INFO-H-509 XML Technologies
XML Schema Languages Part II

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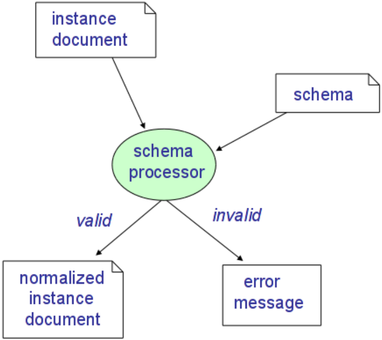
Objectives

1. The essence of **XML Schema Definitions** (XSDs)
2. **Basic features** of XML Schema Definitions
3. **Advanced features** of XML Schema Definitions
4. **Deterministic** Regular Expressions

Our story so far ...

- An **XML Language is a set of XML documents** that belong to the same "application domain"
- A **schema** is a formal definition of the syntax of an XML language
- A document is either **valid** w.r.t. a schema, or not
- A **schema language** is a notation by which schemas can be defined.

The idea of validation:



Our Story so far: Limitations of DTDs

1. Cannot constrain character data
2. Specification of attribute values is too limited
3. Element and attribute declarations are context insensitive
4. Character data cannot be combined with the regular expression content model
5. The content models lack an "interleaving" operator
6. The support for modularity, reuse, and evolution is too primitive
7. The normalization features lack content defaults and proper whitespace control
8. Structured embedded self-documentation is not possible
9. The ID/IDREF mechanism is too simple
10. It does not itself use an XML syntax
11. No support for namespaces

Requirements for XML Schema

XML Schema is W3C's proposal for replacing DTDs

Design Principles:

- More expressive than DTD
- Use XML notation
- Self-describing
- Simplicity

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Design Principles:

- More expressive than DTD
- Use XML notation
- Self-describing → **not really**
- Simplicity → **not really**

Technical Requirements:

- Namespace support
- User-defined datatypes
- Inheritance (OO-like)
- Evolution
- Embedded documentation
- ...

Part I: The Essence

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- XML Schema is a large and complicated standard
- Its syntax in XML is really verbose ...
- ... so it's easy to get lost in the beginning

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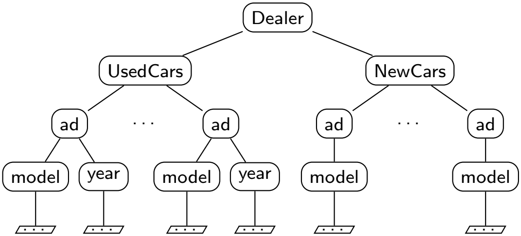
- XML Schema is a large and complicated standard
- Its syntax in XML is really verbose ...
- ... so it's easy to get lost in the beginning

- Let us illustrate the **essential ideas** without using the actual XSD syntax
- Let us focus on **elements**

The Essence of XSDs



- ads under `UsedCars` must contain **both** `model` and `year`
- ads under `NewCars` must contain **only** `model`

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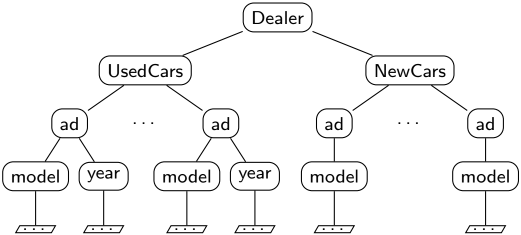

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- This XML language cannot be specified by a DTD

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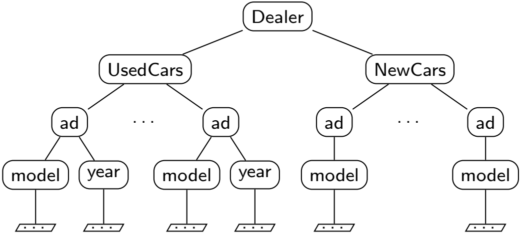

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We need a way to distinguish between UsedCar ads and NewCar ads

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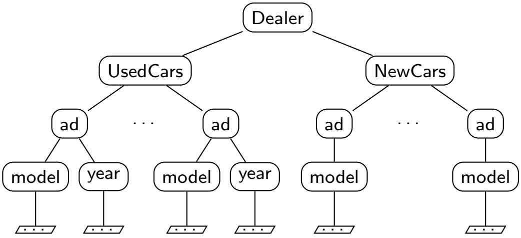

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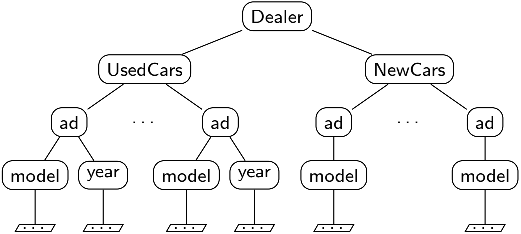
We need a way to distinguish between UsedCar ads and NewCar ads

XML Schema solves this by introducing types

- **Simple types** describe the legal values of text and attribute nodes (`integer`, `string`, `date`, . . .)
- **Complex types** describe the content model for element nodes: each complex type is a regular expression over pairs of the form (*element name*, *type*).
- An XML Schema is a collection of **type definitions**.

The Essence of XSDs (2)



Example:

$$
\begin{aligned}
\texttt{dealerType} &\rightarrow (\texttt{UsedCars}, \texttt{usedType}), (\texttt{NewCars}, \texttt{newType}) \\
\texttt{usedType} &\rightarrow (\texttt{ad}, \texttt{adType1})* \\
\texttt{newType} &\rightarrow (\texttt{ad}, \texttt{adType2})* \\
\texttt{adType1} &\rightarrow (\texttt{model}, \texttt{string}), (\texttt{year}, \texttt{date}) \\
\texttt{adType2} &\rightarrow (\texttt{model}, \texttt{string})
\end{aligned}
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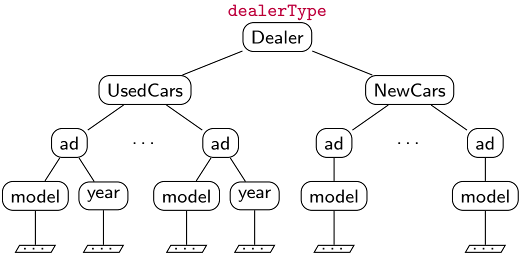

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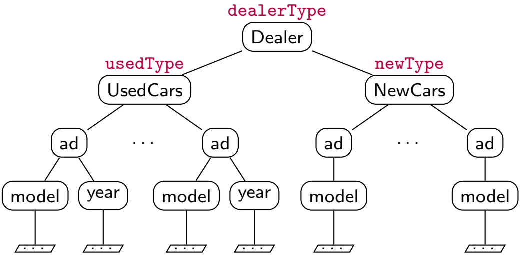

Example:

$$\begin{array}{lll} \texttt{dealerType} & \rightarrow & (\texttt{UsedCars}, \texttt{usedType}), (\texttt{NewCars}, \texttt{newType}) \\ \texttt{usedType} & \rightarrow & (\texttt{ad}, \texttt{adType1})* \\ \texttt{newType} & \rightarrow & (\texttt{ad}, \texttt{adType2})* \\ \texttt{adType1} & \rightarrow & (\texttt{model}, \texttt{string}), (\texttt{year}, \texttt{date}) \\ \texttt{adType2} & \rightarrow & (\texttt{model}, \texttt{string}) \end{array}$$

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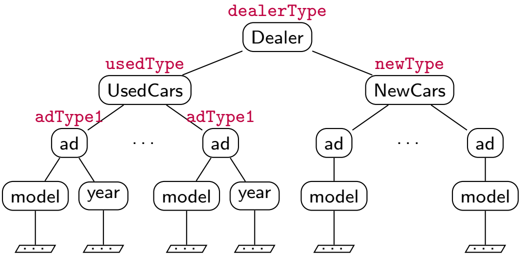

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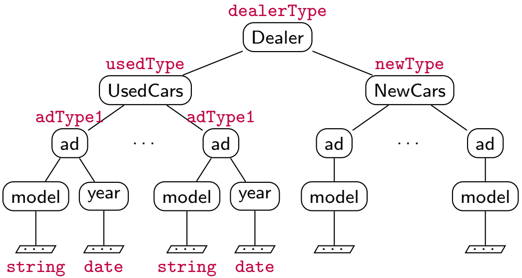

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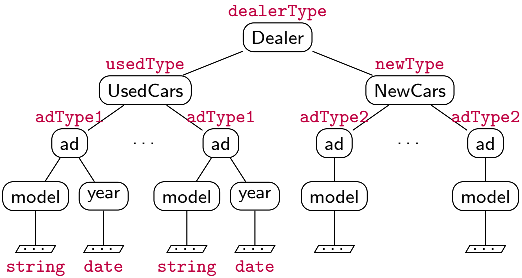

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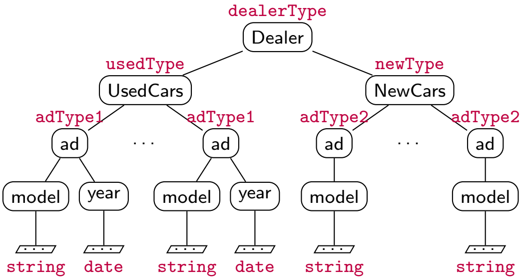

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Definition

XML Schema requires that **within the same type definition** the same element name must occur with the same type. This is called the **element declaration consistent** constraint (EDC).

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- Legal:

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- Legal:

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- Illegal:

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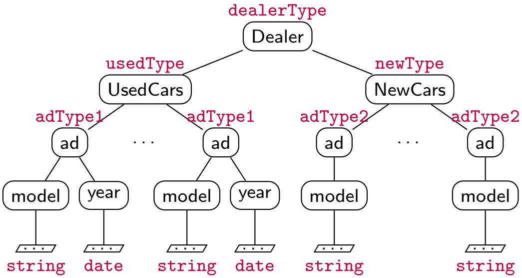

Theorem [Martens, Neven, Schwentick, 2006]

The type assignment is determined by path from element to root

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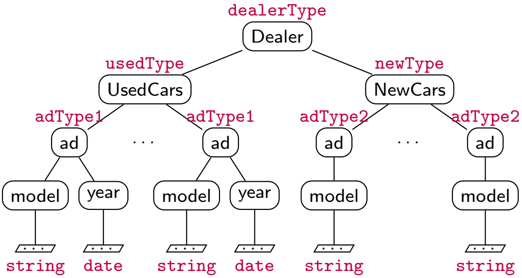
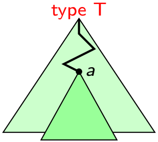


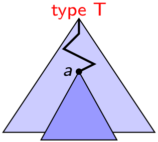
Theorem [Martens, Neven, Schwentick, 2006]

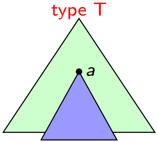
The type assignment is determined by path from element to root

In other words: paths determine types!

What XML languages can we express with an XSD?

Hence if 

$\in S$ and 

$\in S$ then 

$\in S$

We can use this to show that an XML language is not definable in XML Schema

Part II: Basic Syntax

XSDs: XML Schema Definitions - Syntax

Definition

Syntactically, an **XSDs** is a collection of:

- **complex type definitions**: defines content and attributes
- **simple type definitions**: defines a family of legal Unicode text strings
- **element declarations**: associate an element name with a simple or complex type
- **attribute declarations**: associate an attribute name with a simple type

XSDs by Example

- XSDs are written in XML
- All definitions and declarations are put inside an **schema** element

```
<schema xmlns="http://www.w3.org/2001/XMLSchema"
        targetNamespace="http://cardealers.org"
        xmlns:b="http://cardealers.org">

  the definitions go here ...

</schema>
```

XSDs by Example

Example in our made-up syntax:

$$\texttt{dealerType} \quad \rightarrow (\texttt{UsedCars}, \texttt{usedType}), (\texttt{NewCars}, \texttt{newType})$$

Real XSD syntax:

```
<complexType name="dealerType">
  <sequence>
    <element name="UsedCars" type="b:usedType"/>
    <element name="NewCars" type="b:newType" />
  </sequence>
</complexType>
```

XSDs by Example

Example in our made-up syntax:

$$\begin{aligned} \texttt{dealerType} &\rightarrow (\texttt{UsedCars}, \texttt{usedType}), (\texttt{NewCars}, \texttt{newType}) \\ \texttt{usedType} &\rightarrow (\texttt{ad}, \texttt{adType1})* \end{aligned}$$

Real XSD syntax:

```
<complexType name="usedType">
  <sequence>
    <element name="ad" type="b:adType1"
             minOccurs="0" maxOccurs ="unbounded"/>
  </sequence>
</complexType>
```

XSDs by Example

Example in our made-up syntax:

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Real XSD syntax:

```
<complexType name="newType">
  <sequence>
    <element name="ad" type="b:adType2"
             minOccurs="0" maxOccurs ="unbounded"/>
  </sequence>
</complexType>
```

XSDs by Example

Example in our made-up syntax:

```
dealerType  → (UsedCars, usedType), (NewCars, newType)
usedType    → (ad, adType1)*
newType     → (ad, adType2)*
adType1     → (model, string), (year, date)
```

Real XSD syntax:

```
<complexType name="addType1">
  <sequence>
    <element name="model" type="string" />
    <element name="year" type="date" />
  </sequence>
</complexType>
```

XSDs by Example

Example in our made-up syntax:

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\texttt{adType1} & \rightarrow (\texttt{model}, \texttt{string}), (\texttt{year}, \texttt{date}) \\
\texttt{adType2} & \rightarrow (\texttt{model}, \texttt{string})
\end{array}
$$

Real XSD syntax:

```
<complexType name="addType2">
  <sequence>
    <element name="model" type="string" />
  </sequence>
</complexType>
```

XSDs by Example

Example in our made-up syntax:

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\texttt{adType1} & \rightarrow (\texttt{model}, \texttt{string}), (\texttt{year}, \texttt{date}) \\
\texttt{adType2} & \rightarrow (\texttt{model}, \texttt{string})
\end{array}
$$

Finally we need to declare globally that `Dealer` elements have type `dealerType`:

```
<!-- Global element declaration -->
<element name="Dealer" type="b:dealerType"/>
```

The complete XSD

By means of
Online demonstration

Element and attribute declarations

Definition

Declarations (global and local):

- `<element name="`*elem name*`" type="`*simple or complex type name*`"/>`
- `<attribute name="`*attr name*`" type="`*simple type name* `..."/>`

References:

- `<element ref="`*elem name*`"/>`
- `<attribute ref="`*attr name*`"/>`

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- `<attribute name="`*attr name*`" type="`*simple type name ...*`"/>`

References:

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Example
By means of
Online demonstration

Global versus local type definitions

Global style:

```
<complexType name="newType">
  <sequence>
    <element name="ad" type="b:adType2"
              minOccurs="0" maxOccurs ="unbounded"/>
  </sequence>
</complexType>

<complexType name="addType2">
  <sequence>
    <element name="model" type="string" />
  </sequence>
</complexType>
```

Global versus local type definitions

Local style: in-line anonymous type definitions

```
<complexType name="newType">
  <sequence>
    <element name="ad" minOccurs="0" maxOccurs ="unbounded">
      <complexType>
        <sequence>
          <element name="model" type="string" />
        </sequence>
      </complexType>
    </element>
  </sequence>
</complexType>
```

Global versus local declarations

An example with global and local declarations:

```
<element name="ad" type="adType1">

<complexType name="usedType">
  <sequence>
    <element ref="b:ad" minOccurs="0" maxOccurs ="unbounded"/>
  </sequence>
</complexType>

<complexType name="newType">
  <sequence>
    <element name="ad" type="b:adType2"
              minOccurs="0" maxOccurs ="unbounded"/>
  </sequence>
</complexType>
```

Note that we need at least one local element declaration to distinguish between used car ads and new car ads. This is called overloading.

Complex Type Definitions

Definition

- Syntax:

  `<complexType name="...">` *content model/attributes* `</complexType>`

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Element declaration	→	`<element name="..." type="...">`
Element reference	→	`<element ref="...">`
Concatenation	→	`<sequence> ...</sequence>`
Union	→	`<choice> ...</choice>`
All (unordered)	→	`<all> ...</all>`
Element Wildcard	→	`<any namespace="..." processContents="...">`
Cardinalities (*,+)	→	attributes `minOccurs`, `maxOccurs`
Mixed content	→	attribute `mixed="true"`

Complex Type Definitions

Definition

- Syntax:

  <complexType name="..."> *content model/attributes* </complexType>

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Cardinalities (*,+)	→ attributes minOccurs, maxOccurs
Mixed content	→ attribute mixed="true"

- Attributes:

Attribute declaration	→ <attribute name="..." type="..." ...>
Attribute reference	→ <attribute ref="..." ...>
Attribute wildcard	→ <attribute namespace="..."
	→ processContents="...">

Complex Type Definitions (2)

Example:

```
<element name="order" type="n:order_type"/>

<complexType name="order_type" mixed="true">
  <choice>
    <element ref="n:address"/>
     <sequence>
      <element ref="n:email" minOccurs="0" maxOccurs="4"/>
      <element ref="n:phone"/>
    </sequence>
  </choice>

  <attribute ref="n:id" use="required"/>
  <attribute ref="n:email" default="no email address available"/>
  <attribute ref="n:method" fixed="some fixed value"/>
</complexType>
```

Simple types

- XML Schema has a myriad of built-in simple types . . .

`string`	any Unicode string
`boolean`	true, false, 1, 0
`decimal`	3.1415
`float`	6.02214199E23
`double`	42E970
`dateTime`	2004-09-26T16:29:00-05:00
`time`	16:29:00-05:00
`date`	2004-09-26
`hexBinary`	48656c6c6f0a
`base64Binary`	SGVsbG8K
`anyURI`	http://www.brics.dk/ixwt/
`QName`	rcp:recipe, recipe
...	

Simple types

- XML Schema has a myriad of built-in simple types . . .
- . . . but it is **also possible to define your own simple types.**

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`QName`	rcp:recipe, recipe
...	

Simple type definition by example

- New simple types are defined by **restricting existing simple types**

Example:

- To match integers between 0 and 100:

```
<simpleType name="score_from_0_to_100">
  <restriction base="integer">
    <minInclusive value="0"/>
    <maxInclusive value="100"/>
  </restriction>
</simpleType>
```

Simple type definition by example

- New simple types are defined by **restricting existing simple types**

Example:

- To match strings of the form $N\%$ with $0 \leq N \leq 100$:

```
<simpleType name="percentage">
  <restriction base="string">
    <pattern value="([0-9]|[1-9][0-9]|100)%"/>
  </restriction>
</simpleType>
```

Simple type definition by example

- New simple types are defined by **restricting existing simple types**
- By defining **lists of simple types**

Example:

- To match a whitespace-separated list of integers like 1 55 399:

```
<simpleType name="score_from_0_to_100">
  <list itemType="integer"/>
</simpleType>
```

Simple type definition by example

- New simple types are defined by **restricting existing simple types**
- By defining **lists of simple types**
- Or taking **unions of simple types**

Example:

- To match all booleans and decimals:

```
<simpleType name="boolean_or_decimal">
  <union>
    <simpleType>
      <restriction base="boolean"/>
    </simpleType>
    <simpleType>
      <restriction base="decimal"/>
    </simpleType>
  </union>
</simpleType>
```

Deriving simple types by restriction

The things that we restrict by are called **facets**

Available constraining facets:

- length
- minLength
- maxLength
- pattern
- enumeration
- whiteSpace
- maxInclusive
- maxExclusive
- minInclusive
- minExclusive
- totalDigits
- fractionDigits

Built-in derived simple types

XML Schema has a myriad of built-in simple types that are defined by derivation from the primitive simple types

- normalizedString
- token
- language
- Name
- NCName
- ID
- IDREF
- integer
- nonNegativeInteger
- unsignedLong
- long
- int
- short
- byte
- ...

Complex types with simple content

- Sometimes we want to specify that the content of an element should be of some simple type, but that it can also have some attribute.
- This requires a peculiar syntax

Example:

```
<element name="category" type="n:category"/>
<attribute name="class" type="string"/>

<complexType name="category">
  <simpleContent>
    <extension base="integer">
      <attribute ref="n:class"/>
    </extension>
  </simpleContent>
</complexType>
```

Connecting Schemas and Instances

Example instance document:

```
<b:card xmlns:b="http://businesscard.org"
        xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
        xsi:schemaLocation="http://businesscard.org
                            business_card.xsd">
  <b:name>John Doe</b:name>
  <b:title>CEO, Widget Inc.</b:title>
  <b:email>john.doe@widget.com</b:email>
  <b:phone>(202) 555-1414</b:phone>
  <b:logo b:uri="widget.gif"/>
</b:card>
```

- **Only globally declared elements can be starting points for validation!**
- **The targetNamespace of the Schema, and the nameSpace of the elements in the instance document must match!**
- **If the XSD does not have a target namespace, use** `noNameSpaceSchemaLocation` **instead of** `schemaLocation`

Part III: Advanced Features

Complex Type Derivation

- Also complex types can be derived by **restricting or extending existing complex types**
- This is similar to inheritance in object-oriented programming languages

Example:

- Assume given the following complex type:

```
<complexType name="basic_card_type">
  <sequence> <element name="name" type="string"/> </sequence>
</complexType>
```

Complex Type Derivation

- Also complex types can be derived by **restricting or extending existing complex types**
- This is similar to inheritance in object-oriented programming languages

Example:

- We can extend this type with a `title` element and optional `email` elements as follows:

```
<complexType name="extended_type">
  <complexContent>
    <extension base="b:basic_card_type">
      <sequence>
        <element ref="b:title"/>
        <element ref="b:email" minOccurs="0"/>
      </sequence>
    </extension>
  </complexContent>
</complexType>
```

Complex Type Derivation

- Also complex types can be derived by **restricting or extending existing complex types**
- This is similar to inheritance in object-oriented programming languages

Example:

- We can subsequently restrict this type such that `email` becomes required:

```
<complexType name="restricted_type">
  <complexContent>
    <restriction base="b:extended_type">
      <sequence>
        <element name="name" type="string"/>
        <element ref="b:title"/>
        <element ref="b:email"/>
      </sequence>
    </restriction>
  </complexContent>
</complexType>
```

Complex Type Derivation: subsumption

Assume that:

- T is some (complex or simple) type
- T^- is derived from T by **restriction**
- T^+ is derived from T by **extension**

Definition

Subsumption is the principle that whenever a instance of type T is required,

- an instance of type T^- may be used instead (every instance of type T^- is also of type T)
- an instance of type T^+ may be used instead if the instance has attribute `xsi:type="T+"` with

```
xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
```

Complex Type Derivation: subsumption

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```
xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
```

Note: Derivation, instantiation, and subsumption can be constrained using final, abstract, and block

Namespaces

```
<schema targetNamespace="..." ...>
```

- Prefixes are also used in certain attribute values!
- Unqualified Locals:
  - if enabled, the name of a locally declared element or attribute in the instance document must have no namespace prefix (i.e. the empty namespace URI)
  - such an attribute or element “belongs to” the element declared in the surrounding global definition
  - always change the default behavior using `elementFormDefault="qualified"`

Uniqueness, Keys, references

- Keys can be defined by means of `key`
- Keys can be referred to by means of `keyref`
- `unique` functions as `key`, but fields may be absent

Example:

```
<element name="w:widget" xmlns:w="http://www.widget.org">
  <complexType> ... </complexType>

  <key name="my_widget_key">
    <selector xpath="w:components/w:part"/>
    <field xpath="@manufacturer"/>
    <field xpath="w:info/@productid"/>
  </key>

  <keyref name="annotation_references" refer="w:my_widget_key">
    <selector xpath=".//w:annotation"/>
    <field xpath="@manu"/>
    <field xpath="@prod"/>
  </keyref>
</element>
```

Other Features

- Groups
- Substitution groups (essentially subsumption based on element names, not types)
- Nil values
- Annotations
- Defaults and whitespace
- Modularization

Read the book chapter

Specifying RecipyML with XML Schema

By means of
Online demonstration

Problems with the XML Schema Description

We had the following problems with the DTD description:

- `calories` should contain a non-negative number; $\rightarrow$ **FIXED!**
- `protein` should contain a value on the form $N\%$ where N is between 0 and 100; $\rightarrow$ **FIXED!**
- `comment` should be allowed to appear anywhere in the contents of `recipe`; $\rightarrow$ **NOT FIXED!**
- `unit` should only be allowed in an elements where `amount` is also present; $\rightarrow$ **NOT FIXED!**
- nested `ingredient` elements should only be allowed when amount is absent; $\rightarrow$ **NOT FIXED!**

Limitations of XML Schema

- The details are extremely complicated (and the spec is unreadable)
- Declarations are (mostly) context insentitive
- It is impossible to write an XML Schema description of XML Schema
- With mixed content, character data cannot be constrained
- Unqualified local elements are bad practice
- Cannot require specific root element
- Element defaults cannot contain markup
- The type system is overly complicated
- `xsi:type` is problematic
- Simple type definitions are inflexible

An important comment (not in book!)

The regular expressions used as element content models must be **deterministic**, sometimes also called **one-unambiguous**

Intuitively:

- Intuitively, a regular expression is deterministic if, when processing the input sequence from left to right, it is always determined which symbol in the expression matches the next input symbol **without looking ahead**.
- This is supposed to make implementations faster

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Example:

- $a, a \mid a, b$ is **not** deterministic (consider input aa)
- $a, (a \mid b)$ **is** deterministic
- Note that these two expressions match the same sequences!

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Definition

- For a regular expression α, define $\overline{\alpha}$ to be the regular expression obtained from α by replacing, for each i, the i-th occurrence of symbol σ in α (counting from left to right) by σ_i

Example:

- $a, a \mid a, b \to a_1, a_2 \mid a_3, b_1$
- $a, (a \mid b) \to a_1, (a_2 \mid b_1)$
- $(a \mid b)*, a, c, (b \mid c)* \to (a_1 \mid b_1)*, a_2, c_1, (b_2 \mid c_2)*$

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- For a regular expression α, define $\overline{\alpha}$ to be the regular expression obtained from α by replacing, for each i, the i-th occurrence of symbol σ in α (counting from left to right) by σ_i
- So if α is over the alphabet $\{a, b, c, \dots\}$ then $\overline{\alpha}$ is over the alphabet $\{a_1, a_2, \dots, b_1, b_2, \dots, c_1, c_2, \dots\}$.

Example:

- $a, a \mid a, b \rightarrow a_1, a_2 \mid a_3, b_1$
- $a, (a \mid b) \rightarrow a_1, (a_2 \mid b_1)$
- $(a \mid b)^*, a, c, (b \mid c)^* \rightarrow (a_1 \mid b_1)^*, a_2, c_1, (b_2 \mid c_2)^*$

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- A regular expression α is **deterministic** if there are no sequences wa_iv and wa_jv' in $\mathcal{L}(\bar{r})$ with $i \neq j$ (w may be empty).

Example:

- $a, a \mid a, b \rightarrow a_1, a_2 \mid a_3, b_1$
- $a, (a \mid b) \rightarrow a_1, (a_2 \mid b_1)$
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- $a, a \mid a, b \rightarrow a_1, a_2 \mid a_3, b_1$ **not deterministic: consider a_1a_2 and a_3b_1**
- $a, (a \mid b) \rightarrow a_1, (a_2 \mid b_1)$
- $(a \mid b)*, a, c, (b \mid c)* \rightarrow (a_1 \mid b_1)*, a_2, c_1, (b_2 \mid c_2)*$

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- $(a \mid b)*, a, c, (b \mid c)* \rightarrow (a_1 \mid b_1)*, a_2, c_1, (b_2 \mid c_2)*$

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  deterministic? or not?

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not

An important comment (not in book!)

Can we make every regular expression deterministic?

- $a, a \mid a, b \longrightarrow a, (a \mid b)$

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Can we make every regular expression deterministic?

- $a, a \mid a, b \longrightarrow a, (a \mid b)$

Theorem

No there exists regular expressions for which no equivalent deterministic regular expression exists.

So we are limited to a subset of the regular expressions in DTDs and XSDs