XML and DTD

Introduction to Databases

CompSci 316 Spring 2019

DUKE
COMPUTER SCIENCE

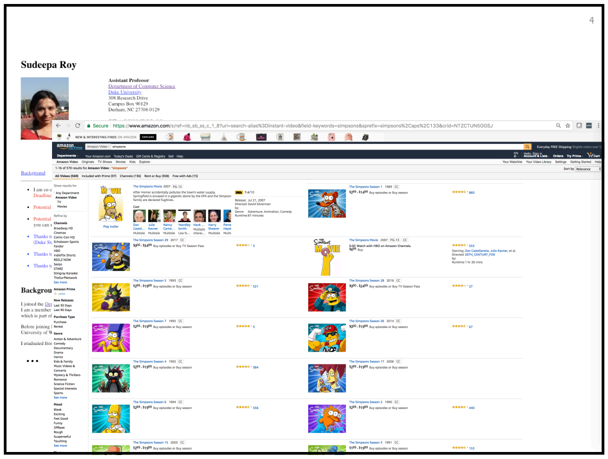
Announcements (Thu. Feb. 28)

- Homework #2 due today (except 1 & 2)
  - Late submissions with 5% penalty per hour
- Homework #3 to be assigned soon
- Project milestone #1 feedback to be emailed by next class

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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Durham, NC 27708-0129

Background

- I am co-c… Deadline…
- Potential…
- Potential… you can s…
- Thanks t… (Duke St…
- Thanks t…
- Thanks t…

Backgrou…

I joined the Dep… I am a member… which is part of…

Before joining… University of W…

I graduated fro…

• • •

Secure https://www.amazon.com/s/ref=nb_sb_ss_c_1_8?url=search-alias%3Dinstant-video&field-keywords=simpsons&sprefix=simpsons%2Caps%2C133&crid=NTZCTUN5GGSJ

1-16 of 570 results for Amazon Video : "simpsons"

All Videos (569) Included with Prime (97) Channels (136) Rent or Buy (308) Free with Ads (15)

The Simpsons Movie 2007 PG-13 — After Homer accidentally pollutes the town's water supply, Springfield is encased in a gigantic dome by the EPA and the Simpson family are declared fugitives. — 7.4/10 — Release: Jul 21, 2007; Directed David Silverman; Genre: Adventure, Animation, Comedy; Runtime: 87 minutes

The Simpsons Season 1 1989 CC — $2.99 - $14.99 Buy episodes or Buy season — 860

The Simpsons Season 29 2017 CC — $0.00 - $34.99 Buy episodes or Buy TV Season Pass — 3

The Simpsons Movie 2007 PG-13 CC — 0.00 Watch with HBO on Amazon Channels. $6.99 Buy — 553 — Starring: Dan Castellaneta, Julie Kavner, et al. Directed 20TH_CENTURY_FOX; Runtime: 1 hr 26 mins

The Simpsons Season 5 1993 CC — $2.99 - $19.99 Buy episodes or Buy season — 321

The Simpsons Season 28 2016 CC — $0.00 - $24.99 Buy episodes or Buy TV Season Pass — 27

The Simpsons Season 7 1995 CC — $2.99 - $19.99 Buy episodes or Buy season — 3

The Simpsons Season 26 2014 CC — $0.00 - $19.99 Buy episodes or Buy season — 67

The Simpsons Season 4 1992 CC — $2.99 - $19.99 Buy episodes or Buy season — 384

The Simpsons Season 17 2006 CC — $2.99 - $19.99 Buy episodes or Buy season

The Simpsons Season 6 1994 CC — $2.99 - $19.99 Buy episodes or Buy season — 556

The Simpsons Season 2 1990 CC — $2.99 - $19.99 Buy episodes or Buy season — 440

The Simpsons Season 15 2003 CC — $2.99 - $19.99 Buy episodes or Buy season

The Simpsons Season 3 1991 CC — $1.99 - $19.99 Buy episodes or Buy season — 153

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Your Watchlist Your Video Library Settings Getting Started Help
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Movies
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Genre
Mood
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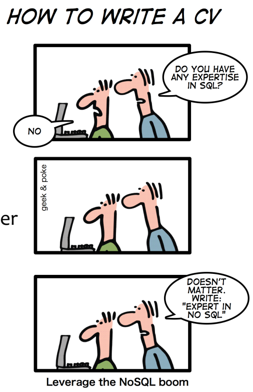
Semi-structured data

- 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"

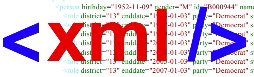
SQL vs. NoSQL

- SQL's rigidity in face of semi-structured data is one of the reasons behind the rise of (some) NoSQL systems
  - NoSQL has other motivations, which we hope to get to in a later part of this course



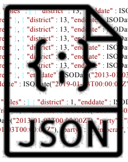
HOW TO WRITE A CV
DO YOU HAVE ANY EXPERTISE IN SQL?
NO
geek & poke
DOESN'T MATTER. WRITE: "EXPERT IN NO SQL"
Leverage the NoSQL boom

Our roadmap thru the NoSQL land



```
<congress>
  <people>
    <person birthday="1952-11-09" gender="M" id="B000944" name="Sherrod Brown">
      <role district="13" enddate="19[illegible]-01-03" pa[illegible]y="Democrat" startdate="1993-01-05" state="OH" type="rep"/>
      <r[illegible]dist[illegible]en[illegible]e="1[illegible]-01-03" p[illegible]Democrat" startdate="1995-01-04" state="OH" type="rep"/>
      [illegible]dist[illegible]="1[illegible]ndd[illegible]="1[illegible]-01-03" [illegible]ty=[illegible]rat" startdate="1997-01-07" state="OH" type="rep"/>
      [illegible]e dist[illegible]="1[illegible]endd[illegible]="2[illegible]-01-03" [illegible]rty="Demo[illegible]" startdate="1999-01-06" state="OH" type="rep"/>
      [illegible]dist[illegible]="1[illegible]endd[illegible]="2[illegible]-01-03"[illegible]arty=[illegible]ocrat" startdate="2001-01-03" state="OH" type="rep"/>
      <ro[illegible] district="13" enddate="200[illegible]-01-03" party="Democrat" startdate="2003-01-07" state="OH" type="rep"/>
      <role district="13" enddate="2007-01-03" party="Democrat" startdate="2005-01-04" state="OH" type="rep"/>
      <role enddate="2013-01-03" party="Democrat" startdate="2007-01-04" state="OH" type="sen"/>
      <role current="1" enddate="2019-01-03" party="Democrat" startdate="2013-01-03" state="OH" type="sen"/>
    </person>
    <person birthday="1958-10-13" gender="F" id="C000127" name="Maria Cantwell">
```

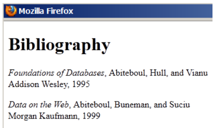
- But can’t relational databases do XML?



```
{ "_id" : "B000944", "birthday" : ISODate("1952-11-09T00:00:00Z"), "gender" : "M", "name" : "Sherrod Brown", "[illegible]les" : [ { "district" : 13, "[illegible]date" : ISODate("1995-01-
03T00:00:00Z"), "party" : "Democrat", "startdate" : ISODate("1993-01-05T00:00:00Z"), "state" : "OH", "type" : "re[illegible] }, { "district" : 13, "end[illegible]te" : ISODate("1997-01-
03T00:00:00Z"), "party" : "Democrat", "startdate" : ISODate("1995-01-04T00:00:00Z"), "state" : "OH", "type" : "re[illegible] }, { "district" : 13, "end[illegible]te" : [illegible]ODate("1999-01-
03T00:00:00Z"), "party" : "Democrat", "startdate" : ISODate("1997-01-07T00:00:00Z"), "state" : "OH", "type" : "re[illegible] }, { "dis[illegible]ict" : 13, "en[illegible]ate("2001-01-
03T00:00:00Z"), "party" : "Democrat", "startdate" : ISODate("1999-01-06T00:00:00Z"), "state" : "OH", "type" : "re[illegible] }, { "di[illegible]rict" : 13, "en[illegible]ate" : ISO[illegible]ate("2003-01-
03T00:00:00Z"), "party" : "Democrat", "startdate" : ISODate("2001-01-03T00:00:00Z"), "state" : "OH", "type" : "re[illegible] }, { "di[illegible]rict" : [illegible], "en[illegible]ate" : ISO[illegible]ate("2005-01-
03T00:00:00Z"), "party" : "Democrat", "startdate" : ISODate("2003-01-07T00:00:00Z"), "state" : "OH", "type" : "re[illegible] }, { [illegible]trict" : 13, "end[illegible]e" : ISO[illegible]ate("2007-01-
03T00:00:00Z"), "party" : "Democrat", "startdate" : ISODate("2005-01-04T00:00:00Z"), "state" : "OH", "type" : "re[illegible] }, { "en[illegible]date" [illegible]SODa[illegible]("2013-01[illegible]03T00:00:00Z"), "party" :
"Democrat", "startdate" : ISODate("2007-01-04T00:00:00Z"), "state" : "OH", "type" : "sen" }, { "current" : 1, "end[illegible]te" : ISO[illegible]te("2[illegible]19-01-[illegible]3T00:00:0[illegible]Z"), "party" : "Democrat",
"startdate" : ISODate("2013-01-03T00:00:00Z"), "state" : "OH", "type" : "sen" } ] }
{ "_id" : "C000127", "birthday" : ISODate("1958-10-13T00:00:00Z"), "gender" : "F", "name" : "Maria Cantwell", "[illegible]les" : [ { "district" : 1, "enddate" : I[illegible]ODate("1995-01-
03T00:00:00Z"), "party" : "Democrat", "startdate" : ISODate("1993-01-05T00:00:00Z"), "state" : "WA", "type" : "r[illegible]03T00:00:00Z"), "party" :
"Democrat", "startdate" : ISODate("2001-01-03T00:00:00Z"), "state" : "WA", "type" : "sen" }, { "enddate" : ISODa[illegible]("2013[illegible]01-0[illegible]T00:[illegible]Z"), "p[illegible]rty" [illegible] "Democrat", "startdate" :
ISODate("2007-01-04T00:00:00Z"), "state" : "WA", "type" : "sen" }, { "current" : 1, "enddate" : ISODate("2019-01[illegible]03T00:[illegible]Z"), [illegible]arty" : [illegible]ocra[illegible], "startdate" :
ISODate("2013-01-03T00:00:00Z"), "state" : "WA", "type" : "sen" } ] }
```

HTML: language of the Web

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



Bibliography

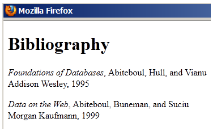
Foundations of Databases, Abiteboul, Hull, and Vianu
Addison Wesley, 1995

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">

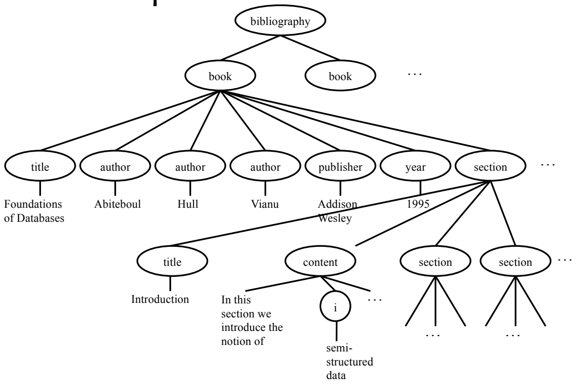
☞Ordering generally matters, except for attributes

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
  - ID value must start with a non-digit

```
<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

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)

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

└→ 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

]>

PCDATA is text that will be parsed

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

```
<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>
```

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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>
    ```

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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*)>

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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?

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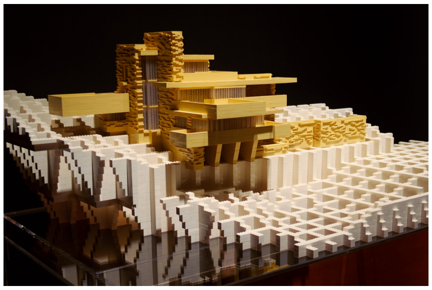
Annoyance: lack of type support

- 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"?

23



Want even more
structure support?

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

24

XML Schema

- A more powerful way of defining the structure and constraining the contents of XML documents
  - Supports a rich set of types and user-defined types/structures
  - Supports notions of keys and foreign keys
- An XML Schema definition is itself an XML document
  - Typically stored as a standalone .xsd file
  - XML (data) documents refer to external .xsd files

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

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

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

```
<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:schema>
```

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)

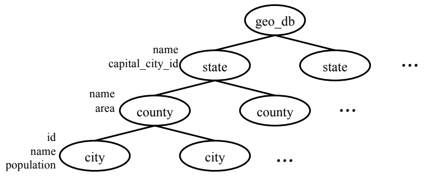
XML versus relational data

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



geo_db
name
capital_city_id
state
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