The Semi-Structured Data Model

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Recap: Data models

- A data model is a notation for describing data, including:
  - structure
  - operations
  - constraints

The relational data model

- Structure: tables
- Operations:
  - choose rows, choose columns, cross-product
  - plus add-ons
- Constraints:
  - keys, foreign keys, and more general constraints
- We learned to express all of this in RA and SQL.

Strengths and weaknesses

- Very rigid structure:
  - Everything must be a table.
  - The schema must be defined in advance.
  - Everything must conform to the schema.
- Small set of operations.
- DBMSs exploit this to give us data we can count on and efficient queries.
- But some data doesn't fit the model well. For example, we may have
  - missing information, and
  - indeterminate quantities.

The semi-structured data model

- Structure: trees (hierachical), or perhaps graphs
- Operations: involve paths through trees
- Constraints: specific to the language

Some data viewed relationally

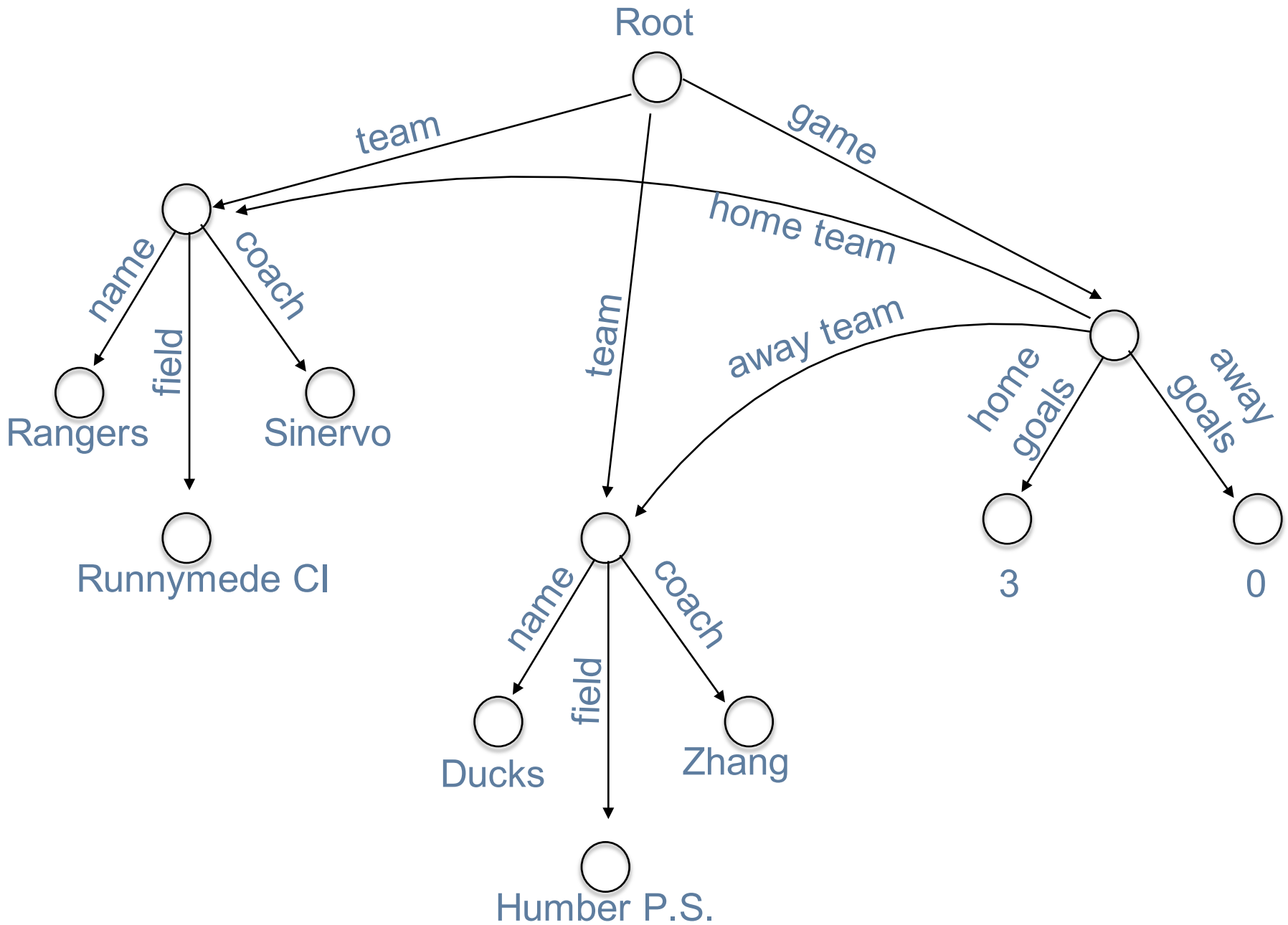
Teams

Name	Home Field	Coach
Rangers	Runnymede CI	Tarvo Sinervo
Ducks	Humber Public	Tracy Zheng
Choppers	High Park	Ammar Jalali

Games

Home team	Away team	Home goals	Away goals
Rangers	Ducks	3	0
Ducks	Choppers	1	1
Rangers	Choppers	4	2
Choppers	Ducks	0	5

Viewed as semi-structured data



Strengths and weaknesses

- More flexible:
  - Optionality is normal; just leave things out.
  - Don't need to have a schema.
- We lose some things:
  - Less support to ensure data is sound.
  - Queries aren't as efficient.
  - There may not even be a (well-established) query language.

XML

Example: party.xml

- “self-describing”
- we choose the tags and attributes to use
- we did not define a schema; fine!
- when data doesn’t exists, just omit it; fine!
    - e.g., Chloe has no nickname or middle name

HTML to XML

- XML grew out of HTML, and is intentionally similar:
  - Tags and attributes
  - Tree-structured format
- But there are important differences:
  - XML data must be well-formed.
  - We define our own tags and attributes.
  - These describe the *meaning* of the data, and imply nothing about its presentation.

What's XML for?

- XML is great for
  - Recording data that software needs.
  - Exchange of information between pieces of software.
- XML is said to be "self-describing".
  - Example:

```
<student stnum="1234" name="Cindylou Who">
  <address>
    <street>99 Alfalfa Way</street>
    <city>Whoville</city>
  </address>
</student>
```

Well-formed vs valid XML

- Well-formed XML
  - Just need a single root element and proper nesting.
  - Any tag or attribute can go anywhere.
- Valid XML
  - A "DTD" (document type definition) specifies what tags and attributes are permitted, where they can go, and how many there must be.
  - A valid XML file is one that has a DTD and follows the rules specified in its DTD.

Well-formed XML

- Begin the document with a declaration, surrounded by `<?xml … ?>`
- Declaration for a document that is merely well-formed (i.e., it has no DTD):
  `<?xml version="1.0" standalone="yes" ?>`
- The rest of the document is a single root tag with tags nested inside it.

Tags

- Tags can be matched pairs, leaving room for text or nested tags in between. Example:

```
<tf-question qid="Q637" solution="False">
   <question>
      The Prime Minister, Justin Trudeau,
      is Canada's Head of State.
   </question>
</tf-question>
```

- Or they may not be matched. Example:

```
<response qid="Q637" answer="False" />
```

  Note the placement of the slash.

- Tag names are case-sensitive.

Example: quiz.xml

Attributes

- As we saw, an opening tag can have attribute name-value pairs within it. Example:

```
<tf-question qid="Q637" solution="False">
   <question>
      The Prime Minister, Stephen Harper,
      is Canada's Head of State.
   </question>
</tf-question>
```

- The pairs are separated by blanks.
- If all the information is in the attributes, the tag becomes empty.

One extreme: all data via attributes

```
<tf-question qid="Q637" solution="False">
   <question>
      The Prime Minister ...
   </question>
</tf-question>
```

could become:

```
<tf-question qid="Q637" solution="False"
   question="The Prime Minister ..."/>
```

Other extreme: no attributes at all

```
<tf-question qid="Q637" solution="False">
   <question>
      The Prime Minister...
   </question>
</tf-question>
```

could become:

```
<tf-question>
   <qid>Q637</qid>
   <solution>False</solution>
   <question>
      The Prime Minister...
   </question>
</tf-question>
```

It's a design decision

- In most cases, something in between makes more sense.
- Matched tags make sense when you need structure within.
- Attributes make sense when you want something like keys and foreign keys. (More on that later.)

Checking for well-formedness

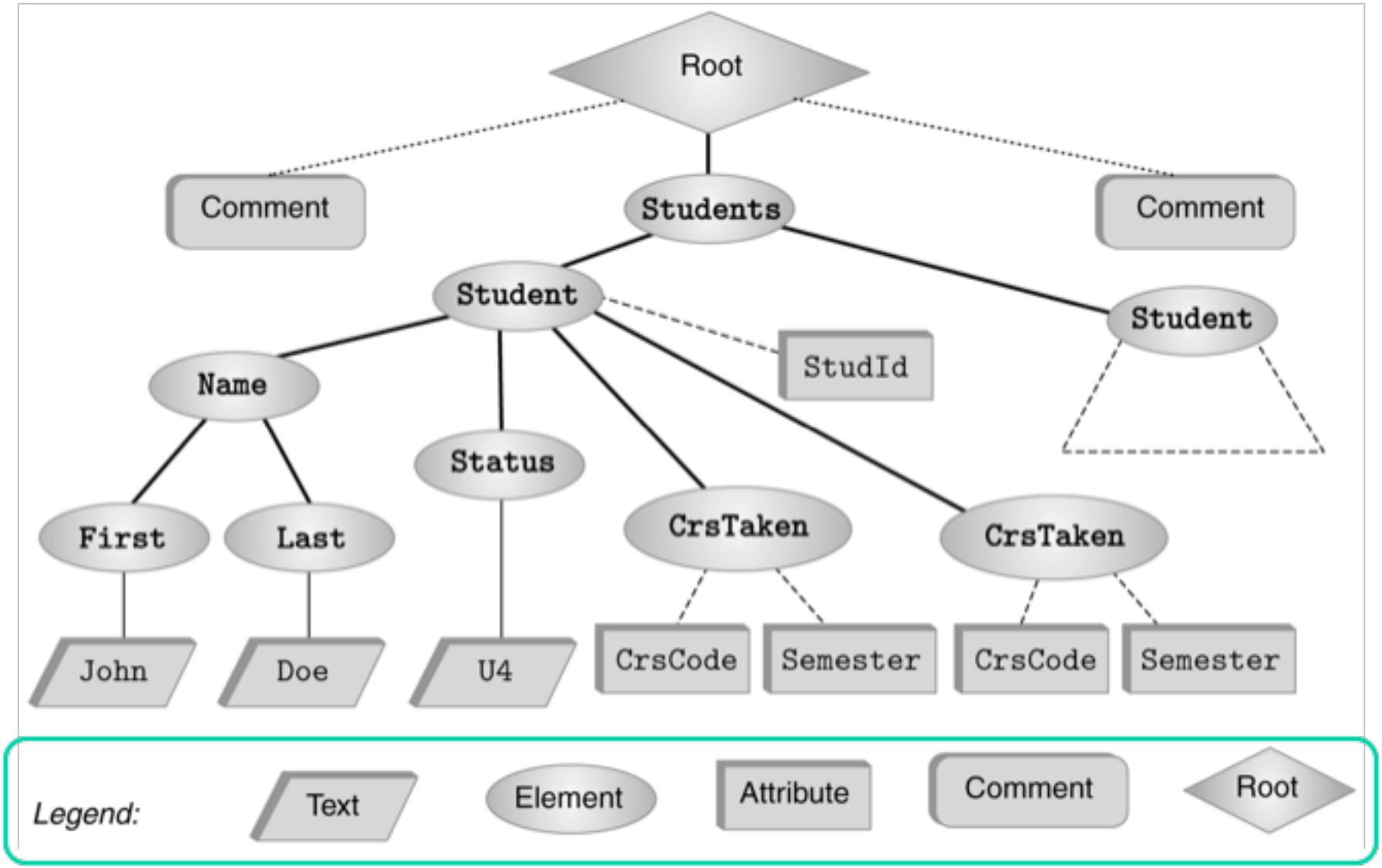
- `http://validator.w3.org`
- `xmllint` command on cdf.
  Default is to check merely for well-formedness.
- `xmllint --debug`
  Outputs an annotated tree of the parsed document.
  Useful for diagnosis of problems.

Recall: XML documents have a tree structure

```
<?xml  version="1.0" ?>
<!-- Some  comment -->
<Students>
  <Student StudId="111111111" >
     <Name><First>John</First><Last>Doe</Last></Name>
     <Status>U2</Status>
     <CrsTaken CrsCode="CS308" Semester="F1997" />
     <CrsTaken CrsCode="MAT123" Semester="F1997" />
  </Student>
  <Student StudId="987654321" >

  <Name><First>Bart</First><Last>Simpson</Last></Name
  >
     <Status>U4</Status>
     <CrsTaken CrsCode="CS308" Semester="F1994" />
  </Student>
</Students>
<!-- Some other comment -->
```

The document tree



Problems with merely well-formed XML

- There are no restrictions on
  - what tags are allowed
  - what order, nesting
  - what attributes each tag can have
  - what is mandatory and what is optional
- If a program is to process our XML, this would be very useful to know.

Valid XML with DTDs

Content of a DTD

- A series of rules.
- An `ELEMENT` rule defines an element that may occur, and what can be within its opening and closing tags.
- An `ATTLIST` rule defines an attribute of an element.
- Order of the rules doesn't matter.

ELEMENT rules

- Form: `<!ELEMENT` *«name»* `(` *«subcomponents»* `)>`
- *name*: the element's tag.
- *subcomponents*: can be
  - A comma-separated list of elements.
    Meaning: the subcomponents must occur inside the element, and in the order given.
  - `#PCDATA`
    Meaning: The element contains simply text (no subelements).
  - `EMPTY`
    Meaning: This is an "empty" element. It may have attributes, but not matching opening & closing tags.

Examples

```
<!ELEMENT INGREDIENT (NAME, QUANTITY)>
<!ELEMENT NAME (#PCDATA)>
<!ELEMENT QUANTITY EMPTY>
```

More expressiveness for subcomponents

- We can us the pipe symbol | to indicate alternatives.
- We specify multiplicity as follows:
  - * means zero or more
  - + means one or more
  - ? means zero or one
    (i.e., the subcomponent is optional)
- We can use brackets for grouping.

ATTLIST rules

- Form:
  `<!ATTLIST` *«elName» «attName» «type» «optionality»* `>`
- *elname*: the element whose attribute this is.
- *attName*: the name of this attribute.
- *type*: either `CDATA` or a list of possible values, e.g., `True|False`.
- *optionality*: Either `#REQUIRED` or `#IMPLIED` (which means optional).
- You can define multiple attributes at once.

```
<!ATTLIST person SIN CDATA #REQUIRED
                 age CDATA #IMPLIED >
```

Example

```
<!ELEMENT RECIPES (RECIPE)+>
<!ELEMENT RECIPE (INGREDIENTS, STEPS)>
<!ATTLIST RECIPE name CDATA #REQUIRED>
<!ATTLIST RECIPE type CDATA #IMPLIED>
<!ATTLIST RECIPE keywords CDATA #IMPLIED>
<!ELEMENT INGREDIENTS (INGREDIENT)+>
<!ELEMENT INGREDIENT (NAME, QUANTITY)>
<!ELEMENT NAME (#PCDATA)>
<!ELEMENT QUANTITY EMPTY>
<!ATTLIST QUANTITY amount CDATA #REQUIRED>
<!ATTLIST QUANTITY units CDATA #IMPLIED>
<!ELEMENT STEPS (STEP+)>
<!ELEMENT STEP (#PCDATA)>
```

Using a DTD

- The declaration must say that the document is not standalone:

```
<?xml version="1.0" standalone="no" ?>
```

- Three possible places for the DTD:
  - In the same file, between the declaration and the XML content.
  - In a separate file on the same computer. Specify the filename, or give the full or relative path.
  - At a URL.
- In all cases, you must specify what the root element will be.

DTD in the same file

```
<?xml version="1.0" standalone="no" ?>
<!DOCTYPE People [
    <!ELEMENT People (Person*)>
    <!ELEMENT Person (#PCDATA)>
]>
<People>
    <Person>Tommy Douglas</Person>
    <Person>Terry Fox</Person>
    <Person>Louise Arbour</Person>
    <Person>Chris Hadfield</Person>
</People>
```

DTD in another file

```
<?xml version="1.0" standalone="no" ?>
<!DOCTYPE People SYSTEM "people.dtd">
<People>
    <Person>Tommy Douglas</Person>
    <Person>Terry Fox</Person>
    <Person>Louise Arbour</Person>
    <Person>Chris Hadfield</Person>
</People>
```

DTD at a URL

```
<?xml version="1.0" standalone="no" ?>
<!DOCTYPE People SYSTEM
"http://www.cs.utoronto.ca/~dianeh/xyyz/people.dtd">
<People>
   <Person>Tommy Douglas</Person>
   <Person>Terry Fox</Person>
   <Person>Louise Arbour</Person>
   <Person>Chris Hadfield</Person>
</People>
```

“Keys” and “foreign keys”

Motivation

- Just as in the relational model, we sometimes want
  - unique identifiers.
  - the ability to refer in one place to some data in another place.
- Example: quiz.xml
- We would like the DTD to express these rules and our tools to enforce them.
- DTDs don't have this full capability, but they do have some modest features in this direction.

Using ID to enforce uniqueness

- To specify that values must be unique:
  - Make an attribute of type `ID` rather than `CDATA`.
  - Example:
    ```
    <!ATTLIST mc-question qid ID #REQUIRED>
    ```
- Values of `ID` attributes are restricted.
  - Must not begin with a digit.
  - Must not have blanks.
- Uniqueness is enforced across *all* IDs in the file

Limitations of ID

- Example: In class.xml,
  - questions have an `ID` attribute called `qid` and
  - students have an `ID` attribute called `sid`.
- Since uniqueness is across *all* IDs in the file:
  - If two questions have the same `qid`, or if two students have the same `sid`, is considered an error. ✓
  - If a question's `qid` is the same as a student's `sid`, this is considered an error. ✗

Using IDREF to enforce referential integrity

- To specify that a value must refer to some ID:
  - Make an attribute of type `IDREF`.
  - Example:
    ```
    <!ATTLIST response qid IDREF #REQUIRED>
    ```
  - We can allow an attribute to have a *list* of values, each of which references some ID:
    ```
    <!ATTLIST response qid IDREFS #REQUIRED>
    ```
- An IDREF attribute needs only to refer to any ID in the file, not specifically to one of a particular type.

Limitations of IDREF

- Example: In class.xml,
  - a response has a `qid` that is an `IDREF`.
- Since an IDREF refers to *any* ID:
  - If a response's `qid` refers to nothing, this is considered an error. ✓
  - If a response's `qid` refers to a student's `sid`, this is considered fine. ✗

Checking for validity

- `xmllint --valid` command on cdf.

Limitations of DTDs

- ID and IDREF are a pale imitation of keys and foreign keys.
  - All ID values are treated as a single set.
- ID and IDREF only work within a single file.
  - References to an ID in another file are flagged as errors.
  - Duplicate ID values across files cannot be detected.
- There are no other types of constraints.
- The only data type is string.
- It is very inconvenient to specify contents but allow them in any order.

XML Schema

- XML Schema has greater expressive power.
  - Rich set of built-in types, plus user-defined types
  - Finer control over sequences of sub-elements.
  - More effective keys and foreign keys
- It is also much more complex.
- Note: XML Schema Definitions (XSDs) are themselves XML documents.
  - They describe “elements” and
  - the things doing the describing are themselves “elements”.