

Chapter 7 – XML Data Modeling



Recent Developments for Data Models

Outline

Overview

I. Object-Relational Database Concepts

1. User-defined Data Types and Typed Tables
2. Object-relational Views and Collection Types
3. User-defined Routines and Object Behavior
4. Application Programs and Object-relational Capabilities

II. Online Analytic Processing

5. Data Analysis in SQL
6. Windowed Tables and Window Functions in SQL

III. XML

7. **XML Data Modeling**
8. XQuery
9. SQL/XML

IV. More Developments (if there is time left)

temporal data models, data streams, databases and uncertainty, ...



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XML Origin and Usages

- Defined by the WWW Consortium (W3C)
- Originally intended as a document markup language, not a database language
 - Documents have tags giving extra information about sections of the document
 - For example:
 - `<title> XML </title>`
 - `<slide> XML Origin and Usages </slide>`
- Derived from SGML (Standard Generalized Markup Language)
 - standard for document description
 - enables document interchange in publishing, office, engineering, ...
 - main idea: separate form from structure
 - XML is simpler to use than SGML
 - roughly 20% complexity achieves 80% functionality
- XML (like SGML) is a meta-language
 - a language for the definition of languages (vocabularies)
 - examples
 - SGML -> HTML
 - XML -> XHTML



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XML – Data and Metadata

- XML documents are to some extent self-describing
 - **Tags** (markup) represent **metadata** about specific parts/data items of a document
 - metadata provided at the 'instance'-level
 - Example

```
<bank>
  <account>
    <account-number> A-101 </account-number>
    <branch-name> Downtown </branch-name>
    <balance> 500 </balance>
  </account>
  <depositor>
    <account-number> A-101 </account-number>
    <customer-name> Johnson </customer-name>
  </depositor>
</bank>
```
- Schema provides 'global' metadata (optional!)
 - defines the vocabulary, rules for document structure, permitted or default content
 - associated with/referenced by the document



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Forces Driving XML

- Document Processing
 - Goal: use document in various, evolving systems
 - structure – content – layout
 - grammar: markup vocabulary for mixed content
- Data Bases and Data Exchange
 - Goal: data independence
 - structured, typed data – schema-driven – integrity constraints
- Semi-structured Data and Information Integration
 - Goal: integrate autonomous data sources
 - data source schema not known in detail – schemata are dynamic
 - schema might be revealed through analysis only after data processing



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XML Documents

- XML documents are text (unicode)
 - markup (always starts with '<' or '&')
 - start/end tags
 - references (e.g., < & ...)
 - declarations, comments, processing instructions, ...
 - data (character data)
 - characters '<' and '&' need to be indicated using references (e.g., <) or using the character code
 - alternative syntax: `<![CDATA[(a<b)&(c<d)]]>`
- XML documents are **well-formed**
 - logical structure:
 - [`<declaration>`] [`<.dtd>`] [`<comment-or-PI>`] `<element>` [`<comment-or-PI>`]
 - (optional) XML declaration (XML version, encoding, ...)
 - (optional) schema (DTD)
 - single root element (possibly nested)
 - comments
 - processing instructions
 - example: reference to a stylesheet, used by a browser
 - additional requirements on the structure and content of `<element>`



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XML Documents: Elements

- **Tag:** label for a section of data
- **Element:**
 - start tag `<tagname>`
 - content: text and/or nested element(s)
 - may be empty, alternative syntax: `<tagname/>`
 - end tag `</tagname>`
- Elements must be properly **nested** for the document to be **well-formed**
 - Formally: every start tag must have a unique matching end tag, that is in the context of the same parent element.
- Mixture of text with sub-elements (mixed content) is legal in XML
 - Example:

```
<account>
  This account is seldom used any more.
  <account-number> A-102</account-number>
  <branch-name> Perryridge</branch-name>
  <balance>400 </balance>
</account>
```
 - Useful for document markup, but discouraged for data representation
- Element content (i.e., text and nested elements) is ordered!



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XML Element Structure

- Arbitrary levels of nesting
- Same element tag can appear multiple times
 - at the same level

```
<bank-1>
  <customer>
    <customer-name> Hayes </customer-name>
    <account>
      <account-number> A-102 </account-number>
      <balance> 400 </balance>
    </account>
    <account> ... </account>
  </customer>
  ...
</bank-1>
```
 - at different levels

```
<product>
  <prodName> ... </prodName>
  <part>
    <id> ... </id>
    <part> ... </part>
    <part> ... </part>
  </part>
  ...
</product>
```



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XML Documents: Attributes

- **Attributes:** can be used to further describe elements
 - attributes are specified by *name="value"* pairs inside the starting tag of an element
 - value is a text string
 - no further structuring of attribute values
 - attributes are not ordered
- Example:

```
<account acct-type = "checking" >
  <account-number> A-102 </account-number>
  <branch-name> Perryridge </branch-name>
  <balance> 400 </balance>
</account>
```
- Well-formed documents:
 - attribute names must be unique within the element
 - attribute values are enclosed in single or double quotation marks



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Attributes vs. Subelements

- Distinction between subelement and attribute
 - In the context of documents, attributes are part of markup, while subelement contents are part of the basic document content
 - markup used to interpret the content, influence layout for printing, etc.
 - In the context of data representation, the difference is unclear and may be confusing
 - Same information can be represented in two ways
 - `<account account-number = "A-101"> ... </account>`
 - `<account>`
`<account-number>A-101</account-number> ...`
`</account>`
- Limitations of attributes
 - single occurrence within element
 - no further attribute value structure, no ordering



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Namespaces

- A single XML document may contain elements and attributes defined by different vocabularies
 - Motivated by modularization considerations, for example
- Name collisions have to be avoided
- Example:
 - A **Book** vocabulary contains a Title element for the title of a book
 - A **Person** vocabulary contains a Title element for an honorary title of a person
 - A **BookOrder** vocabulary uses both vocabularies
- Namespaces specifies how to construct universally unique names



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Namespaces (cont.)

- Namespace is a collection of names identified by a URI
- Namespaces are declared via a set of special attributes
 - These attributes are prefixed by xmlns - Example:

```
<BookOrder xmlns:Customer="http://mySite.com/Person"
xmlns:Item="http://yourSite.com/Book">
```
 - Namespace applies to the element where it is declared, and all elements within its content
 - unless overridden
- Elements/attributes from a particular namespace are prefixed by the name assigned to the namespace in the corresponding declaration of the using XML document
 - ...**Customer**:Title='Dr'...
 - ...**Item**:Title='Introduction to XML'...
- Default namespace declaration for fixing the namespace of unqualified names
 - Example:

```
<BookOrder xmlns="http://mySite.com/Person"
xmlns:Item="http://yourSite.com/Book">
```



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XML Document Schema

- XML documents may optionally have a schema
 - standardized data exchange, ...
- Schema restricts the structures and data types allowed in a document
 - document is **valid**, if it follows the restrictions defined by the schema
- Two important mechanisms for specifying an XML schema
 - Document Type Definition (DTD)
 - XML Schema



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Document Type Definition - DTD

- Original mechanism to specify type and structure of an XML document
 - What elements can occur
 - What attributes can/must an element have
 - What subelements can/must occur inside each element, and how many times.
- DTD does not constrain data types
 - All values represented as strings in XML
- Special DTD syntax
 - `<!ELEMENT element (subelements-specification) >`
 - `<!ATTLIST element (attributes) >`
- DTD is
 - contained in the document, or
 - stored separately, referenced in the document
- DTD clause in XML document specifies the root element type, supplies or references the DTD
 - `<!DOCTYPE bank [...]>`



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Element Specification in DTD

- Subelements can be specified as
 - names of elements, or
 - #PCDATA (parsed character data), i.e., character strings
 - EMPTY (no subelements) or ANY (anything defined in the DTD can be a subelement)
- Structure is defined using regular expressions
 - sequence (*subel, subel, ...*), alternative (*subel | subel | ...*)
 - number of occurrences
 - "?" - 0 or 1 occurrence
 - "+" - 1 or more occurrences
 - "*" - 0 or more occurrences
- Example

```
<!ELEMENT depositor (customer-name, account-number)>
<!ELEMENT customer-name(#PCDATA)>
<!ELEMENT account-number (#PCDATA)>
<!ELEMENT bank ( ( account | customer | depositor)+)>
```



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Attribute Specification in DTD

- Attribute list of an element defines for each attribute
 - name
 - type of attribute (as relevant for data modeling)
 - character data (CDATA)
 - identifiers (ID) or references to an identifier attribute (IDREF, IDREFS)
 - see next chart for details
 - XML name tokens (NMTOKEN, NMTOKENS)
 - enumeration type
 - whether
 - mandatory (#REQUIRED)
 - default value (*value*)
 - optional without default (#IMPLIED), or
 - the value, if present, must not differ from the given one (#FIXED *value*)
- Examples
 - ```
<!ATTLIST account acct-type CDATA "checking">
```
  - ```
<!ATTLIST customer
customer-id ID #REQUIRED
accounts IDREFS #REQUIRED >
```



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IDs and IDREFs

- An element can have at most one attribute of type ID
- The ID attribute value of each element in an XML document must be distinct
 - ID attribute (value) is an object identifier
- An attribute of type IDREF must contain the ID value of an element in the same document
- An attribute of type IDREFS contains a set of (0 or more) ID values. Each ID value must contain the ID value of an element in the same document
- IDs and IDREFs are untyped, unfortunately
 - Example below: The *owners* attribute of an account may contain a reference to another account, which is meaningless; *owners* attribute should ideally be constrained to refer to customer elements



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Example: Extended Bank DTD

- Bank DTD with ID and IDREF attribute types

```
<!DOCTYPE bank [  
  <!ELEMENT account (branch-name, balance)>  
  <!ATTLIST account  
    account-number ID #REQUIRED  
    owners IDREFS #REQUIRED>  
  <!ELEMENT customer(customer-name, customer-street,  
    customer-city)>  
  <!ATTLIST customer  
    customer-id ID #REQUIRED  
    accounts IDREFS #REQUIRED>  
  ... declarations for bank, branch-name, balance, customer-name,  
    customer-street and customer-city  
>
```



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XML data with ID and IDREF attributes

```
<bank>
  <account account-number="A-401" owners="C100 C102">
    <branch-name> Downtown </branch-name>
    <balance>500 </balance>
  </account>
  ...
  <customer customer-id="C100" accounts="A-401">
    <customer-name>Joe</customer-name>
    <customer-street>Monroe</customer-street>
    <customer-city>Madison</customer-city>
  </customer>
  <customer customer-id="C102" accounts="A-401 A-402">
    <customer-name> Mary</customer-name>
    <customer-street> Erin</customer-street>
    <customer-city> Newark </customer-city>
  </customer>
</bank>
```



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Schema Definition with XML Schema

- XML Schema is closer to the general understanding of a (database) schema
- XML Schema (unlike DTD) supports
 - Typing of values
 - E.g. integer, string, etc
 - Constraints on min/max values
 - Typed references
 - User defined types
 - Schema specification in XML syntax
 - schema is a well-formed and valid XML document
 - Integration with namespaces
 - Many more features
 - List types, uniqueness and foreign key constraints, inheritance ..
- BUT: significantly more complicated than DTDs



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Types in XML Schema

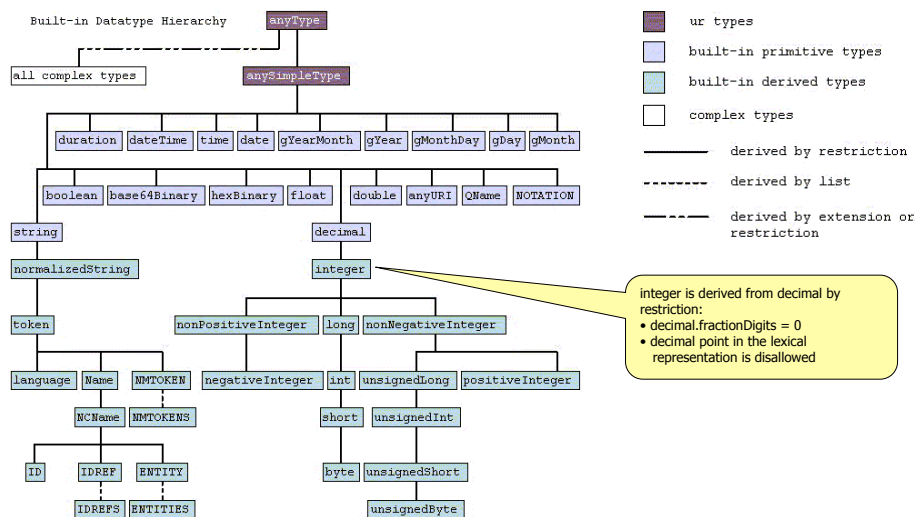
- Simple vs. complex types
 - Simple type
 - no further structure, does not contain child elements or attributes
 - can be used as a type for both **attribute** values and **element** content
 - broad repertoire of pre-defined simple types
 - facets of simple types provide additional characteristics
 - e.g., pattern, length
 - Complex type
 - consists of attribute declarations (optional) and a content model
 - content model defines possible child elements, content based on simple types, mixed content
- Primitive vs. derived types
 - Primitive types
 - subset of the simple types that are not defined in terms of other types
 - Examples: string, decimal
 - Derived types
 - defined in terms of other (derived or primitive) base types
 - different derivation mechanisms
 - by restriction – derived type permits only subset of value or literal space of the base type
 - by list, union – similar to composite types
 - by extension – similar to subtyping
- Built-in vs. user-derived types



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XML Schema Built-in Types



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Derivation By Restriction

- Based on the following facets
 - upper/lower bounds for value domain
 - minExclusive, minInclusive
 - maxExclusive, maxInclusive
 - length for strings, names, URIs or lists
 - length
 - maxLength
 - minLength
 - length restrictions for decimal
 - totalDigits
 - fractionDigits
 - value enumeration
 - enumeration
 - regular expression limiting the lexical space
 - pattern
- Examples
 - ```
<xs:simpleType name="MoneyAmt">
 <xs:restriction base="xs:decimal">
 <xs:totalDigits value="10"/>
 <xs:fractionDigits value="2"/>
 </xs:restriction>
</xs:simpleType>
```
  - ```
<xs:simpleType name="Phone">  
  <xs:restriction base="xs:string">  
    <xs:pattern  
      value="0[1-9][0-9]+\-[1-9][0-9]+"/>  
    </xs:restriction>  
</xs:simpleType>
```



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Complex Types

- Needed for modeling attributes and content model of elements
 - defines the type of the element, but not the element tag name
- Simple content: no child elements, extends/restricts a simple type for element content
 - ```
<xs:complexType name="Money">
 <xs:simpleContent>
 <xs:extension base="MoneyAmt">
 <xs:attribute name="currency" type="xs:string" use="required"/>
 </xs:extension>
 </xs:simpleContent>
</xs:complexType>
```



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## Complex Types (cont.)

- Complex content
    - three types of content models (may be nested arbitrarily)
      - sequence – subelements have to occur in the specified order
      - choice – only one of the subelements may occur
      - all – each subelement can appear at most once, in arbitrary order
- ```
<xs:complexType name="AccountT">  
  <xs:sequence>  
    <xs:element name="account-number" type="xs:string"/>  
    <xs:element name="branch-name" type="xs:string"/>  
    <xs:element name="balance" type="Money"/>  
  </xsd:sequence>  
</xs:complexType>
```
- Specifying the number of occurrences
 - minOccurs, maxOccurs attributes can be used in element and content model definitions
 - <xs:element name="account" type="AccountT minOccurs="0" maxOccurs="10"/>
 - <xs:choice minOccurs="2" maxOccurs="unbounded"> ... </xs:choice>



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Restricting And Extending Complex Types

- Derivation by restriction
 - derived type has the same content model as the base type in terms of valid attributes, elements
 - restrictions possible by
 - limiting the number of occurrences by choosing a larger min or smaller max value
 - supplying a default or fixed attribute value
 - remove an optional component
 - replacing a simple type with a derivation of the simple type
 - Derivation by extension
 - new attributes and elements can be added to the type definition inherited from the base type
 - append-only for elements, implying a sequence model
- ```
<xs:complexType name="SavingsAccountT">
 <xs:complexContent>
 <xs:extension base="AccountT">
 <xs:sequence>
 <xs:element name="interest-rate" type="xs:decimal"/>
 </xsd:sequence>
 </xs:extension>
 </xs:complexContent>
</xs:complexType>
```



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## Derived Types and "Substitutability"

- Derived types can be explicitly used in schema definitions
- At the document (i.e., "instance") level
  - an instance of a derived type may appear instead of an instance of its base type
    - derivation by extension or by restriction
    - may be explicitly blocked for a base type in the schema definition
  - the derived type has to be indicated using `xsi:type`
    - example (assuming that element `account` has type `AccountT`):

```
<account xsi:type="SavingsAccountT">
 <account-number>1234</account-number>
 <branch-name>Kaiserslautern</branch-name>
 <balance currency="Euro">3245.78</balance>
 <interest-rate>3.5</interest-rate>
</account>
```
    - the element name is not affected, only the content
- Substitution groups
  - extends the concept to the element level
  - a named head element may be substituted by any element in the substitution group
    - group elements have to be derived from head element
- Elements and types may be declared as "abstract"



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## Namespaces and XML Schema

- XML-Schema elements and data types are imported from the XML-Schema namespace `http://www.w3.org/2001/XMLSchema`
  - `xsd` is generally used as a prefix
- The vocabulary defined in an XML Schema file belongs to a target namespace
  - declared using the **targetNamespace** attribute
  - declaring a target namespace is optional
    - if none is provided, the vocabulary does not belong to a namespace
    - required for creating XML schemas for validating (pre-namespace) XML1.0 documents
- XML document using an XML schema
  - declares namespace, refers to the target namespace of the underlying schema
  - can provide additional hints where an XML schema (xsd) file for the namespace is located
    - `schemaLocation` attribute



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## XML Schema Version of Bank DTD

```
<xsd:schema xmlns:xsd="http://www.w3.org/2001/XMLSchema"
 targetNamespace="http://www.banks.org"
 xmlns="http://www.banks.org" >
 <xsd:element name="bank" type="BankType"/>
 <xsd:element name="account">
 <xsd:complexType>
 <xsd:sequence>
 <xsd:element name="account-number" type="xsd:string"/>
 <xsd:element name="branch-name" type="xsd:string"/>
 <xsd:element name="balance" type="xsd:decimal"/>
 </xsd:sequence>
 </xsd:complexType>
 </xsd:element>
 definitions of customer and depositor
 <xsd:complexType name="BankType">
 <xsd:choice minOccurs="1" maxOccurs="unbounded">
 <xsd:element ref="account"/>
 <xsd:element ref="customer"/>
 <xsd:element ref="depositor"/>
 </xsd:choice>
 </xsd:complexType>
</xsd:schema>
```



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## XML Document Using Bank Schema

```
<bank xmlns="http://www.banks.org"
 xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
 xsi:schemaLocation="http://www.banks.org Bank.xsd">
 <account>
 <account-number> ... </account-number>
 <branch-name> ... </branch-name>
 <balance> ... </balance>
 </account>
 ...
</bank>
```



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## Assertions in XML-Schema

- Uniqueness: UNIQUE-Element, KEY-Element
  - forces uniqueness of attribute or element values
    - <field> element(s)
  - can be applied to/declared for specific parts of the XML document
    - <selector> element
  - Example: within a bank element, all accounts should have a unique account number
    - ```
<xs:element name="bank" type="bankType">
          <xs:unique name="uniqueAcctNo">
            <xs:selector xpath="/account"/>
            <xs:field xpath="account-number"/>
          </xs:unique>
        </xs:element>
```
- Some remarks
 - NULL value semantics: **nillable** at the schema level, **nil** in the document
 - <key> equivalent to <unique> and nillable="false"
 - composite keys/unique elements

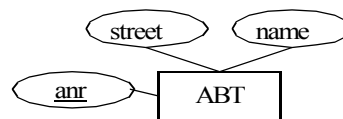


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Mapping ER-Model -> XML Schema

- Mapping Entities
 - 1:1 mapping to XML elements
 - use <key> to represent ER key attributes



```
...
<element name="ABT">
  <complexType>
    <attribute name="anr" type="string" />
    <attribute name="street" type="string" />
    <attribute name="name" type="string" />
  </complexType>
</element>
...
<key name="abt_pk">
  <selector xpath="."/ />
  <field xpath="@anr" />
</key>
...
```



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Mapping 1:N Relationships

- Mapping alternative: nesting
 - using local element definition

```

<element name="ABT">
  <complexType>
    <sequence>
      <element name="ANG">
        <complexType>
          <attribute name="name" type="string"/>
          <attribute name="office" type="string"/>
        </complexType>
      </element>
    </sequence>
    <attribute name="street" type="string"/>
    <attribute name="name" type="string"/>
  </complexType>
</element>

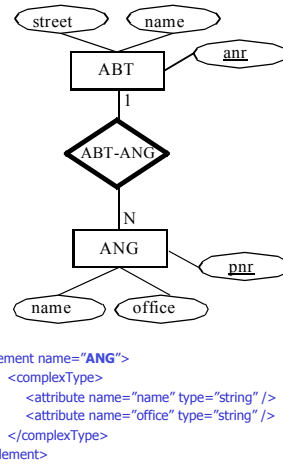
```

- using global element definition

```

<element name="ABT">
  <complexType>
    <sequence>
      <element ref="ANG"/>
    </sequence>
    <attribute name="street" type="string" />
    <attribute name="name" type="string" />
  </complexType>
</element>

```



```

...
<element name="ANG">
  <complexType>
    <attribute name="name" type="string" />
    <attribute name="office" type="string" />
  </complexType>
</element>

```



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Primary/Foreign Keys

- Problem
 - nesting alone is not sufficient for modeling a 1:n relationship
 - element identity is required to avoid duplicate entries
- Foreign Keys
 - guarantee referential integrity: <key> / <keyref> elements

```

<element name="ABT">
  <complexType>
    <sequence>
      <element name="ANG">
        <complexType>
          <attribute name="pnr" type="string"/>
          <attribute name="name" type="string"/>
          <attribute name="office" type="string"/>
          <attribute name="abtid" type="string"/>
        </complexType>
      </element>
    </sequence>
    <attribute name="anr" type="string"/>
    <attribute name="name" type="string"/>
    <attribute name="street" type="string"/>
  </complexType>
</element>
...
<key name="abt_pk">
  <selector xpath="//ABT" />
  <field xpath="@anr" />
</key>
...
<key name="ang_uniq">
  <selector xpath="//ABT/ANG" />
  <field xpath="@pnr" />
</unique>
...
<keyref name="abt_fk" refer="abt_pk">
  <selector xpath="//ABT/ANG" />
  <field xpath="@abtid" />
</key>
...

```



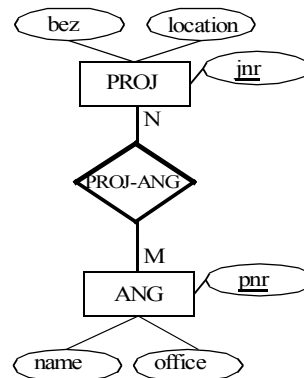
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Primary/Foreign Keys

- Advantages over ID/IDREF
 - based on equality of data types
 - composite keys
 - locality, restricting scope to parts of the XML document
- Mapping of N:M – relationships
 - use <key>/<keyref> elements
 - flat modeling plus "pointers"
 - addition of helper element similar to mapping to relational model

```
<element name="PROJ_ANG">  
  <complexType>  
    <attribute name="pnr" type="string" />  
    <attribute name="jnr" type="string" />  
  </complexType>  
</element>
```



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Summary

- XML introduction and overview
 - document structure – elements, attributes
 - namespaces
- XML schema support
 - document type definitions (DTD)
 - document structure, but no support for data types, namespaces
 - XML Schema specification
 - powerful: structure, data types, complex types, type refinement, constraints, ...
 - complex!
- Mapping ER -> XML
 - 1:1, 1:n, n:m relationships
 - primary/foreign keys



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