Big Data

Beyond Relational Data

- ✓ Introduction to XML
- ✓ XML basics
- ✓ DTD
- ✓ XML Schema
- ✓ XML Constraints

Semi-structured Data

- ✓ In many applications, data does not have a rigidly and predefined schema:
  - e.g., structured files, emails, scientific data, XML, JSON.
- ✓ Managing such data requires rethinking the design of components of a DBMS:
  - data model, query language, optimizer, storage system.
- ✓ The emergence of XML data underscores the importance of semi-structured data.

Main Characteristics

Schema is not what it used to be:

- ✓ not given in advance (often implicit in the data)
- ✓ descriptive, not prescriptive,
- ✓ partial,
- ✓ rapidly evolving,
- ✓ may be large (compared to the size of the data)

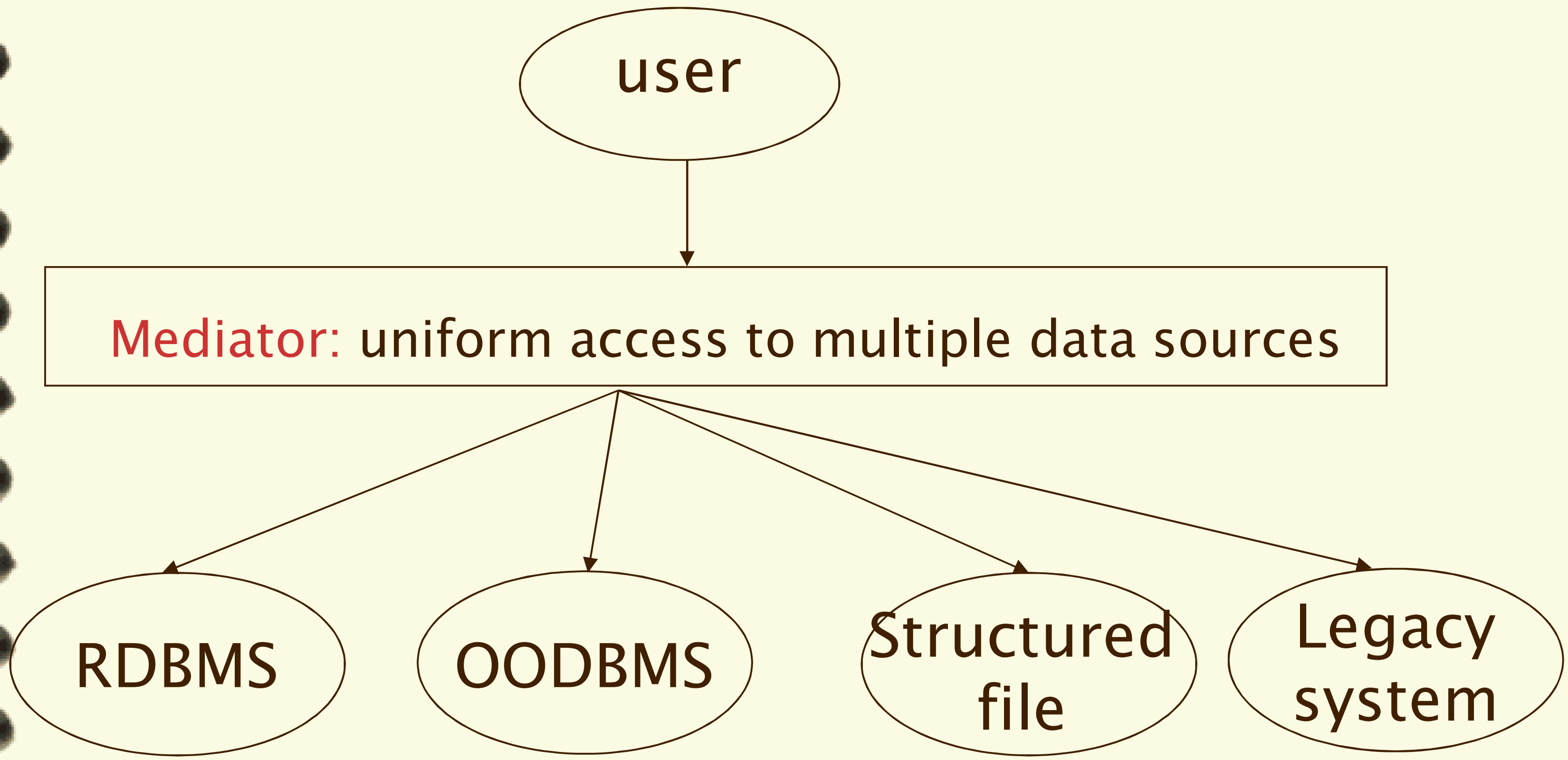
Types are not what they used to be:

- ✓ objects and attributes are not strongly typed
- ✓ objects in the same collection have different representations.

Example: XML

```
<bib>
  <book year="1995">
      <title>  Database Systems </title>
     <author> <lastname> Date </lastname> </author>
     <publisher> Addison-Wesley  </publisher>
  </book>
  <book year="1998">
     <title> Foundation for Object/Relational Databases
</title>
     <author> <lastname> Date </lastname> </author>
     <author> <lastname> Darwen </lastname> </author>
     <ISBN> <number> 01-23-456 </number >  </ISBN>
  </book>
 </bib>
```

Example: Data Integration



Each source represents data differently:
different data models, different schemas

Physical versus Logical Structure

- In some cases, data can be modeled in relational or object-oriented models, but extracting the tuples is hard
- Semi-structured data: when the data cannot be modeled naturally or usefully using a standard data model.

Managing Semi-structured Data

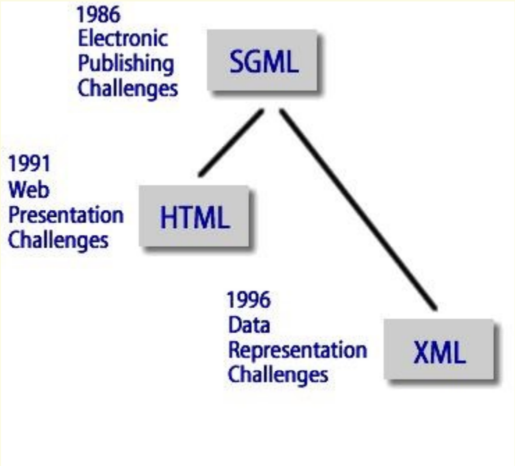
- How do we model it? (directed labeled graphs).
- How do we query it? (many proposals, all include regular path expressions).
- Optimize queries? (beginning to understand).
- Store the data? (looking for patterns)
- Integrity constraints, views, updates,…,

- We start with introduction of XML

History: SGML, HTML, XML

SGML: Standard Generalized Markup Language

-- Charles Goldfarb, ISO 8879, 1986



- ✓ DTD (Document Type Definition)
- ✓ powerful and flexible tool for structuring information, but
  - – complete, generic implementation of SGML is difficult
  - – tools for working with SGML documents are expensive
- ✓ two sub-languages that have outpaced SGML:
  - – HTML: HyperText Markup Language (Tim Berners-Lee, 1991). Describing presentation.
  - – XML: eXtensible Markup Language, W3C, 1998. Describing content.

From HTML to XML

HTML is good for presentation (human friendly), but does not help automatic data extraction by means of programs (not computer friendly).

Why? HTML tags:

- ✓ predefined and fixed
- ✓ describing display format, not the structure of the data.

<h3> Văn Giang Nguyễn </h3>

 Học 12375151

 GPA: 1.5

 Big Data

XML: a first glance

XML tags:

- ✓ user defined
- ✓ describing the structure of the data

```
<school>
    <student   id = “011”>
        <name>
            <firstName>Giang</firstName>  <lastName>Nguyễn</lastName>
        </name>
        <taking> 12375151</taking>
        <GPA>   1.5  </GPA>
    </student>
    <course   cno = “12375151”>
          <title> Big Data</title>
    </course>
</school>
```

XML vs. HTML

- ✓ user-defined new tags, describing structure instead of display
- ✓ structures can be arbitrarily nested (even recursively defined)
- ✓ optional description of its grammar (DTD) and thus validation is possible

What is XML for?

- ✓ The prime standard for data exchange on the Web
- ✓ A uniform data model for data integration

XML presentation:

- ✓ XML standard does not define how data should be displayed
- ✓ Style sheet: provide browsers with a set of formatting rules to be applied to particular elements
  - CSS (Cascading Style Sheets), originally for HTML
  - XSL (eXtensible Style Language), for XML

Tags and Text

- XML consists of tags and text

  <course cno = "Eng 055">

  <title> Spelling </title>

  </course>

- tags come in pairs: markups
  - start tag, e.g., <course>
  - end tag, e.g., </course>
- tags must be properly nested
  - <course> <title> … </title> </course> -- good
  - <course> <title> … </course> </title> -- bad
- XML has only a single "basic" type: text, called PCDATA (Parsed Character DATA)

XML Elements

- ✓ Element: the segment between an start and its corresponding end tag
- ✓ subelement: the relation between an element and its component elements.

```
<person>
  <name> Văn Giang </name>
  <tel> 069515333</tel>
  <email> giangnv@mta.edu.vn </email>
  <email> giangnv@lqdtu.edu.vn </email>
</person>
```

Nested Structure

- nested tags can be used to express various structures, e.g., “records”:

  <person>

  <name> Văn-Giang </name>

  <tel> 069515333</tel>

  <email> giangnv@mta.edu.vn </email>

  <email> giangnv@lqdtu.edu.vn </email>

  </person>

- a list: represented by using the same tags repeatedly:

  <person> … </person>

  <person> … </person>

  ...

Ordered Structure

XML elements are ordered!

- ✓ How to represent sets in XML?
- ✓ How to represent an unordered pair (a, b) in XML?
- ✓ Can one directly represent the following in a relational database?
  - <person> … </person>
    <person> … </person> …
  - <person>
    <name> Văn-Giang </name>
    <tel> 069515333 </tel>
    <email> giangnv@mta.edu.vn </email>
    <email> giangnv@lqdtu.edu.vn </email>
    </person>

XML attributes

An start tag may contain attributes describing certain “properties” of the element (e.g., dimension or type)

<picture>

<height dim=“cm”> 2400</height>

<width dim=“in”> 96 </width>

<data encoding=“gif”> M05-+C$ … </data>

</picture>

References (meaningful only when a DTD is present):

<person id = “011” pal=“012”>

<name> Barack Obama </name>

</person>

<person id = “012” pal=“011”>

<name> Hillary Clinton </name>

</person>

The “structure” of XML attributes

- XML attributes cannot be nested -- flat
- the names of XML attributes of an element must be unique.

  one can’t write <person pal=“Blair” pal=“Saddam”> ...
- XML attributes are not ordered

```
<person   id = “011”    pal=“012”>
  <name> Barack Obama </name>
</person>
```

is the same as

```
<person  pal=“012”    id = “011”>
  <name> Barack Obama </name>
</person>
```

- Attributes vs. subelements: unordered vs. ordered, and
  - attributes cannot be nested (flat structure)
  - subelements cannot represent references

Representing relational databases

A relational database for school:

student:

id	name	gpa
001	Joe	3.0
002	Mary	4.0
…	…	…

course:

cno	title	credit
331	DB	3.0
350	Web	3.0
…	…	…

enroll:

id	cno
001	331
001	350
002	331
…	…

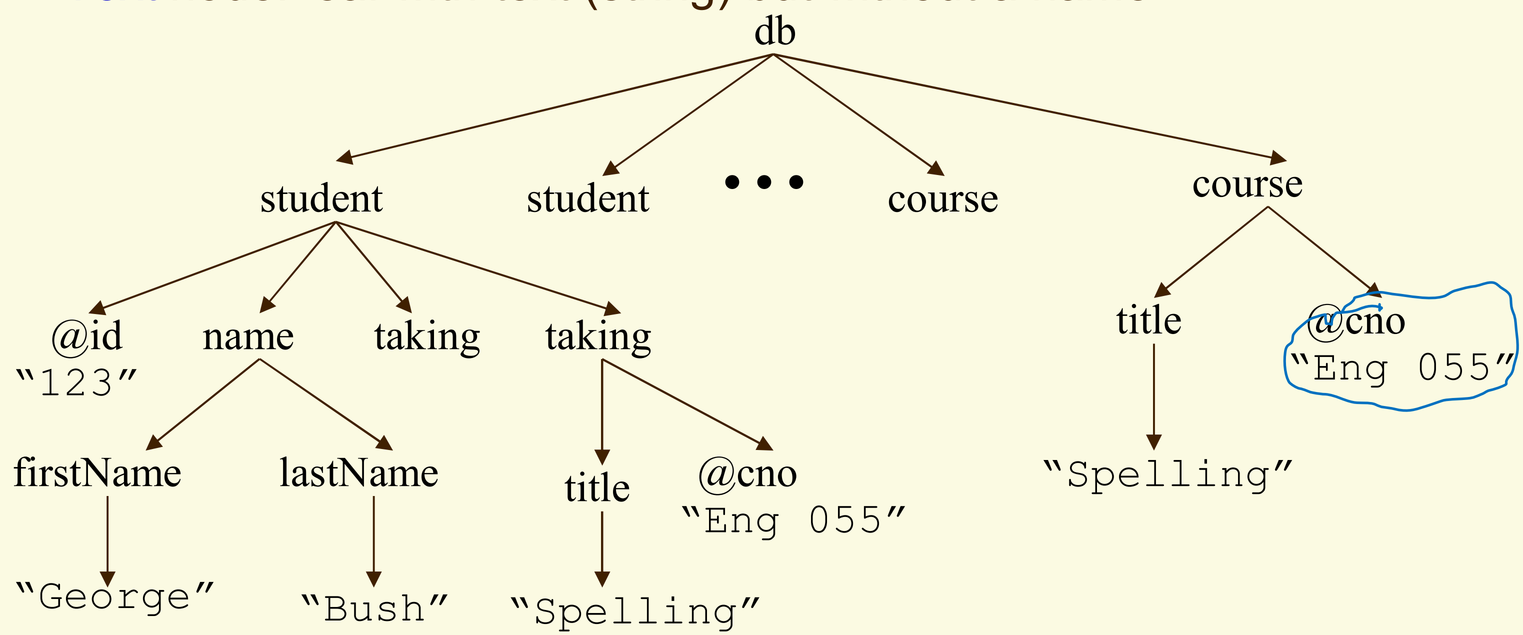
XML representation

```
<school>
    <student   id="001">
        <name>  Joe </name>            <gpa>    3.0  </gpa>
    </student>
    …
    <course   cno="331">
        <title>  DB </title>          <credit>    3.0  </credit>
    </course>
    …
    </course>
    <enroll>
        <id>  001 </id>               <cno>    331  </cno>
    </enroll>
    …
</school>
```

The XML tree model

An XML document is modeled as a node-labeled ordered tree.

- ✓ Element node: typically internal, with a name (tag) and children (subelements and attributes), e.g., student, name.
- ✓ Attribute node: leaf with a name (tag) and text, e.g., @id.
- ✓ Text node: leaf with text (string) but without a name.



Introduction to XML

- ✓ XML basics
- ✓ DTDs
- ✓ XML Schema
- ✓ XML Constraints

Document Type Definition (DTD)

An XML document may come with an optional DTD – “schema”

```
<!DOCTYPE  db [
    <!ELEMENT   db  (book*)>
    <!ELEMENT   book   (title,  authors*, section*, ref*)>
    <!ATTLIST    book  isbn   ID   #required>
    <!ELEMENT   section  (text | section)*>
    <!ELEMENT   ref  EMPTY>
    <!ATTLIST      ref  to    IDREFS   #implied>
    <!ELEMENT  title  #PCDATA>
    <!ELEMENT  author  #PCDATA>
    <!ELEMENT  text  #PCDATA>
]>
```

Element Type Definition (1)

for each element type E, a declaration of the form:

<!ELEMENT E P> $E \rightarrow P$

where P is a regular expression, i.e.,

P ::= EMPTY | ANY | #PCDATA | E' |

P1, P2 | P1 | P2 | P? | P+ | P*

- E': element type
- P1 , P2: concatenation
- P1 | P2: disjunction
- P?: optional
- P+: one or more occurrences
- P*: the Kleene closure

Element Type Definition (2)

- ✓ Extended context free grammar: <!ELEMENT E P>

  Why is it called extended?

  E.g., book → title, authors*, section*, ref*
- ✓ single root: <!DOCTYPE db […] >
- ✓ subelements are ordered.

  The following two definitions are different. Why?

  <!ELEMENT section (text | section)*>

  <!ELEMENT section (text* | section*)>

  How to declare E to be an unordered pair (a, b)?

  <!ELEMENT E ((a, b) | (b, a)) >
- ✓ recursive definition, e.g., section, binary tree:

  <!ELEMENT node (leaf | (node, node))

  <!ELEMENT leaf (#PCDATA)>

Element Type Definition (3)

- ✓ more on recursive DTDs

  <!ELEMENT person (name, father, mother)>

  <!ELEMENT father (person)>

  <!ELEMENT mother (person)>

  What is the problem with this? How to fix it?

  - Attributes
  - optional (e.g., father?, mother?)

<!ELEMENT person (name, father?, mother?)>

<!ELEMENT father (person) >

<!ELEMENT mother (person)>

Attribute declarations

General syntax:

<!ATTLIST element_name

attribute-name attribute-type default-declaration>

example: “keys” and “foreign keys”

<!ATTLIST book

isbn ID #required>

<!ATTLIST ref

to IDREFS #implied>

Note: it is OK for several element types to define an attribute of the same name, e.g.,

<!ATTLIST person name ID #required>

<!ATTLIST pet name ID #required>

XML reference mechanism

- ✓ ID attribute: unique within the entire document.
  - An element can have at most one ID attribute.
  - No default (fixed default) value is allowed.
    - #required: a value must be provided
    - #implied: a value is optional
- ✓ IDREF attribute: its value must be some other element's ID value in the document.
- ✓ IDREFS attribute: its value is a set, each element of the set is the ID value of some other element in the document.

  <person id="898" father="332" mother="336"
  children="982 984 986">

Specifying ID and IDREF attributes

```
<!ATTLIST     person
              id        ID       #required
              father    IDREF    #implied
              mother    IDREF    #implied
              children  IDREFS   #implied>
```

e.g.,

```
<person  id="898"  father="332"  mother="336"
         children="982  984  986">
  ….
</person>
```

Valid XML documents

A **valid** XML document must have a DTD.

- ✓ It conforms to the DTD:
  - elements conform to the grammars of their type definitions (nested only in the way described by the DTD)
  - elements have all and only the attributes specified by the DTD
  - ID/IDREF attributes satisfy their constraints:
    - ID must be distinct
    - IDREF/IDREFS values must be existing ID values

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DTDs vs. schemas (types)

- ✓ By the database (or programming language) standard, XML DTDs are rather weak specifications.
  - – Only one base type -- PCDATA.
  - – No useful “abstractions”, e.g., unordered records.
  - – No sub-typing or inheritance.
  - – IDREFs are not typed or scoped -- you point to something, but you don’t know what!
- ✓ XML extensions to overcome the limitations.
  - – Type systems: XML-Data, XML-Schema, SOX, DCD
  - – Integrity Constraints

XML Schema

Official W3C Recommendation

A rich type system:

- ✓ Simple (atomic, basic) types for both element and attributes
- ✓ Complex types for elements
- ✓ Inheritance
- ✓ Constraints
  - key
  - keyref (foreign keys)
  - uniqueness: “more general” keys
- ✓ . . .

See www.w3.org/XML/Schema for the standard and much more

Atomic types

- ✓ string, integer, boolean, date, …,
- ✓ enumeration types
- ✓ restriction and range [a-z]
- ✓ list: list of values of an atomic type, …

Example: define an element or an attribute

```
<xs:element   name="car"   type="carType">
<xs:attribute   name="car"   type ="carType">
```

Define the type:

```
<xs:simpleType   name="carType">
    <xs:restriction   base="xs:string">
        <xs:enumeration  value="Audi">
        <xs:enumeration  value="BMW">
    </xs:restriction>
</xs:simpleType>
```

Complex types

- Sequence: “record type” – ordered
- All: record type – unordered
- Choice: variant type

- Occurrence constraint: maxOccurs, minOccurs

- Group: mimicking parameter type to facilitate complex type definition
- Any: “open” type – unrestricted
- …

Example

A complex type for publications:

```
<xs:complexType  name="publicationType">
   <xs:sequence>
      <xs:choice>
         <xs:group  ref="journalType">
         <xs:element  name="conference" type="xs:string"/>
      </xs:choice>
      <xs:element  name="title"  type="xs:string"/>
      <xs:element  name="author"  type="xs:string"
                minOccur="0"   maxOccur="unbounded"/>
   </xs:sequence>
</xs:complexType>
```

Example (cont'd)

```
<xs:group    name="journalType">
   <xs:sequence>
        <xs:element   name="name"    type="xs:string"/>
        <xs:element   name="volume"    type="xs:integer"/>
         <xs:element   name="number"    type="xs:integer"/>
   </xs:sequence>
</xs:group>
```

Inheritance -- Extension

Subtype: extending an existing type by including additional fields

```
<xs:complexType    name="datedPublicationType">
    <xs:complexContent>
        <xs:extension   base="publicationType">
                <xs:sequence>
                    <xs:element  name="isbn" type="xs:string"/>
                </xs:sequence>
            <xs:attribute   name="publicationDate"   type="xs:date"/>
        </xs:extension>
    </xs:complexContent>
</xs:complexType>
```

Inheritance -- Restriction

Supertype: restricting/removing certain fields of an existing type

```
<xs:complexType   name="anotherPublicationType">
    <xs:complexContent>
        <xs:restriction   base="publicationType">
            <xs:sequence>
                <xs:choice>
                    <xs:group   ref="journalType">
                    <xs:element  name="conference"   type="xs:string"/>
                </xs:choice>
                <xs:element   name="author"   type="xs:string"
                        minOccur="0"     maxOccur="unbounded"/>
            </xs:sequence>
        </xs:restriction>
    </xs:complexContent>
</xs:complexType>
```

Removed title

Introduction to XML

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Keys and Foreign Keys

Example: school document

<!ELEMENT db (student+, course+) >
<!ELEMENT student (id, name, gpa, taking*)>
<!ELEMENT course (cno, title, credit, taken_by*)>
<!ELEMENT taking (cno)>
<!ELEMENT taken_by (id)>

- ✓ keys: locating a specific object, an invariant connection from an object in the real world to its representation

  student.@id $\rightarrow$ student, course.@cno $\rightarrow$ course

- ✓ foreign keys: referencing an object from another object

  taking.@cno $\subseteq$ course.@cno, course.@cno $\rightarrow$ course
  taken_by.@id $\subseteq$ student.@id, student.@id $\rightarrow$ student

Constraints are important for XML

- ✓ Constraints are a fundamental part of the semantics of the data; XML may not come with a DTD/type – thus constraints are often the only means to specify the semantics of the data
- ✓ Constraints have proved useful in
  - semantic specifications: obvious
  - query optimization: effective
  - database conversion to an XML encoding: a must
  - data integration: information preservation
  - update anomaly prevention: classical
  - normal forms for XML specifications: “BCNF”, “3NF”
  - efficient storage/access: indexing,
  - …

The limitations of the XML standard (DTD)

ID and IDREF attributes in DTD vs. keys and foreign keys in RDBs

- ✓ Scoping:
  - ID unique within the entire document while a key needs only to uniquely identify a tuple within a relation
  - IDREF untyped: one has no control over what it points to -- you point to something, but you don't know what it is!

<student id="01" name="Hillary" taking="CPTS580"/>

<student id="02" name="Bush" taking="CPTS580 05"/>

<course id="CPTS580"/>

The limitations of the XML standard (DTD)

- ✓ keys can be multi-valued, while IDs must be single-valued (unary)

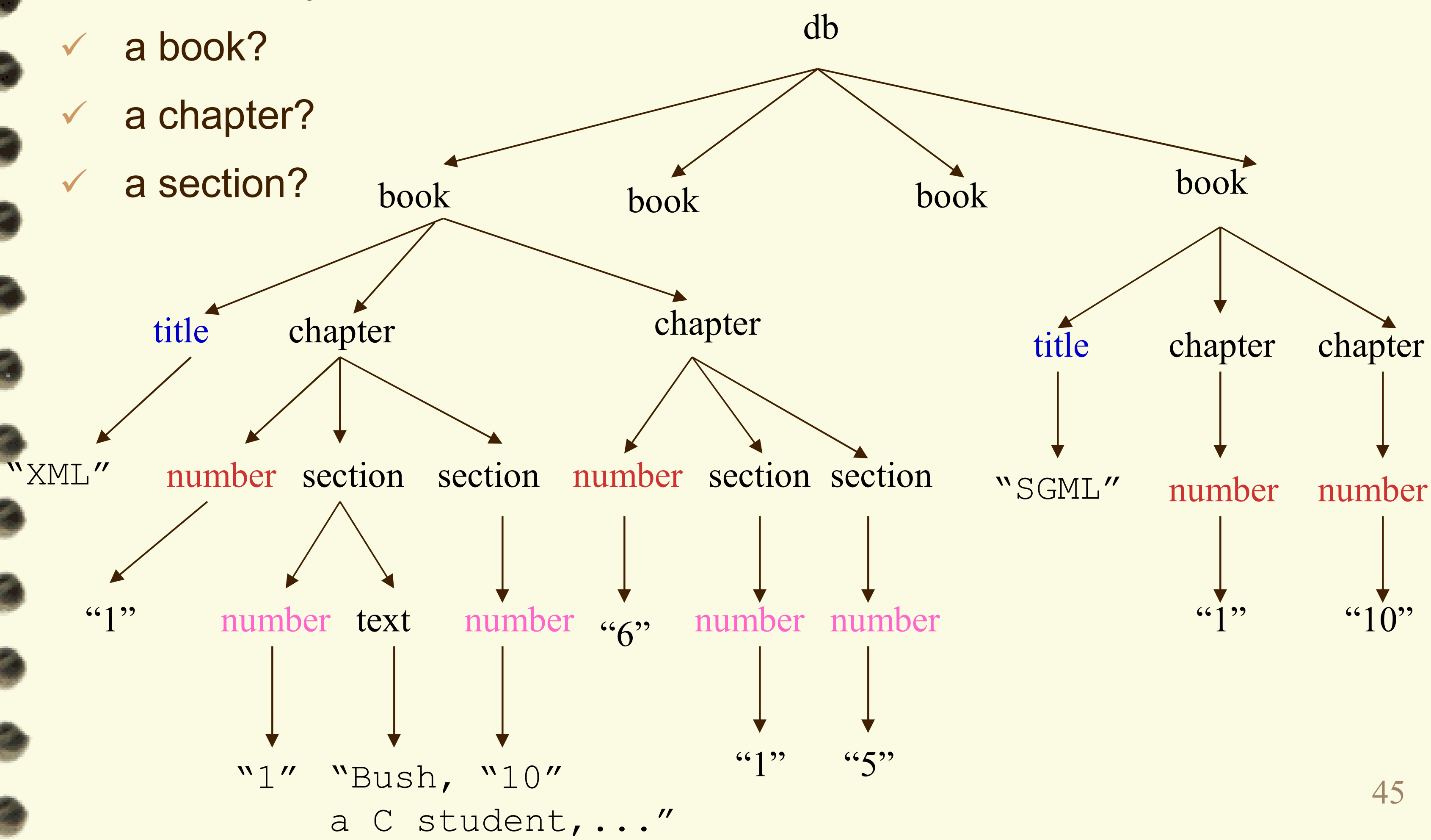
  enroll (<u>sid: string, cid: string</u>, grade:string)

- ✓ a relation may have multiple keys, while an element can have at most one ID (primary)
- ✓ ID/IDREF can only be defined in a DTD, while XML data may not come with a DTD/schema
- ✓ ID/IDREF, even relational keys/foreign keys, fail to capture the semantics of hierarchical data – will be seen shortly

New challenges of hierarchical XML data

How to identify in a document

- ✓ a book?
- ✓ a chapter?
- ✓ a section?



Path expressions

Path expression: navigating XML trees

A simple path language:

$$q \quad ::= \quad \varepsilon \quad | \quad l \quad | \quad q/q \quad | \quad //$$

- ✓ ε: empty path
- ✓ l: tag
- ✓ q/q: concatenation
- ✓ //: descendants and self – recursively descending downward

To overcome the limitations

Absolute key: (Q, $\{P_1, \ldots, P_k\}$)

- ✓ target path Q: to identify a target set [[Q]] of nodes on which the key is defined (vs. relation)
- ✓ a set of key paths $\{P_1, \ldots, P_k\}$: to provide an identification for nodes in [[Q]] (vs. key attributes)
- ✓ semantics: for any two nodes in [[Q]], if they *have all the key paths* and agree on them up to value equality, then they must be the same node (value equality and node identity)

(//student, {@id})

(//student, {//name})

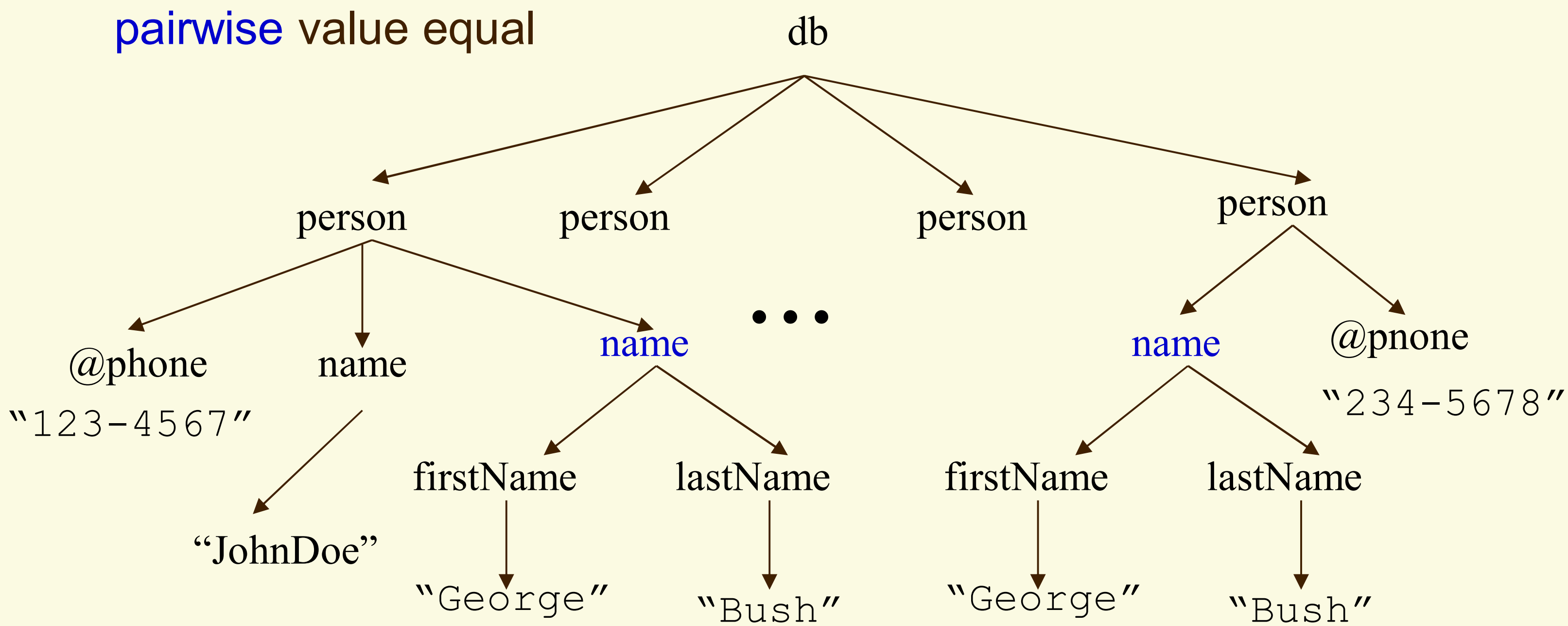
(//enroll, {@id, @cno})

(//, {@id})

Value equality on trees

Two nodes are value equal iff

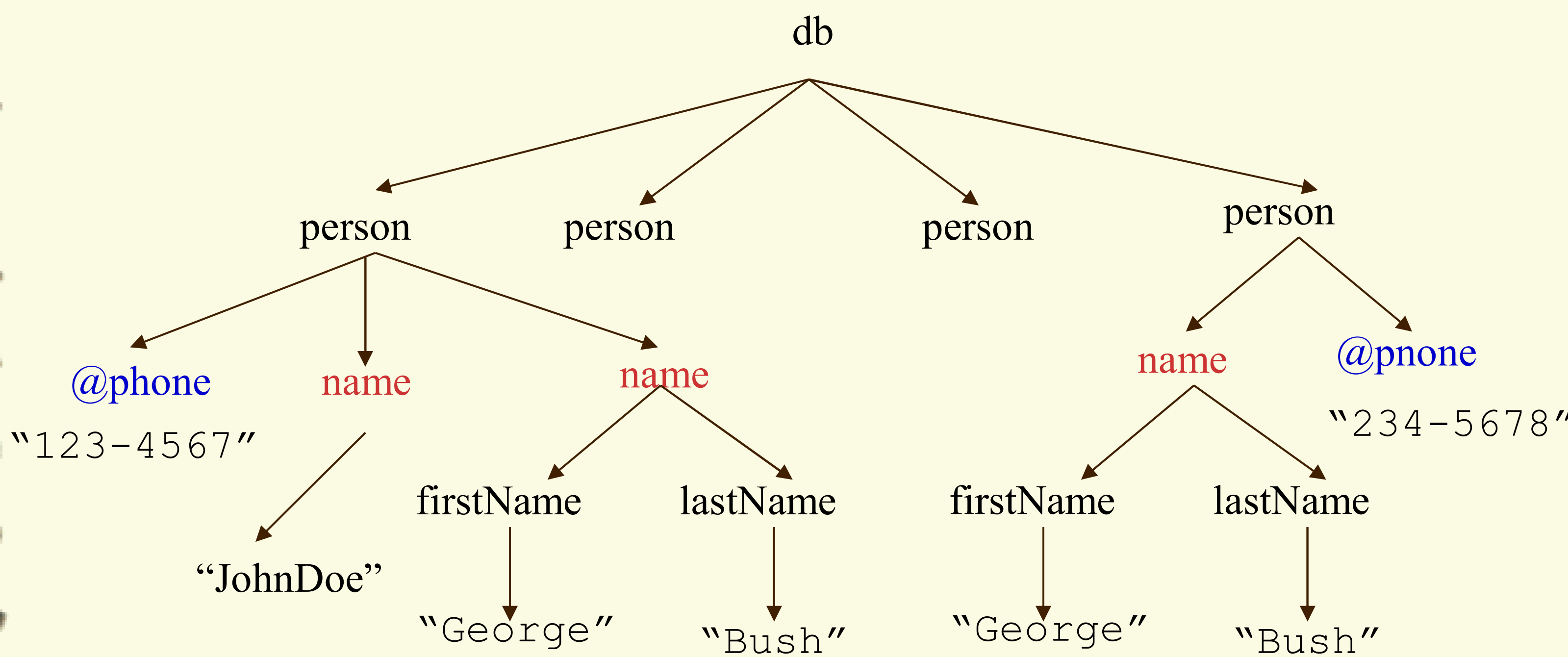
- ✓ either they are text nodes (PCDATA) with the same value;
- ✓ or they are attributes with the same tag and the same value;
- ✓ or they are elements having the same tag and their children are pairwise value equal



Capturing the semistructured nature of XML data

- ✓ independent of types – no need for a DTD or schema
- ✓ no structural requirement: tolerating missing/multiple paths

(//person, {name}) (//person, {name, @phone})



Relative constraints

Relative key: (Q, K)

- ✓ path Q identifies a set [[Q]] of nodes, called the context;
- ✓ k = (Q', {P_1, . . ., P_k}) is a key on sub-documents rooted at nodes in [[Q]] (relative to Q).

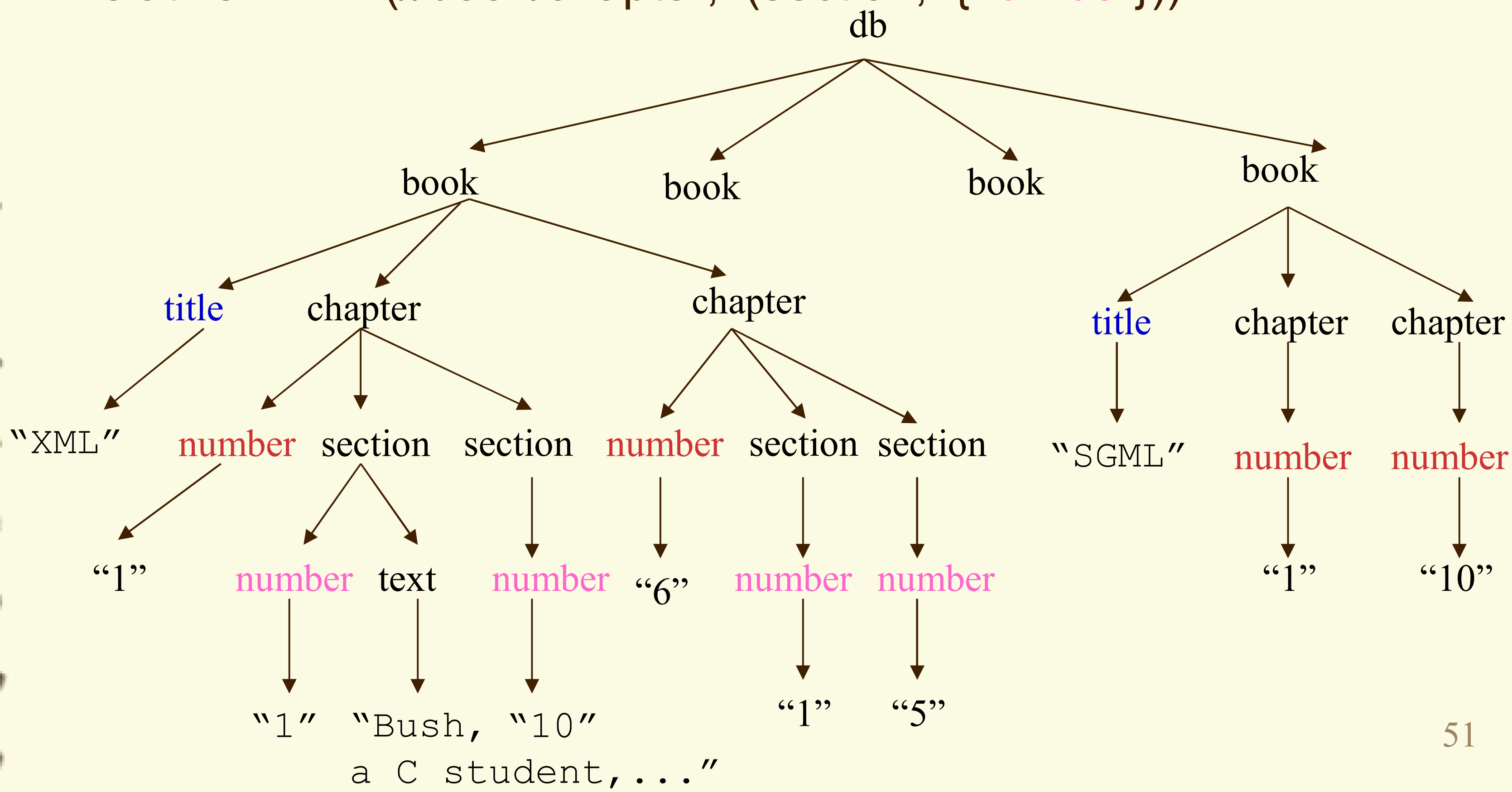
Example. (//book, (chapter, {number}))

(//book/chapter, (section, {number}))

(//book, {title}) -- absolute key

Examples of XML constraints

absolute	(//book, {title})
relative	(//book, (chapter, {number}))
relative	(//book/chapter, (section, {number}))



Absolute vs. relative keys

- ✓ Absolute keys are a special case of relative keys:

  (Q, K) when Q is the empty path
- ✓ Absolute keys are defined on the entire document, while relative keys are scoped within the context of a sub-document
- ✓ Important for hierarchically structured data: XML, scientific databases, …

absolute	(//book, {title})
relative	(//book, (chapter, {number}))
relative	(//book/chapter, (section, {number}))

XML keys are more complex than relational keys!

Summary and Review

- ✓ XML is a prime data exchange format.
- ✓ DTD provides useful syntactic constraints on documents.
- ✓ XML Schema extends DTD by supporting a rich type system
- ✓ Integrity constraints are important for XML, yet are nontrivial

Exercise:

- ✓ Design a DTD and an XML Schema to represent student, enroll and course relations. Give necessary XML constraints
- ✓ Convert student and course relations to an XML document based on your DTD/Schema
- ✓ Is XML capable of modeling an arbitrary relational/object-oriented database?
- ✓ Take a look at XML interface: DOM (Document-Object Model), SAX (Simple API for XML). What are the main differences?
- ✓ Study tutorials for XPath, XSLT and XQuery