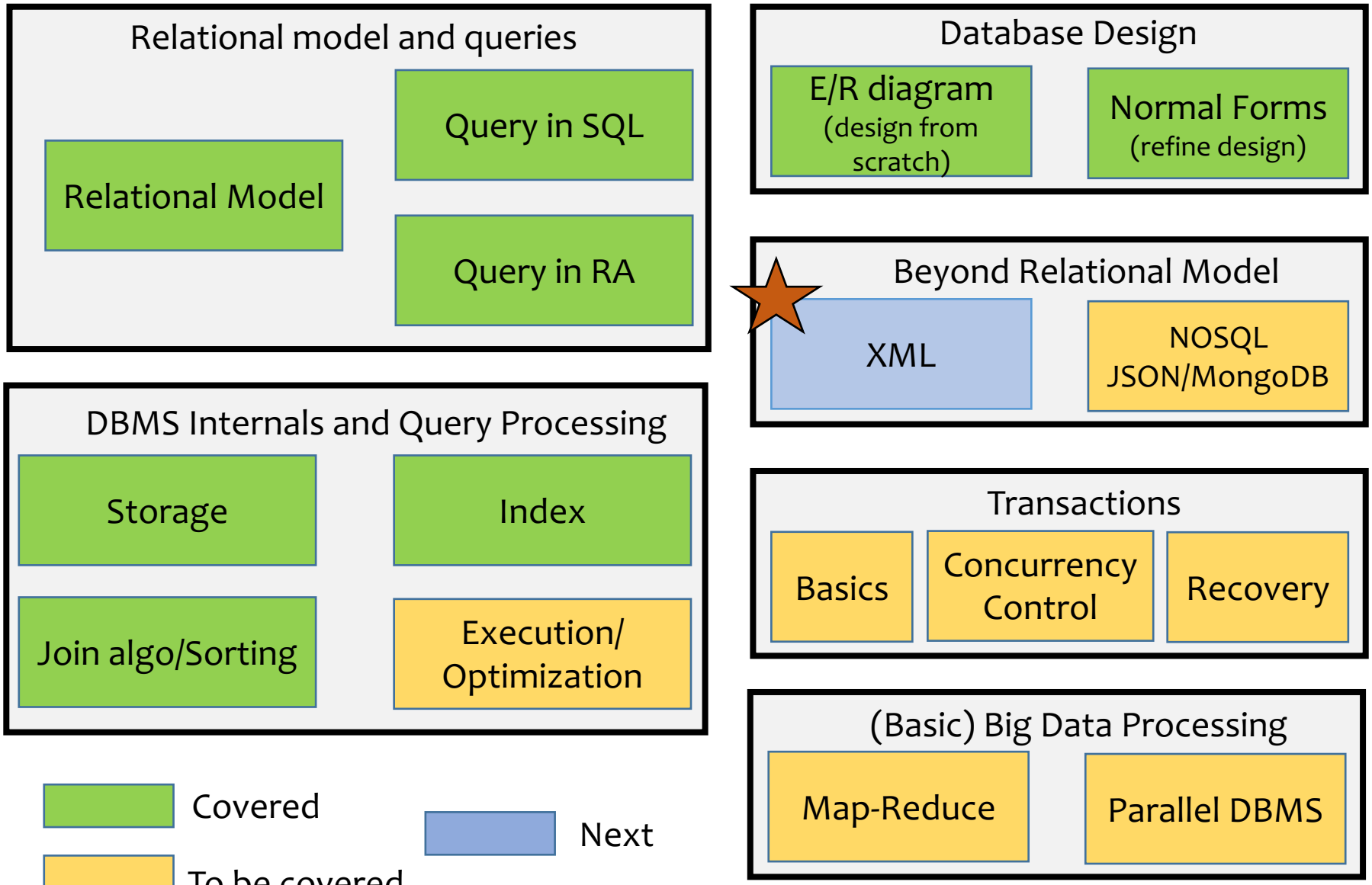
XML

Introduction to Databases

CompSci 316 Fall 2020

DUKE
COMPUTER SCIENCE

Where are we now?



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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Background

- I am co-c
  Deadline:
- Potential
- Potential
  you can s
- Thanks to
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Backgrou

I joined the Dep
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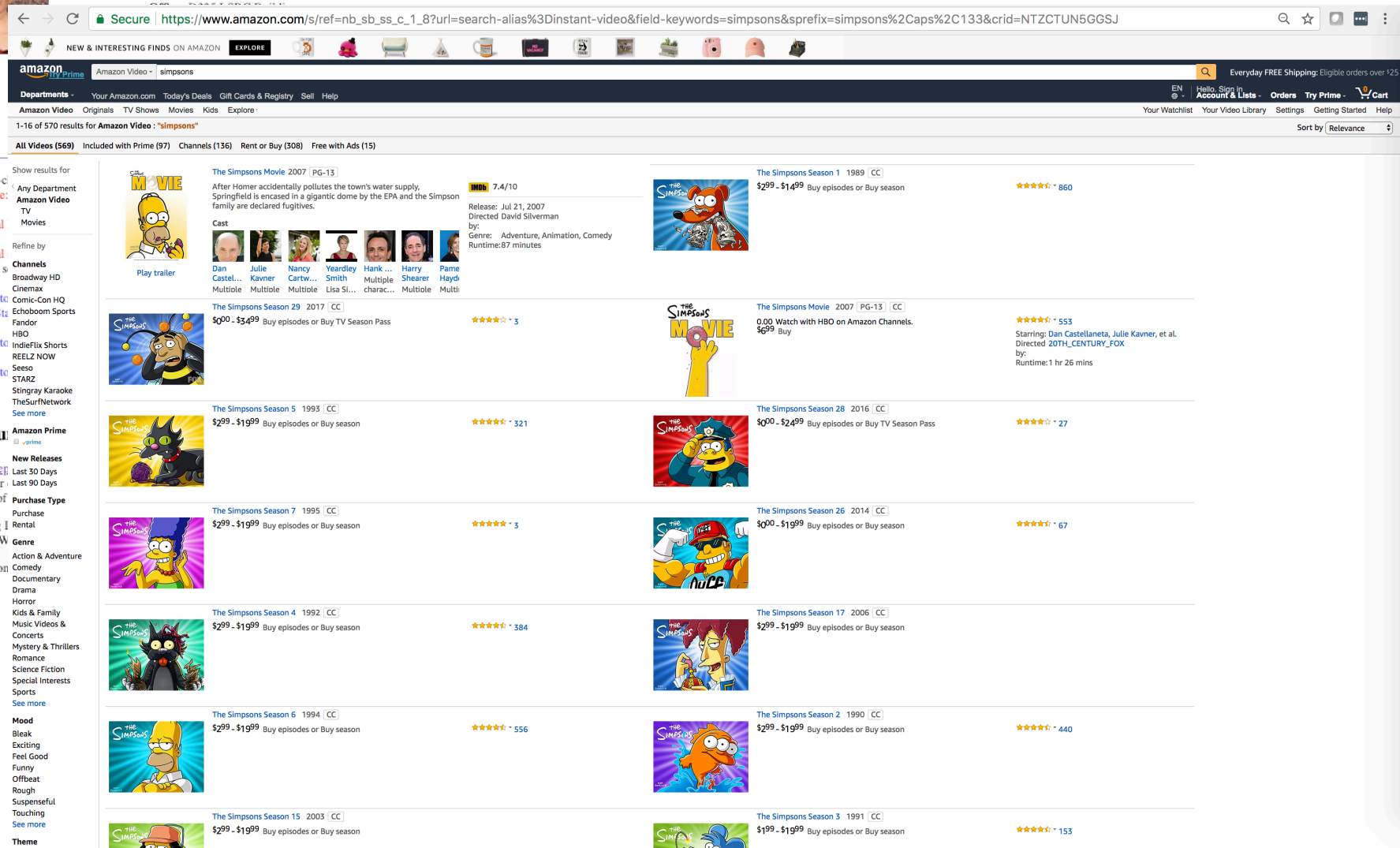
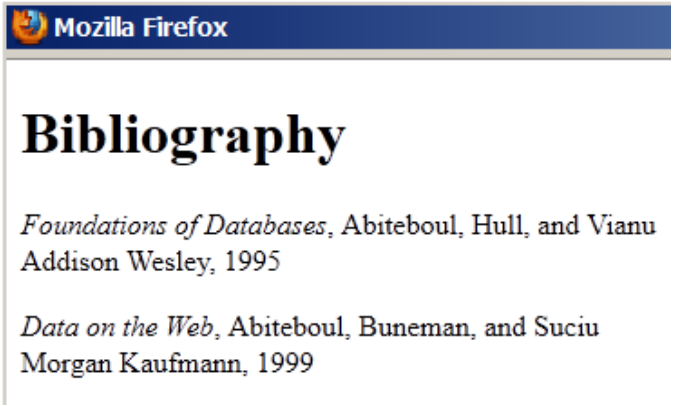


Semi-structured data

- 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.

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>
```



- Text-based
- Capture data (content), not presentation
  - Similar but different from HTML
- 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">
- Many other features

☞Ordering generally matters, except for attributes

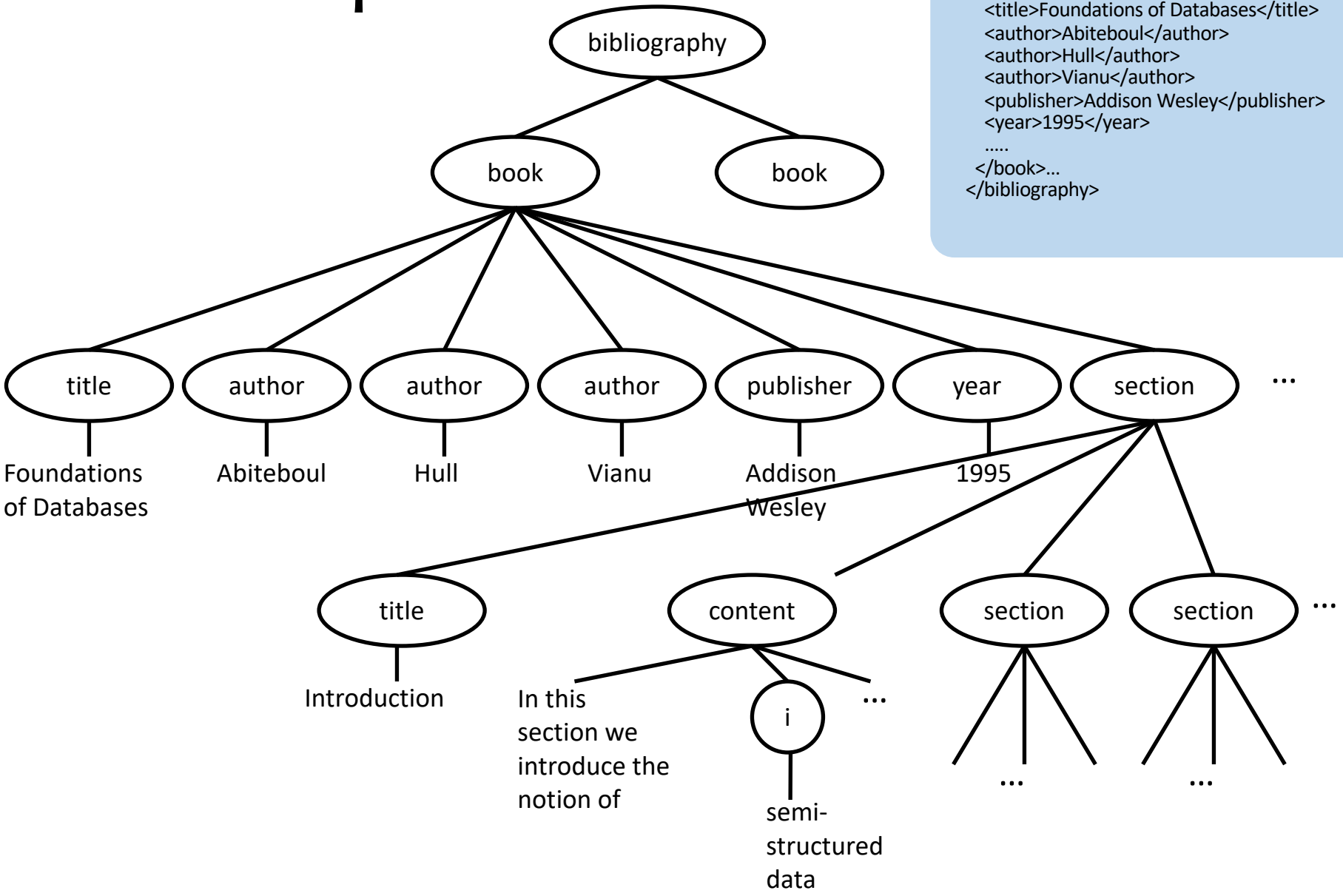
Well-formed XML documents

A well-formed XML document

- Follows XML lexical conventions
  - Wrong: <section>We show that x < 0…</section>
  - Right: <section>We show that x < 0…</section>
    - Other special entities: > becomes > and & becomes &
- Contains a single root element
- Has properly matched tags and properly nested elements (like parentheses matching)
  - Right: <section>…<subsection>…</subsection>…</section>
  - Wrong: <section>…<subsection>…</section>…</subsection>
  - Think of {{()}([])} matching!

A tree representation

```
<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>
```



FYI - NOT COVERED

DTD and Schema (details omitted)

- DTD (Document Type Definitions)
- Specifies Schema and constraints for XML
- Specifies a grammar (e.g. +, ? for one or more, zero or 1 etc.)
- Another option XML schema (.xsd)

```
<?xml version="1.0"?>

<!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*)>
   ]>

<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>
       <section>…</section>…
     </book>
     …
   </bibliography>
```

XML versus relational data

Relational data

- Schema is always fixed in advance and difficult to change
- Simple, flat table structures
- Ordering of rows and columns is unimportant
- 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

Announcements (Thu. Oct 22)

- HW6a (probs 1, 2) due today (10/22)
- HW6b (prob 3) due Tuesday (10/27)
- Short Lecture-quiz-3 (Sorting etc.) due today (10/22)
- No Gradiance this week.

- Review of keys/superkeys/FDs/BCNF (if we have time, Join Algos) on Monday

- Please let Yesenia know if you would like to meet me
- Please check out the email on tutoring + IREX feedback session for SQL

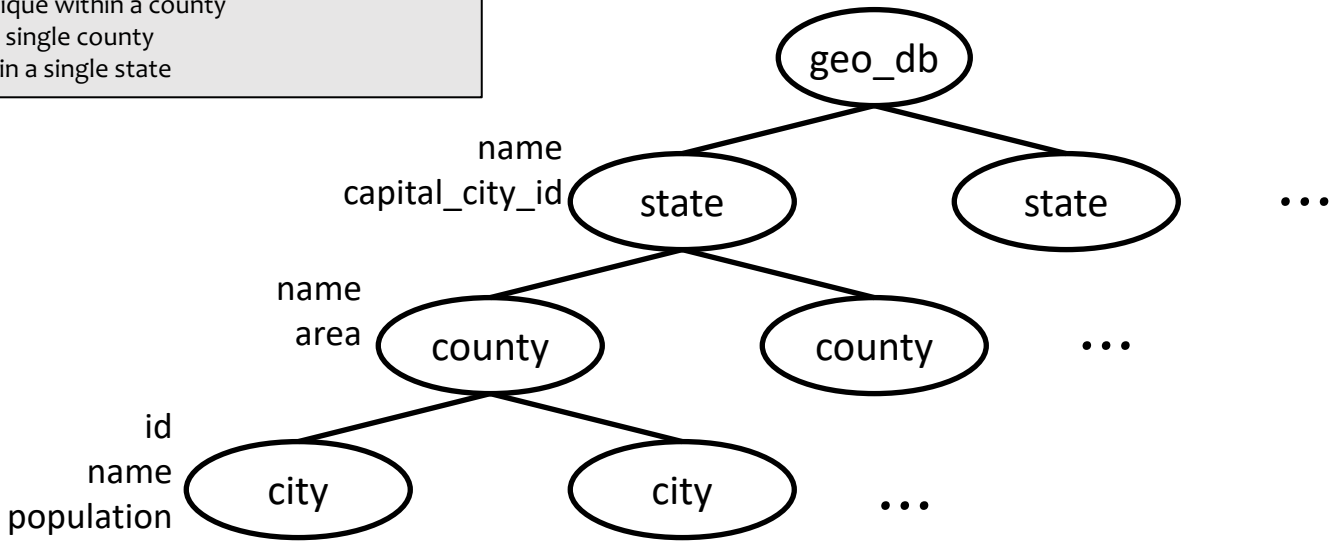
Case study

- 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

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



XPath and XQuery

Query languages for XML

- XPath
  - Path expressions with conditions

  ☞Building block of other standards (XQuery, XSLT, XLink, XPointer, etc.)

- XQuery
  - XPath + full-fledged SQL-like query language

- Also XSLT (not covered)

- We would cover only simple queries

Try the queries in this lecture online

- There are many online Xpath/Xquery testers e.g.
- http://codebeautify.org/Xpath-Tester (XPATH)
- http://videlibri.sourceforge.net/cgi-bin/xidelcgi (XQUERY)
- Try with this example (or change it for different queries)
- Caveats
  - if you see bad characters, you might have to replace them like " or .
  - Not everything works all the time! Try different websites and config

```
<bibliography>
<book ISBN="ISBN-10" price="70">
<title>Foundations of Databases</title>
<author>Abiteboul</author>
<author>Hull</author>
<author>Vianu</author>
<publisher>Addison Wesley</publisher>
<year>1995</year>
<section>abc</section>
</book>
<book ISBN="ISBN-11"price="20">
 <title>DBSTS</title>
 <author>Ramakrishnan</author>
 <author>Gehrke</author>
 <publisher>Addison Wesley</publisher>
 <year>1999</year>
 <section>abc</section>
 </book>
</bibliography>
```

XPath

- XPath specifies path expressions that match XML data by navigating down (and occasionally up and across) the tree
- Example
  - Query: /bibliography/book/author
    - Like a file system path, except there can be multiple "subdirectories" with the same name
  - Result: all author elements reachable from root via the path /bibliography/book/author

```
<bibliography>
<book ISBN="ISBN-10" price="70">
<title>Foundations of Databases</title>
<author>Abiteboul</author>
<author>Hull</author>
<author>Vianu</author>
<publisher>Addison Wesley</publisher>
<year>1995</year>
<section>abc</section>
</book>
<book ISBN="ISBN-11"price="20">
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 <author>Ramakrishnan</author>
 <author>Gehrke</author>
 <publisher>Addison Wesley</publisher>
 <year>1999</year>
 <section>abc</section>
 </book>
</bibliography>
```

Basic XPath constructs

/ separator between steps in a path

name matches any child element with this tag name

* matches any child element

@name matches the attribute with this name

@* matches any attribute

// matches any descendent element or the current element itself

. matches the current element

.. matches the parent element

Simple XPath examples

```
<bibliography>
<book ISBN="ISBN-10" price="70">
<title>Foundations of Databases</title>
<author>Abiteboul</author>
<author>Hull</author>
<author>Vianu</author>
<publisher>Addison Wesley</publisher>
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<book ISBN="ISBN-11"price="20">
 <title>DBSTS</title>
 <author>Ramakrishnan</author>
 <author>Gehrke</author>
 <publisher>Addison Wesley</publisher>
 <year>1999</year>
 <section>abc</section>
 </book>
</bibliography>
```

- All book titles

  /bibliography/book/title

- All book ISBN numbers

  /bibliography/book/@ISBN

- All title elements, anywhere in the document

  //title

- All section titles, anywhere in the document

  //section/title

- Authors of bibliographical entries (suppose there are articles, reports, etc. in addition to books)

  /bibliography/*/author

Predicates in path expressions

[*condition*] matches the "current" element if *condition* evaluates to true on the current element

- Books with price lower than $50

  /bibliography/book[@price<50]

  - XPath will automatically convert the price string to a numeric value for comparison

```
<bibliography>
<book ISBN="ISBN-10" price="70">
<title>Foundations of Databases</title>
<author>Abiteboul</author>
<author>Hull</author>
<author>Vianu</author>
<publisher>Addison Wesley</publisher>
<year>1995</year>
<section>abc</section>
</book>
<book ISBN="ISBN-11"price="20">
 <title>DBSTS</title>
 <author>Ramakrishnan</author>
 <author>Gehrke</author>
 <publisher>Addison Wesley</publisher>
 <year>1999</year>
 <section>abc</section>
 </book>
</bibliography>
```

Predicates in path expressions – contd.

- Books with author “Abiteboul”

  /bibliography/book[author='Abiteboul']

- Books with a publisher child element

  /bibliography/book[publisher]

- Prices of books authored by “Abiteboul”

  /bibliography/book[author='Abiteboul']/@price

```
<bibliography>
<book ISBN="ISBN-10" price="70">
<title>Foundations of Databases</title>
<author>Abiteboul</author>
<author>Hull</author>
<author>Vianu</author>
<publisher>Addison Wesley</publisher>
<year>1995</year>
<section>abc</section>
</book>
<book ISBN="ISBN-11"price="20">
 <title>DBSTS</title>
 <author>Ramakrishnan</author>
 <author>Gehrke</author>
 <publisher>Addison Wesley</publisher>
 <year>1999</year>
 <section>abc</section>
 </book>
</bibliography>
```

More complex predicates

Predicates can use and, or, and not

- Books with price between $40 and $50

  /bibliography/book[40<=@price and @price<=50]

- Books authored by "Abiteboul" or those with price no lower than $50

  /bibliography/book[author='Abiteboul' or @price>=50]

  /bibliography/book[author='Abiteboul' or not(@price<50)]

  - Any difference between these two queries?

```
<bibliography>
<book ISBN="ISBN-10" price="70">
<title>Foundations of Databases</title>
<author>Abiteboul</author>
<author>Hull</author>
<author>Vianu</author>
<publisher>Addison Wesley</publisher>
<year>1995</year>
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<book ISBN="ISBN-11"price="20">
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 <author>Ramakrishnan</author>
 <author>Gehrke</author>
 <publisher>Addison Wesley</publisher>
 <year>1999</year>
 <section>abc</section>
 </book>
</bibliography>
```

A tricky example

- Suppose for a moment that price is a child element of book, and there may be multiple prices per book
- Books with some price in range [20, 50]
  - Wrong answer:
    /bibliography/book[price >= 20 and price <= 50]
    (returns true with one price 10 and one 70!)
  - Correct answer:
    /bibliography/book[price[. >= 20 and . <= 50]]

Predicates involving node-sets

/bibliography/book[author='Abiteboul']

- There may be multiple authors, so author in general returns a node-set (in XPath terminology)
- The predicate evaluates to true as long as it evaluates true for at least one node in the node-set, i.e., at least one author is "Abiteboul"
- Another tricky query

  /bibliography/book[author='Abiteboul' and author!='Abiteboul']

  - Will it return any books?

  - (Returns books with at least one "Abiteboul" and one non-Abiteboul as authors!)

More XPath operators and functions

Frequently used in conditions:

x + *y*, *x* – *y*, *x* * *y*, *x* div *y*, *x* mod *y*

contains(*x*, *y*) true if string *x* contains string *y*

count(*node-set*) counts the number nodes in *node-set*

position() returns the "context position" (roughly, the position of the current node in the node-set containing it)

last() returns the "context size" (roughly, the size of the node-set containing the current node)

name() returns the tag name of the current element

Books with fewer than 10 sections

```
/bibliography/book[count(section)<10]
```

All elements whose tag names contain "section" (e.g., "subsection")

```
//*[contains(name(), 'section')]
```

Title of the first section in each book

```
/bibliography/book/section[position()=1]/title
```

A shorthand: `/bibliography/book/section[1]/title`

Title of the last section in each book

```
/bibliography/book/section[position()=last()]/title
```

XQuery

- XPath + full-fledged SQL-like query language
- XQuery expressions can be
  - XPath expressions
  - FLWOR expressions
  - Quantified expressions
  - Aggregation, sorting, and more…
- An XQuery expression can return a new result XML document

Sample online Xquery tester:
http://videlibri.sourceforge.net/cgi-bin/xidelcgi

Use Xquery 3.0, node format = xml, output format = adhoc, and compatibility = Standard Xquery in the settings

A simple XQuery based on XPath

Find all books with price lower than $50

```
<result>{
  doc("bib.xml")/bibliography/book[@price<50]
}</result>
```

- Things outside {}'s are copied to output verbatim
- Things inside {}'s are evaluated and replaced by the results
  - doc("bib.xml") specifies the document to query
  - Omit this in the online tester
  - The XPath expression returns a sequence of book elements
  - These elements (including all their descendants) are copied to output

FLWR expressions

- Retrieve the titles of books published before 2000, together with their publisher

```
<result>{
 for $b in /bibliography/book
 let $p := $b/publisher
 where $b/year < 2000
 return
  <book>
   { $b/title }
   { $p }
  </book>
}</result>
```

- for: loop
  - $b ranges over the result sequence, getting one item at a time
- let: "assignment"
  - $p gets the entire result of $b/publisher (possibly many nodes)
- where: filtering by condition
- return: result structuring
  - Invoked in the "innermost loop," i.e., once for each successful binding of all query variables that satisfies where

An equivalent formulation

- Retrieve the titles of books published before 2000, together with their publisher

```
<result>{
 for $b in /bibliography/book[year<2000]
 return
   <book>
     { $b/title }
     { $b/publisher }
   </book>
}</result>
```

Another formulation

- Retrieve the titles of books published before 2000, together with their publisher

```
<result>{
 for $b in /bibliography/book,
     $p in $b/publisher
 where $b/year < 2000
 return
  <book>
   { $b/title }
   { $p }
  </book>
}</result>
```

} Nested loop

- Is this query equivalent to the previous two?
- Yes, if there is one publisher per book
- No, in general
  - Two result book elements will be created for a book with two publishers
  - No result book element will be created for a book with no publishers

Yet another formulation

- Retrieve the titles of books published before 2000, together with their publisher

```
<result>{
  let $b := /bibliography/book
  where $b/year < 2000
  return
    <book>
      { $b/title }
      { $b/publisher }
    </book>
}</result>
```

- Is this query correct?
- No!
- It will produce only one output book element, with all titles clumped together and all publishers clumped together
- All books will be processed (as long as one is published before 2000)

An explicit join

- Find pairs of books that have common author(s)

```
<result>{
 for $b1 in doc("bib.xml")//book
 for $b2 in doc("bib.xml")//book
 where $b1/author = $b2/author
   and $b1/title > $b2/title
 return
  <pair>
   {$b1/title}
   {$b2/title}
  </pair>
}</result>
```

← These are string comparisons, not identity comparisons!

FYI - NOT COVERED

More features

- Subqueries
  - normalize-space(*string*) removes leading and trailing spaces from string, and replaces all internal sequences of white spaces with one white space
- Existential (some) and Universal (all)
- Aggregation
- Conditional
  - Use anywhere you'd expect a value, e.g.:
  - let $foo := if (...) then ... else ...
  - return <bar blah="{ if (...) then ... else ... }"/>

List each publisher and the average prices of all its books

```
<result>{
  for $pub in distinct-
values(doc("bib.xml")//publisher)
  let $price :=
avg(doc("bib.xml")//book[publisher=$pub
]/@price)
  return
    <publisherpricing>
      <publisher>{$pub}</publisher>
      <avgprice>{$price}</avgprice>
    </publisherpricing>
}</result>
```

Extract book titles and their authors; make title an attribute and rename author to writer

```
<bibliography>{
 for $b in doc("bib.xml")/bibliography/book
 return
   <book title="{normalize-space($b/title)}">{
    for $a in $b/author
    return <writer>{string($a)}</writer>
   }</book>
}</bibliography>
```

Find titles of books in which XML is mentioned in some section

```
<result>{
 for $b in doc("bib.xml")//book
 where (some $section in $b//section
satisfies
      contains(string($section),
"XML"))
 return $b/title
}</result>
```

Find titles of books in which XML is mentioned in every section

```
<result>{
 for $b in doc("bib.xml")//book
 where (every $section in $b//section
satisfies
      contains(string($section),
"XML"))
 return $b/title
}</result>
```

XML to Relational Data

Which one is easier?

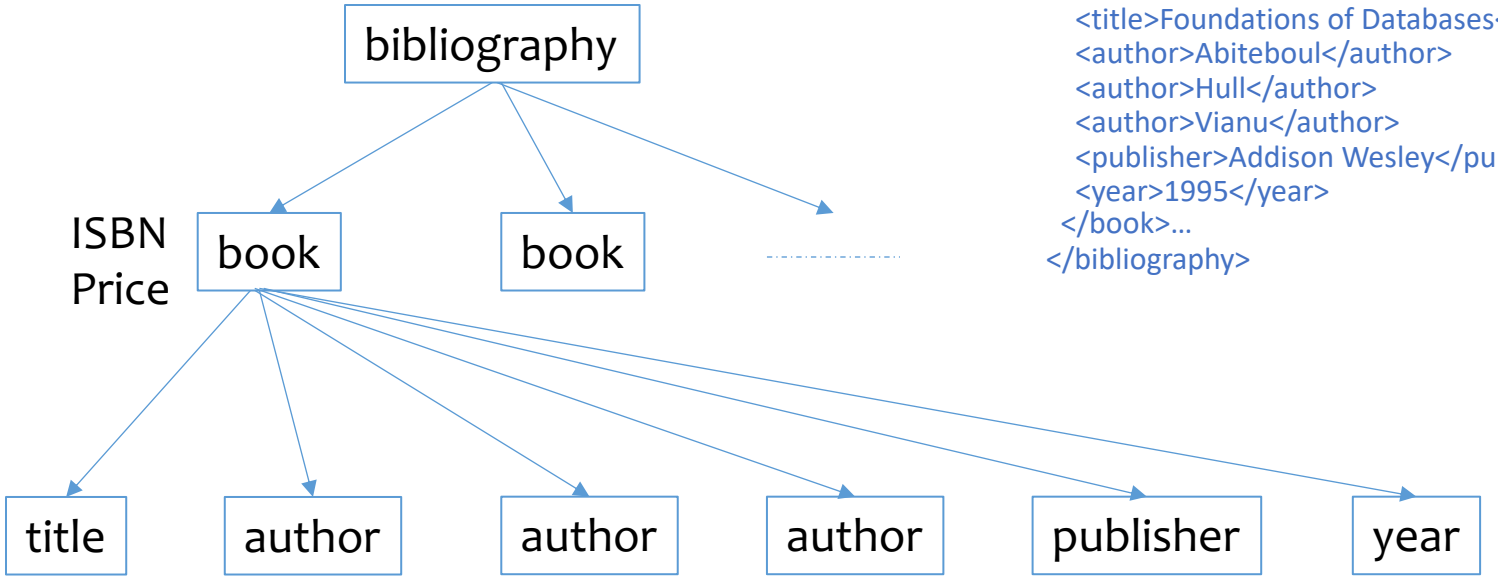
- XML to relational?
- Or
- Relational to XML?

Mapping XML to relational

- Store XML in a column
  - CLOB (Character Large OBject) type
  - Not much useful!
- Alternatives?
  - Schema-oblivious mapping:
    well-formed XML → generic relational schema
    - Node/edge-based mapping for graphs
    - Interval-based mapping for trees
    - Path-based mapping for trees (not covered)
  - Schema-aware mapping (not covered):
    valid XML → special relational schema based on DTD

Only this one in this class

Example – Node/Edge Based




```
<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>
```

- How would you translate it to a relational schema?
  - Element? Attribute? Parent-child relationship?
  - Keys? (Do not see the next slides yet!)

Node/edge-based: schema

- *Element*(<u>*eid*</u>, *tag*)
- *Attribute*(*eid*, *attrName*, *attrValue*) Key: (*eid*, *attrName*)
  - Attribute order does not matter
- *ElementChild*(*eid*, *pos*, *child*) Keys: (*eid*, *pos*), (*child*)
  - *pos* specifies the ordering of children
  - *child* references either *Element*(*eid*) or *Text*(*tid*)
- *Text*(<u>*tid*</u>, *value*)
  - *tid* cannot be the same as any *eid*

☞ Need to "invent" lots of *id*'s

☞ Need indexes for efficiency, e.g., *Element*(*tag*), *Text*(*value*)

Node/edge-based: example

```
<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>
```

Element

eid	tag
e0	bibliography
e1	book
e2	title
e3	author
e4	author
e5	author
e6	publisher
e7	year

ElementChild

eid	pos	child
e0	1	e1
e1	1	e2
e1	2	e3
e1	3	e4
e1	4	e5
e1	5	e6
e1	6	e7
e2	1	t0
e3	1	t1
e4	1	t2
e5	1	t3
e6	1	t4
e7	1	t5

Attribute

eid	attrName	attrValue
e1	ISBN	ISBN-10
e1	price	80

Text

tid	value
t0	Foundations of Databases
t1	Abiteboul
t2	Hull
t3	Vianu
t4	Addison Wesley
t5	1995

Node/edge-based: queries

eid	attrName	attrValue
e1	ISBN	ISBN-10
e1	price	80

Attribute

eid	pos	child
e0	1	e1
e1	1	e2
e1	2	e3
e1	3	e4
e1	4	e5
e1	5	e6
e1	6	e7
e2	1	t0
e3	1	t1
e4	1	t2
e5	1	t3
e6	1	t4
e7	1	t5

ElementChild

eid	tag
e0	bibliography
e1	book
e2	title
e3	author
e4	author
e5	author
e6	publisher
e7	year

Element

- //title
  - SELECT eid FROM Element WHERE tag = 'title';
- //section/title
  - SELECT e2.eid
    FROM Element e1, ElementChild c, Element e2
    WHERE e1.tag = 'section'
    AND e2.tag = 'title'
    AND e1.eid = c.eid
    AND c.child = e2.eid;

☞Path expression becomes joins!

- Number of joins is proportional to the length of the path expression

- //bibliography/book[author="Abiteboul"]/@price
  - More complex SQL queries with EXISTS needed
- //book//title
  - Needs recursion (not covered yet)

Text

tid	value
t0	Foundations of Databases
t1	Abiteboul
t2	Hull
t3	Vianu
t4	Addison Wesley
t5	1995