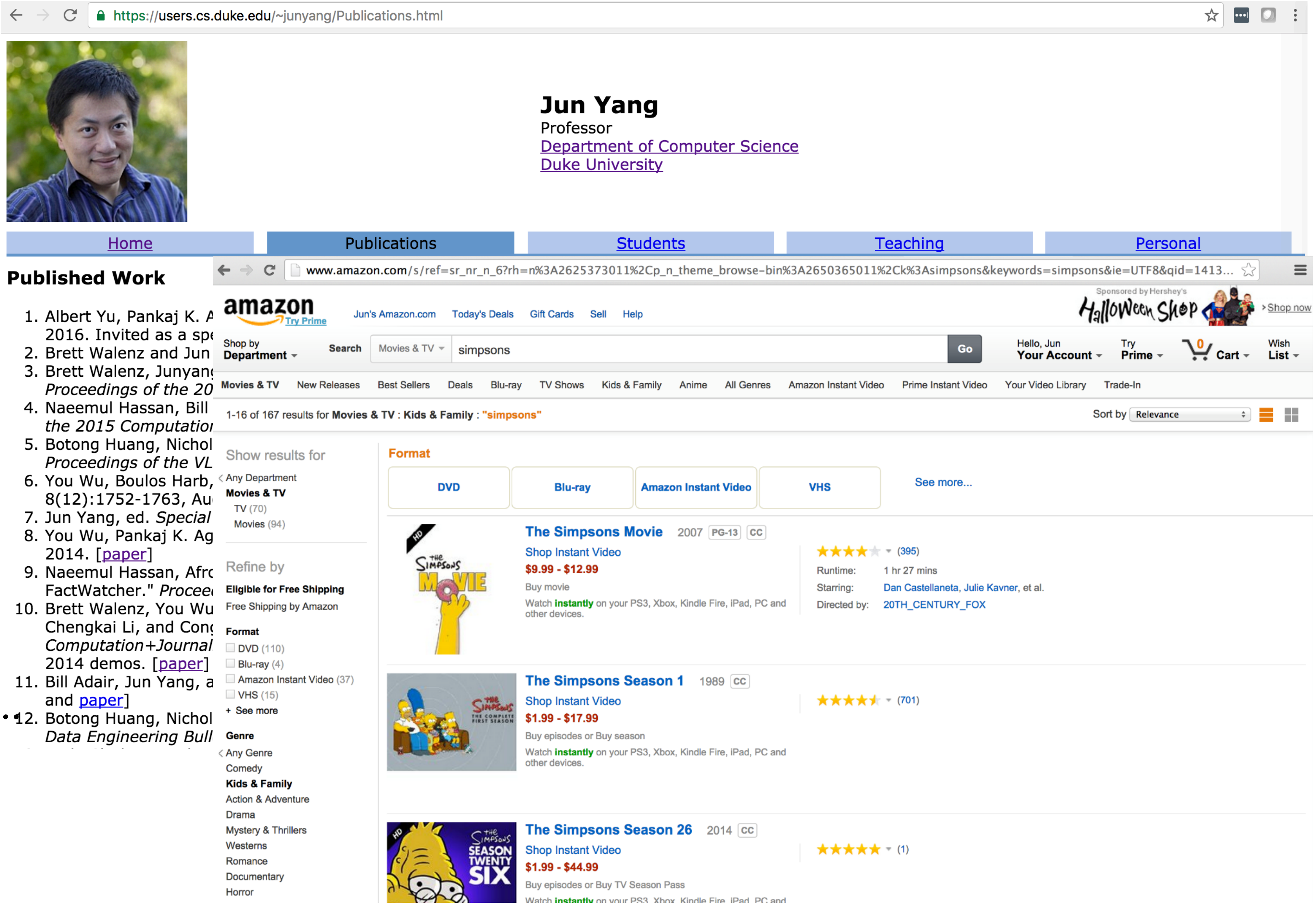
Announcements (Thu. Oct. 20)

- Homework #3 assigned today; due in ~2 weeks
- Midterm graded
  - Mean: 77.4 + 1.4 extra credit = 78.8
    - I will make a +6-point adjustment when calculating final grade
  - Median: 80; highest: 106
  - Sample solution has been posted
  - Two problems where folks had most trouble:
    - FD implication
    - Exactly-2 in RA
- Project milestone #1 feedback to be emailed this weekend

Structured vs. unstructured data

- Relational databases are highly structured
  - All data resides in tables
  - You must define schema before entering any data
  - Every row confirms to the table schema
  - Changing the schema is hard and may break many things
- Texts are highly unstructured
  - Data is free-form
  - There is no pre-defined schema, and it’s hard to define any schema
  - Readers need to infer structures and meanings

What’s in between these two extremes?



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Published Work

1. Albert Yu, Pankaj K. A
2016. Invited as a spe
2. Brett Walenz and Jun
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Proceedings of the 20
4. Naeemul Hassan, Bill
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5. Botong Huang, Nichol
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6. You Wu, Boulos Harb,
8(12):1752-1763, Au
7. Jun Yang, ed. *Special*
8. You Wu, Pankaj K. Ag
2014. [paper]
9. Naeemul Hassan, Afro
FactWatcher." *Procee*
10. Brett Walenz, You Wu
Chengkai Li, and Con
Computation+Journal
2014 demos. [paper]
11. Bill Adair, Jun Yang, a
and paper]
12. Botong Huang, Nichol
Data Engineering Bull

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The Simpsons Movie 2007 PG-13 CC
Shop Instant Video
$9.99 - $12.99
Buy movie
Watch **instantly** on your PS3, Xbox, Kindle Fire, iPad, PC and other devices.
★★★★☆ (395)
Runtime: 1 hr 27 mins
Starring: Dan Castellaneta, Julie Kavner, et al.
Directed by: 20TH_CENTURY_FOX

The Simpsons Season 1 1989 CC
Shop Instant Video
$1.99 - $17.99
Buy episodes or Buy season
Watch **instantly** on your PS3, Xbox, Kindle Fire, iPad, PC and other devices.
★★★★½ (701)

The Simpsons Season 26 2014 CC
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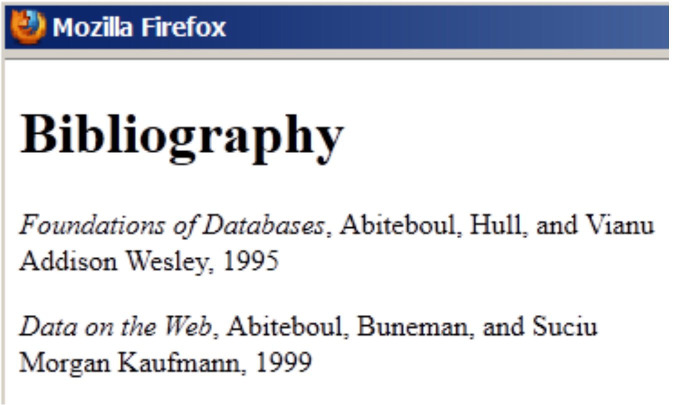
Watch **instantly** on your PS3, Xbox, Kindle Fire, iPad, PC and
★★★★★ (1)

Semi-structured data

- Observation: most data have some structure, e.g.:
  - Book: chapters, sections, titles, paragraphs, references, index, etc.
  - Item for sale: name, picture, price (range), ratings, promotions, etc.
  - Web page: HTML
- Ideas:
  - Ensure data is “well-formatted”
  - If needed, ensure data is also “well-structured”
    - But make it easy to define and extend this structure
  - Make data “self-describing”

HTML: language of the Web

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



Bibliography

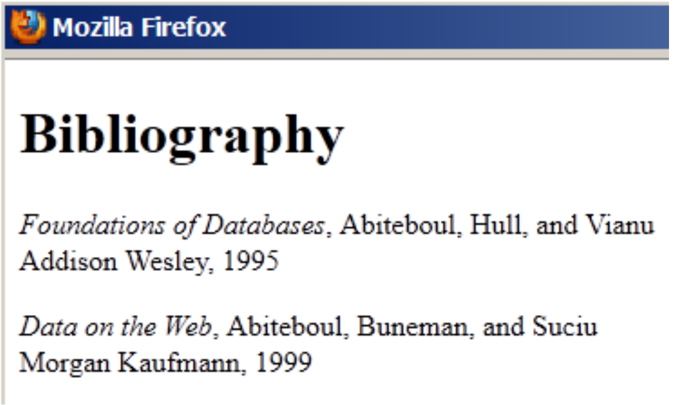
Foundations of Databases, Abiteboul, Hull, and Vianu
Addison Wesley, 1995

Data on the Web, Abiteboul, Buneman, and Suciu
Morgan Kaufmann, 1999

- It’s mostly a “formatting” language
- It mixes presentation and content
  - Hard to change presentation (say, for different displays)
  - Hard to extract content

XML: eXtensible Markup Language

```
<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>
```



Bibliography

Foundations of Databases, Abiteboul, Hull, and Vianu
Addison Wesley, 1995

Data on the Web, Abiteboul, Buneman, and Suciu
Morgan Kaufmann, 1999

- Text-based
- Capture data (content), not presentation
- Data self-describes its structure
  - Names and nesting of tags have meanings!

Other nice features of XML

- Portability: Just like HTML, you can ship XML data across platforms
  - Relational data requires heavy-weight API's
- 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>
    <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">`

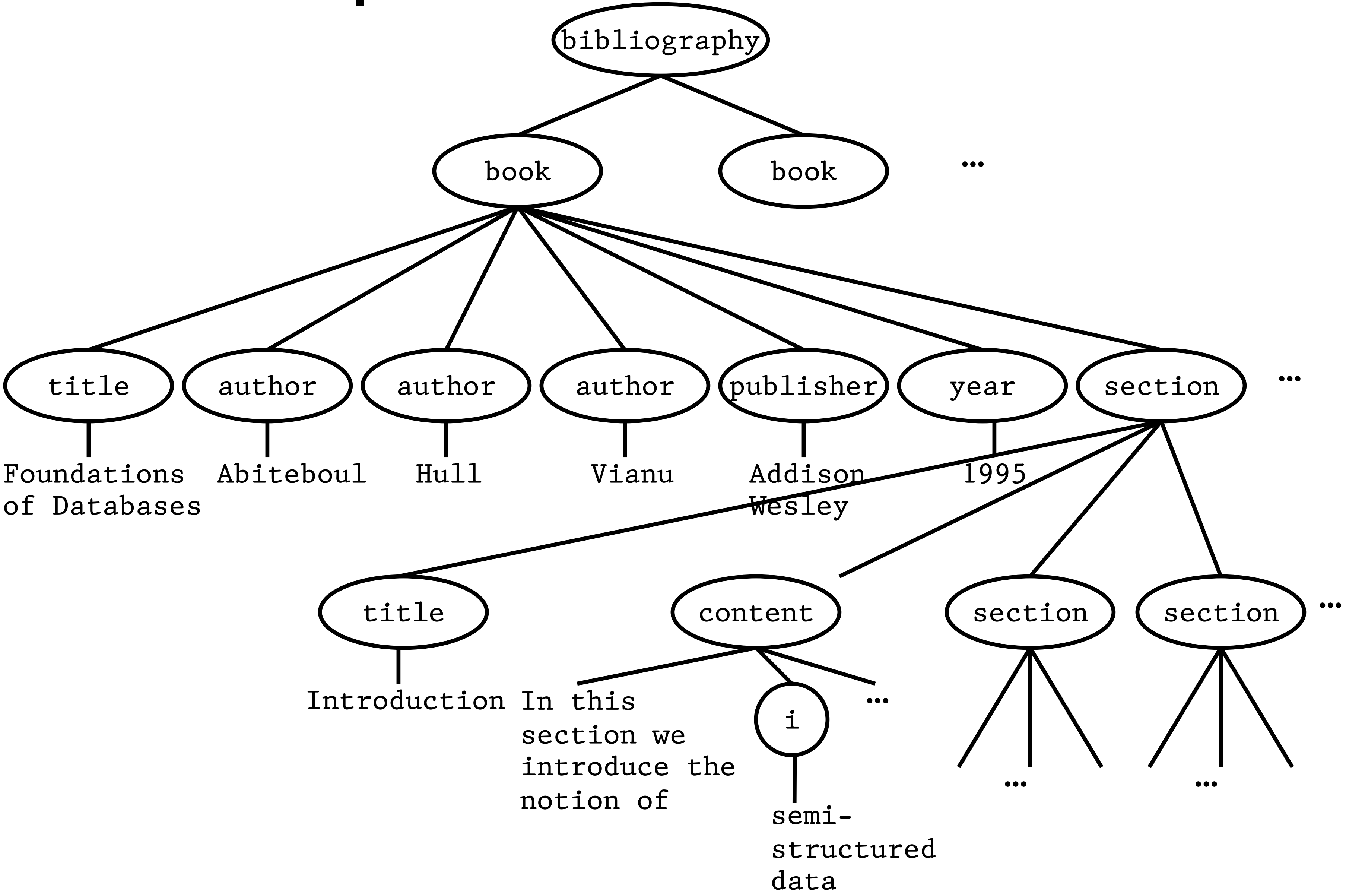
☞Ordering generally matters, except for attributes

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



More XML features

- 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

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

- And more…

Now for some more structure…

https://commons.wikimedia.org/wiki/File:Hundertwasser_04.jpg

Valid XML documents

- 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 ID #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

```
<!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 authors, 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

```
<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>
```

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

DTD explained (cont’d)

```
<!ELEMENT title (#PCDATA)>
<!ELEMENT author (#PCDATA)>
<!ELEMENT publisher (#PCDATA)>
<!ELEMENT year (#PCDATA)>
<!ELEMENT i (#PCDATA)>
```

PCDATA is text that will be parsed

- `&lt;` etc. will be parsed as entities
- Use a CDATA section to include text verbatim

↳ `author`, `publisher`, `year`, and `i` contain parsed character data

```
<!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

- 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>
    ```

Annoyance: content grammar

- Consider this 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*)>`

Annoyance: element name clash

- 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 we just infer a `title`'s context?

Annoyance: lack of type support

- 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, even if they have different types (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”?

Now for even
more structure support…

http://thenewsherald.com/content/articles/2012/11/10/entertainment/doc509deb9f9207c2452179065.jpg

XML Schema

- 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)

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

  … …
</xs:schema>
```

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

```
<xs:element name="book"> We are now defining an element named book
  <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" type="xs:string"
                  minOccurs="0" maxOccurs="unbounded"/>Like author* in DTD
      <xs:element name="publisher" type="xs:string" Like publisher? in DTD
                  minOccurs="0" maxOccurs="1"/>
      <xs:element name="year" type="xs:integer" A leaf element with integer content
                  minOccurs="0" maxOccurs="1"/>
      <xs:element ref="section" Like section* in DTD; section is defined elsewhere
                  minOccurs="0" maxOccurs="unbounded"/>
    </xs:sequence>
    <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"/>
  </xs:complexType>             This attribute has a decimal value, and it is optional
</xs:element>
```

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)

`min`/`maxOccurs` can be attached to compositors too

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

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=“1" 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`, 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 `bibliography`, for elements reachable by selector "`.//book-ref`" (i.e., any `book-ref` underneath): values of field "`@ISBN`" (i.e., `ISBN` attributes) must appear as values of `bookKey`, the key referenced
  - Make sure `keyref` is declared in the same scope

Why use DTD or XML Schema?

- 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)

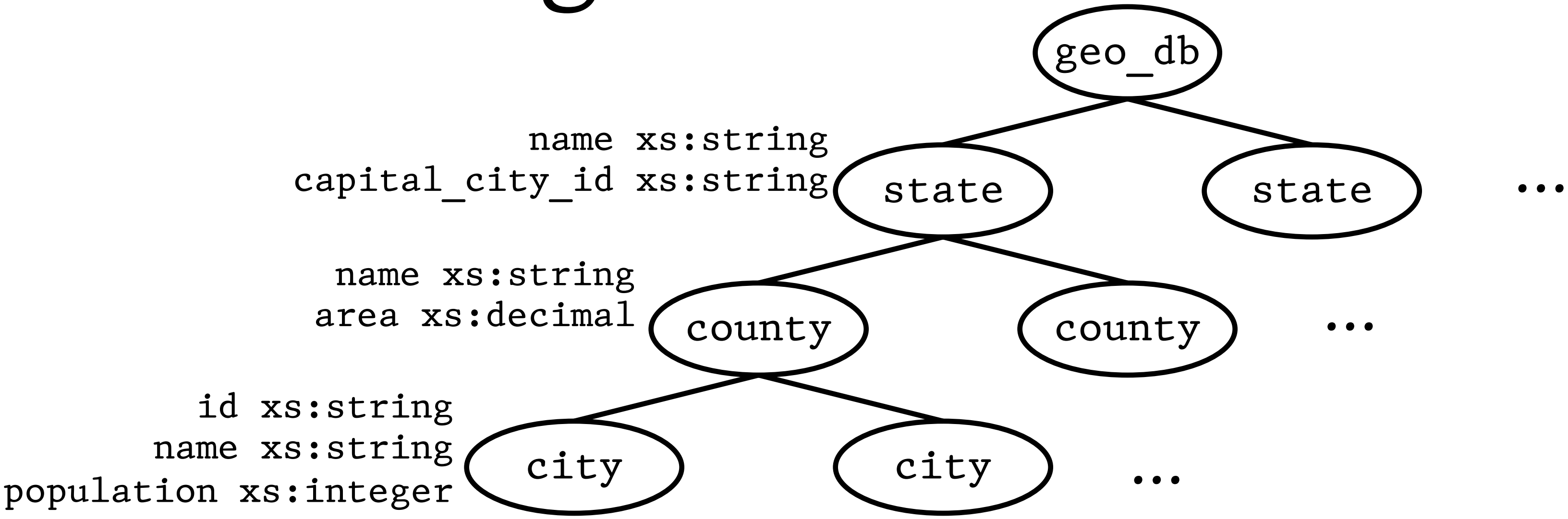
XML versus relational data

Relational data	XML data
Schema is always fixed in advance and difficult to change	Well-formed XML does not require predefined, fixed schema
Simple, flat table structures	Nested structure; `ID/IDREF(S)` permit arbitrary graphs
Ordering of rows and columns is unimportant	Ordering forced by document format; may or may not be important
Exchange is problematic	Designed for easy exchange
"Native" support in all serious commercial DBMS	Often implemented as an "add-on" on top of relations

Case study

- 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



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