Course: Introduction to XML

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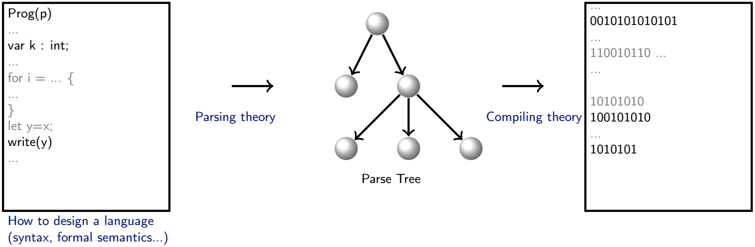
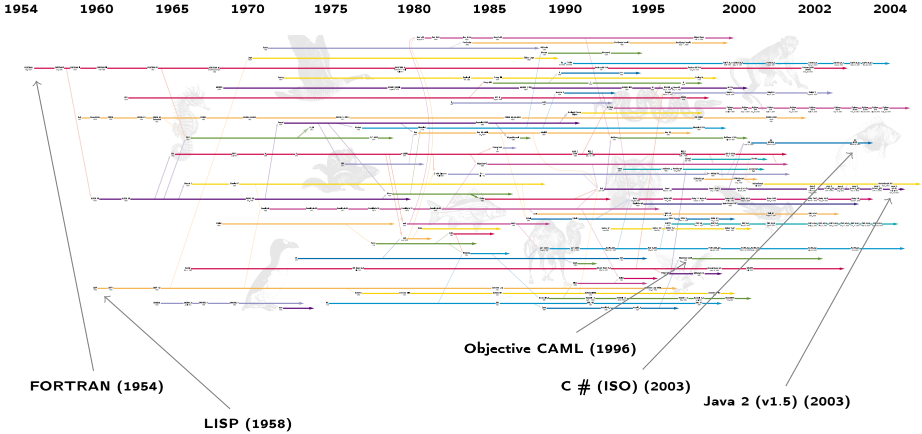
University of Grenoble, 2012–2013

What you should probably know...



How to design, implement and use a programming language

History of Programming Languages



What about Data?

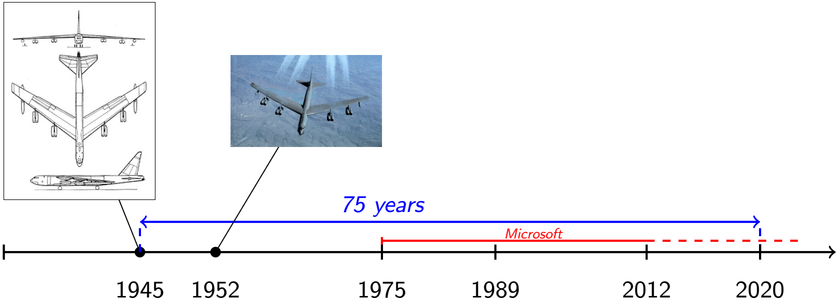
- Often, data is more important than programs (*e.g.* banks, aeronautical technical documentation, ...)
- One reason for this is that data often have a much longer life cycle than programs

→ **How to ensure long-term access to data?**

→ How to design software systems such that manipulated data can still be accessed 15 or 50 years later?

Example: Aeronautical Technical Documentation

In aeronautics, it is common to find products with life cycles that last for several decades, *e.g.* the B-52:



→ **How to ensure long-term access to data?**

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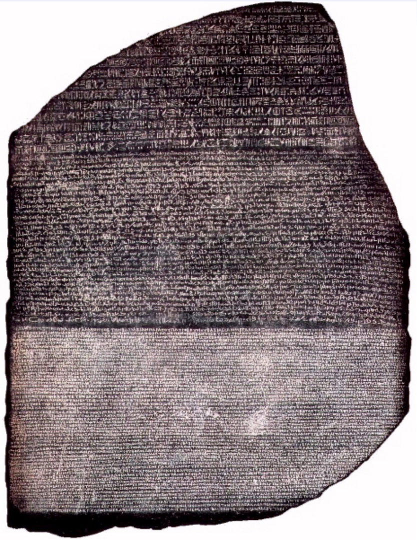
→ An old concern...

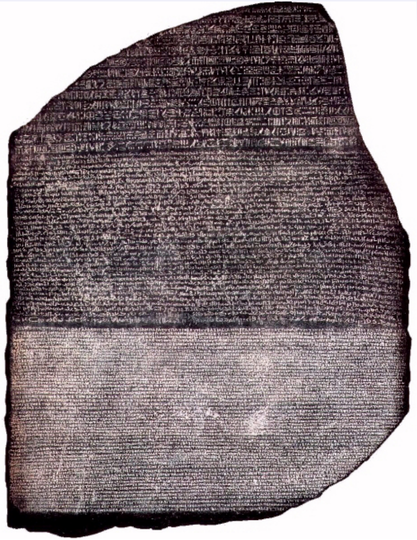


La pierre de Rosette.

→ **How to ensure long-term access to data?**

→ An old concern...

- Can we really do better with computers?



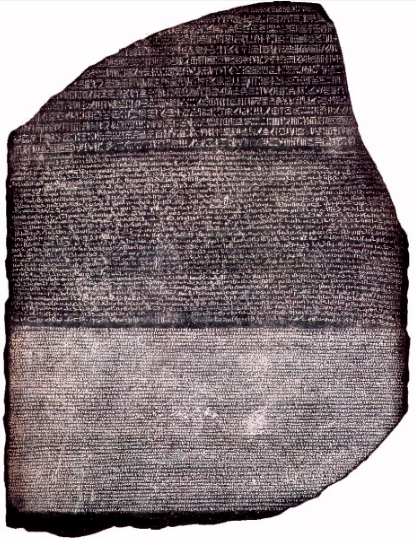
La pierre de Rosette.

→ **How to ensure long-term access to data?**

→ An old concern...

- Can we really do better with computers?

→ A computer museum? ☺



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What has not changed for 50 years in Computer Science?

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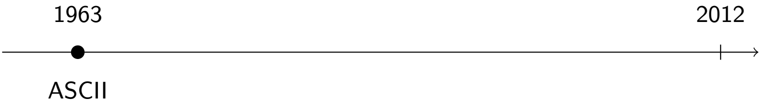

Data Exchange – What Happened

- Often, data must be sent to a third-party program/person
- Data must be made explicit (*e.g.* storage in files)
- Widespread approach until the 1990's for defining a *file format*:
  - Define (binary?) representation for data + instructions, *e.g.* records
  - Write file format spec (v1.0?) + implement parser

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MachinCompany
File format X
Parser P_X

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Bidule Inc.
File format Y
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File format X
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TrucMuche SA
File format Z
Parser P_Z

...

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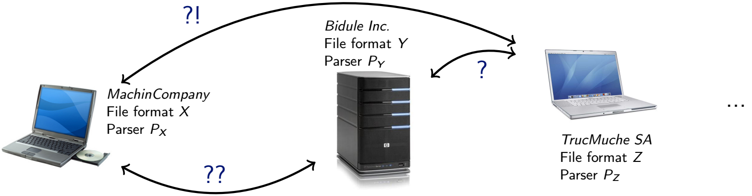

- **Problems:** - exchanging data → exchanging programs!

  - this approach cannot scale (and costs $\$^{\$\$\$}$)

→ Need for normalization of data exchange

Motivation for XML:

To have one language to describe and exchange data

XML = Data

```
Pierre Genevès
CNRS
pierre.geneves@inria.fr

...

Nabil Layaïda
INRIA
nabil.layaida@inria.fr
```

Text file

XML = Data + Structure

Pierre Genevès
CNRS
pierre.geneves@inria.fr

...

Nabil Layaïda
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nabil.layaida@inria.fr

Text file

⟶ "Mark it up!"

```
<people>
 <person>
  <name>Pierre Genevès</name>
  <affil>CNRS</affil>
  <email>pierre.geneves@inria.fr</email>
 </person>
 ...
 <person>
  <name>Nabil Layaïda</name>
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  <email>nabil.layaida@inria.fr</email>
  </person>
</people>
```

XML Document

XML = Data + Structure

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```

Text file

→ "Mark it up!"

```xml
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 ...
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</people>
```

XML Document

Tags describe structure, independently from processors (tags are **not** implicit parameters for a given processor, *e.g.* tags are **not** intended for describing presentation)

XML = Data + Structure

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  </person>
</people>
```

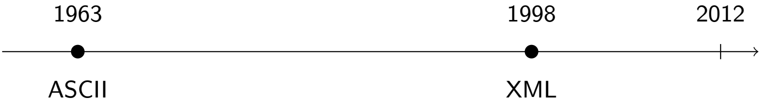
XML Document

Is this a good template? What about first/last name?
Several affil's? email's...?

XML Documents

- Ordinary text files (UTF8, UTF16, ...)
- Originates from typesetting/DocProcessing community
- Idea of labeled brackets ("mark up") for structure is not new (already used by Chomsky in the 1960's)
- Properly nested brackets/tags describe a **tree structure**
- Allows applications from different vendors to exchange data
- **Standardized, extremely widely accepted**
- The Lingua franca for communicating on the web...

Standards for Data Exchange



- Before: file format tied to a processor (due to processor-specific instructions)
- After: markup language for describing (structured) data in itself (independently from processors)

XML History

Ancestors

1974 SGML (Charles Goldfarb at IBM Research)

1989 HTML (Tim Berners-Lee at CERN, Geneva)

1994 Berners-Lee founds World Wide Web Consortium (W3C)

1996 **XML** (W3C draft, v1.0 in 1998)
http://www.w3.org/TR/REC-xml/

Initial W3C Goals for XML[1]

"The design goals for XML are:

1. *XML shall be straightforwardly usable over the Internet.*
2. *XML shall support a wide variety of applications.*
3. *XML shall be compatible with SGML.*
4. *It shall be easy to write programs which process XML documents.*
5. *The number of optional features in XML is to be kept to the absolute minimum, ideally zero.*
6. *XML documents should be human-legible and reasonably clear.*
7. *The XML design should be prepared quickly.*
8. *The design of XML shall be formal and concise.*
9. *XML documents shall be easy to create.*
10. *Terseness is of minimal importance."*

[1] `http://www.w3.org/TR/WD-xml-961114`

XML is a Data Exchange Format

- **Contra..** extremely verbose, lots of repetitive markup, large files
- **Pro..** answers ambitious goals:
  - → long-standing (mark-up does not depend on the system where it was created nor on processings)
  - → One of the pillars of the web
  - → We have a standard!... **A STANDARD!**
  - → If you use XML properly, you will never need to write a parser again

XML is a Meta-Language

- XML makes it possible to create Markup-Languages
- Instead of writing a parser, **you simply fix your own "XML Dialect"**

  by describing all "admissible structures" :

  - allowed element names
  - how they can be assembled together
  - maybe even the specific data types that may appear inside

  You do this using an XML Type definition language such as DTD or Relax NG (Oasis).

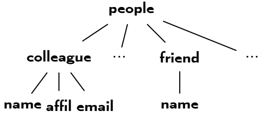
  Of course, such type definition languages are simple, because you want the parsers to be efficient!

XML Document Type Definition

- The XML Recommendation[2] includes an XML type definition language for specifying **document types**: DTD

people	$\rightarrow$	(colleague | friend)*
colleague	$\rightarrow$	name, affil^{+}, email
friend	$\rightarrow$	name, affil*, phone*, email?
…		

Document Type



- Each element is associated with its content model: a reg. expr. (, | ? * +)
- A document type (a set of such associations + a particular root element) describes a set of valid documents used by an organisation

[2]http://www.w3.org/TR/REC-xml/

XML: What Else?

- → Attributes
- → Comments
- → Processing Instructions
- → Entity References
- → Namespaces
- → Text (a specific node kind)

XML: What Else?

```
<friend surname="Pitou" birthday="08/08">..</friend>
```

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<!-- a comment here -->
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<?php sql("SELECT * FROM .") ...  ?)>
```

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DTD: `<!ENTITY notice "All rights...">`

instance: `<p> Copyright:  &notice; </p>`

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DTD: `<!ENTITY notice "All rights...">`
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```
<book xmlns="http://www.books.com/xml"
      xmlns:cars="http://www.cars.com/xml">
 <part><cars:part>Avoids collisions..</cars:part></part>
</book>
```

XML: What Else?

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<friend surname="Pitou" birthday="08/08">..</friend>
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XML Today

"There is essentially no computer in the world, desktop, handheld, or backroom, that doesn't process XML sometimes..."
T. Bray

Some Widespread XML Dialects...

- XHTML (W3C) – the XML version of HTML
- SVG (W3C) – Animated Vector Graphics
- SMIL (W3C) – Synchronized Multimedia Documents, and MMS
- MathML (W3C) – Mathematical formulas
- XForms (W3C) – Web forms
- Fix, FPML – Financial structured products, transactions ...
- CML – Chemical molecules
- X3D (Web3D) - 3D Graphics
- XUL (Mozilla), MXML (Macromedia), XAML (Microsoft) – Interface Definition Languages
- SOAP (RPC using HTTP), WSDL (W3C), WADL (Sun) – Web Services
- RDF (W3C), OWL (W3C) – Metadata/Knowledge in the Semantic Web
- ...

Outline of the Sequel

- Two notions of correctness:
  - Well-formedness
  - Validity
- Defining your own classes of documents
  - DTDs, XML Schemas
  - Modeling trees and graphs
- Parsing (with or without validation)

XML Defines 2 Levels of Correctness

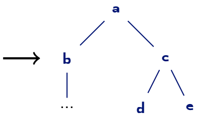
1. Well-formed XML (minimal requirement)
   - The **flat text format** seen on the **physical** side, *i.e.* a set of (UTF8/16) character sequences being well-formed XML
   - Ensures data correspond to logical tree-like structures (applications that want to analyse and transform XML data in any meaningful manner will find processing flat character sequences hard and inefficient)
2. Valid XML (optional, stricter requirement)
   - More often than not, applications require the XML input **trees** to conform to a **specific XML dialect**, defined by *e.g.* a DTD

Well-Formed XML

```
<a att="v">                     <a att="v1" att="v2">
  <bar><e/></foo>                 <b>...</b>
  <c>...</c>                      <c><e></c></e>
</a>                            </a>
```

Not Well-formed XML

```
<a>
  <b>...</b>
  <c><d/><e/></c>
</a>
```



Well-formed XML

Characters	<	>	"	'	&
Entities	<	>	"	'	&

- Proper nesting of opening/closing tags
- Shortcut: <e/> for <e></e>
- Every attribute must have a (unique) value
- A document has one and only one root
- No ambiguity between structure and data

→ Any XML processor considers well-formed XML as a logical tree structure which is:
  - ordered (except attributes!)
  - finite (leaves are empty elements or character data)

→ It **must** stop for not well-formed XML.

Valid XML

- The header of a document **may** include a reference to a DTD:

```
<!DOCTYPE root PUBLIC "public-identifier" "uri.dtd">
```

- A document with such a declaration must be valid wrt the declared type

→ The parser will validate it

Example

```
<!DOCTYPE html PUBLIC "-//W3C//DTD XHTML 1.1//EN"
  "http://www.w3.org/TR/xhtml11/DTD/xhtml11.dtd">
 <html>
   ...
 </html>
```

Why Validate?

- A document type is a contract between data producers and consumers
- Validation allows:
  - → a producer to check that he produces what he promised
  - → a consumer to check what the producer sends
  - → a consumer to protect his application
  - → **leaving error detection up to the parser**
  - → simplifying applications (we know where to find relevant information in valid documents)
  - → delivering high-speed XML throughput (once the input is validated, a lot of runtime checks can be avoided)

Document Type Definition (DTD)

- Any element e to be used in the XML dialect needs to be introduced via

<!ELEMENT e *cm*>

<table>
<tr><th>Content model cm</th><th>Valid content</th></tr>
<tr><td>ANY</td><td>arbitrary well-formed XML content</td></tr>
<tr><td>EMPTY</td><td>no child elements allowed (attributes OK)</td></tr>
<tr><td>Reg. exp. over tag names, #PCDATA, and constructors
| , + * ?</td><td>order and occurence of child elements and text content must match the regular expression</td></tr>
</table>

- Example (XHTML 1.0 Strict DTD): <!ELEMENT img EMPTY>

Reg. Exp. in DTD Content Models

Reg. Exp.	**Semantics**
`tagname`	element named `tagname`
`#PCDATA`	text content (parsed character data)
c_1 , c_2	c_1 directly followed by c_2
$c_1 \mid c_2$	c_1 or, alternatively, c_2
c^+	c, one or more times
$c?$	optional c

Example: recipes.xml (fragment)

```
<!ELEMENT recipe (title,ingredient*,preparation,comment?,nutrition)>
<!ELEMENT title (#PCDATA)>
<!ELEMENT ingredient (ingredient*,preparation)?>
<!ELEMENT preparation (step*)>
```

Declaring Attributes

- Using the DTD ATTLIST declaration, validation of XML documents is extended to attributes
- The ATTLIST declaration associates a list of attribute names a_i with their owning element e:

<!ATTLIST e

$$\begin{array}{ccc} a_1 & \tau_1 & d_1 \\ & \dots & \\ a_n & \tau_n & d_n \end{array}$$

>

→ The attribute types τ_i define which values are valid for attributes a_i.

→ The defaults d_i indicate if a_i is required or optional (and, if absent, if a default value should be assumed for a_i).

→ In XML, attributes of an element are unordered. The ATTLIST declaration prescribes no order of attribute usage.

- Via attribute types, control over the valid attribute values can be exercised:

Attribute Type τ_i	Semantics
CDATA	character data (no < but <, ...)
$(v_1 \mid v_2 \mid \ldots \mid v_n)$	enumerated literal values
ID	value is document-wide unique identifier for owner element
IDREF	references an element via its ID attribute

Example: academic.xml

```
<!ELEMENT academic (Firstname, Middlename*, Lastname)>
<!ATTLIST academic
   title (Prof|Dr) #REQUIRED
   team CDATA #IMPLIED
>

 <academic title="Dr" team="WAM"> ... </academic>
```

- Attribute defaulting in DTDs:

Attribute Default d_i	**Semantics**
`#REQUIRED`	element must have attribute a_i
`#IMPLIED`	attribute a_i is optional
v (a value)	attribute a_i is optinal, if absent, default value v for a_i is assumed
`#FIXED` v	attribute a_i is optional, if present, must have value v

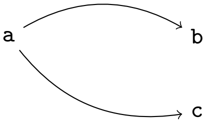
Example: contacts.xml

```
<!ELEMENT contact (name, email+, phone*)>
<!ATTLIST contact
   emailMode (text|xhtml) "text"     <!--send safely-->
>
```

Crossreferencing via ID and IDREF

- Well-formed XML documents essentially describe tree-structured data
- Attributes of type `ID` and `IDREF` may be used to encode graph structures in XML. A validating XML parser can check such a graph encoding for consistent connectivity.
- To establish a directed edge between two XML nodes `a` and `b`:

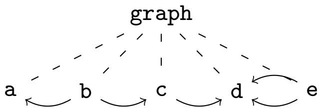
1. attach a unique identifier to node `b` (using an `ID` attribute), then
2. refer to `b` from `a` via this identifier (using an `IDREF` attribute).
3. For an outdegree > 1 (see below), use an `IDREFS` attribute.



Graphs in XML – An Example

Graph.xml

```
<?xml version="1.0"?>
<!DOCTYPE graph [
  <!ELEMENT graph (node+) >
  <!ELEMENT node ANY > <!-- attach arbitrary data to a node -->
  <!ATTLIST node
    id ID #REQUIRED
    edges IDREFS #IMPLIED > <!-- we may have nodes with outdegree 0 -->
]>

<graph>
  <node id="A">a</node>
  <node id="B" edges="A C">b</node>
  <node id="C" edges="D">c</node>
  <node id="D">d</node>
  <node id="E" edges="D D">e</node>
</graph>
```



Example (Character references in “ComicsML”)

ComicsML.dtd (fragment)

```
<!DOCTYPE strip [
  ...
  <!ELEMENT character (#PCDATA) >
  <!ATTLIST character
      id        ID                        #REQUIRED >
  <!ELEMENT bubble (#PCDATA) >
  <!ATTLIST bubble
      speaker   IDREF                     #REQUIRED
      to        IDREFS                    #IMPLIED
      tone      (angry|question|...)      #IMPLIED >
]>
```

Validation results (message generated by Apache's Xerces):

- Setting attribute to some random non-existent character identifier:
  `ID attribute 'yoda' was referenced but never declared`
- Using a non-enumerated value for attribute tone:
  `Attribute 'tone' does not match its defined enumeration list`

Other DTD Features

- **User-defined entities** via `<!ENTITY e d>` declarations (usage: &*e*;)

```
<!ENTITY pam "Pierre-Antoine-Marie">
```

- **Parameter Entities** ("DTD macros") via `<!ENTITY % e d >` (usage: %e;)

```
<!ENTITY ident "ID #REQUIRED">
...
<!ATTLIST character
  id %ident; >
```

- **Conditional sections** in DTDs via `<![INCLUDE[...]]>` and `<![IGNORE[...]]>`

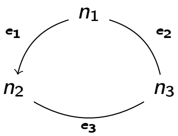
```
<!ENTITY % draft 'INCLUDE' >
<!ENTITY % final 'IGNORE' >

<![%draft;[
<!ELEMENT book (comments*, title, body, supplements?)>
]]>
<![%final;[
<!ELEMENT book (title, body, supplements?)>
]]>
```

A “Real Life” DTD – GraphML

- GraphML[3] has been designed to provide a convenient file format to represent arbitrary graphs
- Graphs (element `graph`) are specified as lists of `nodes` and `edges`
- Edges point from `source` to `target`
- Nodes and edges may be annotated using arbitrary description and data
- Edges may be `directed` (+ attribute `edgedefault` of `graph`)

Graph.xml

```
<graphml>
  <graph edgedefault="undirected">
    <node id="n1"/>
    <node id="n2"/>
    <node id="n3"/>
    <edge id="e1" source="n1" target="n2" directed="true"/>
    <edge id="e2" source="n2" target="n3" directed="false"/>
    <edge id="e3" source="n3" target="n1"/>
  </graph>
</graphml>
```



[3] http://graphml.graphdrawing.org/

GraphML.dtd (main part)

```
<!-- GRAPHML DTD (flat version) =========================================== -->
<!ELEMENT graphml  ((desc)?,(key)*,((data)|(graph))*)>

<!ELEMENT locator EMPTY>
<!ATTLIST locator
          xmlns:xlink   CDATA    #FIXED    "http://www.w3.org/TR/2000/PR-xlink-20001220/"
          xlink:href    CDATA    #REQUIRED
          xlink:type    (simple) #FIXED    "simple">

<!ELEMENT desc (#PCDATA)>

<!ELEMENT graph    ((desc)?,((((data)|(node)|(edge)|(hyperedge))*)|(locator)))>
<!ATTLIST graph
          id          ID                     #IMPLIED
          edgedefault (directed|undirected) #REQUIRED>

<!ELEMENT node   (desc?,(((data|port)*,graph?)|locator))>
<!ATTLIST node
          id        ID      #REQUIRED>

<!ELEMENT port ((desc)?,((data)|(port))*)>
<!ATTLIST port
          name    NMTOKEN  #REQUIRED>

<!ELEMENT edge ((desc)?,(data)*,(graph)?)>
<!ATTLIST edge
          id         ID           #IMPLIED
          source     IDREF        #REQUIRED
          sourceport NMTOKEN      #IMPLIED
          target     IDREF        #REQUIRED
          targetport NMTOKEN      #IMPLIED
          directed   (true|false) #IMPLIED>

<!ELEMENT key (#PCDATA)>
<!ATTLIST key
          id  ID                                                #REQUIRED
          for (graph|node|edge|hyperedge|port|endpoint|all) "all">

<!ELEMENT data  (#PCDATA)>
<!ATTLIST data
          key      IDREF        #REQUIRED
          id       ID           #IMPLIED>
```

Concluding Remarks

- DTD syntax:
  - ✓ **Pro:** compact, easy to understand
  - × **Con:** ?

Concluding Remarks

- DTD syntax:
  - ✓ **Pro:** compact, easy to understand
  - × **Con:** not in XML!
- DTD functionality:
  - × no fine-grained types (everything is character data; what about, *e.g.* integers?)
  - × no further occurence constraints (*e.g.* cardinality of sequences)

→ DTD is a very simple but quite limited type definition language

XML Schema

- With XML Schema[4], W3C provides an XML type definition language that goes beyond the capabilities of the "native" DTD concept:
    - XML Schema descriptions are valid XML documents themselves
    - XML Schema provides a rich set of built-in data types
    - Users can extend this type system via user-defined types
    - XML element (and attribute) types may even be derived by inheritance

XML Schema *vs.* DTDs

→ Why would you consider its XML syntax as an advantage?

[4] http://www.w3.org/TR/xmlschema-0/

Some XML Schema Constructs

- Declaring an element

  ```
  <xsd:element name="author"/>
  ```

  No further typing specified: the `author` element may contain string values only.

- Declaring an element with bounded occurence

  ```
  <xsd:element name="character" minOccurs="0" maxOccurs="unbounded"/>
  ```

  Absence of `minOccurs`/`maxOccurs` implies exactly once.

- Declaring a typed element

  ```
  <xsd:element name="year" type="xsd:date"/>
  ```

  Content of year takes the format YYYY-MM-DD. Other simple types: `string`, `boolean`, `number`, `float`, `duration`, `time`, `AnyURI`, ...

- Simple types are considered **atomic** with respect to XML Schema (e.g., the YYYY part of an xsd:date value has to be extracted by the XML application itself).

- Non-atomic complex types are built from simple types using type constructors.

Declaring sequenced content

```
<xsd:complexType name="Characters">
  <xsd:sequence>
    <xsd:element name="character" minOccurs="1"
                                  maxOccurs="unbounded"/>
  </xsd:sequence>
</xsd:complexType>
<xsd:complexType name="Prolog">
  <xsd:sequence>
    <xsd:element name="series"/>
    <xsd:element name="author"/>
    <xsd:element name="characters" type="Characters"/>
  </xsd:sequence>
</xsd:complexType>
<xsd:element name="prolog" type="Prolog"/>
```

An `xsd:complexType` may be used anonymously (no `name` attribute).

- With attribute `mixed="true"`, an `xsd:complexType` admits **mixed content**.

- New complex types may be **derived** from an existing (base) type.

Deriving a new complex type

```
<xsd:element name="newprolog">
  <xsd:complexType>
    <xsd:complexContent>
      <xsd:extension base="Prolog">
        <xsd:element name="colored" type="xsd:boolean"/>
      </xsd:extension>
    </xsd:complexContent>
  </xsd:complexType>
</xsd:element>
```

- **Attributes** are declared within their owner element.

Declaring attributes

```
<xsd:element name="strip">
  <xsd:attribute name="copyright"/>
  <xsd:attribute name="year" type="xsd:gYear"/> ...
</xsd:element>
```

Other `xsd:attribute` modifiers: `use` (`required`, `optional`, `prohibited`), `fixed`, `default`.

- The validation of an XML document against an XML Schema goes as far as peeking into the **lexical representation** of simple typed values.

Restricting the value space of a simple type (enumeration)

```
<xsd:simpleType name="Car">
  <xsd:restriction base="xsd:string">
    <xsd:enumeration value="Audi"/>
    <xsd:enumeration value="BMW"/>
    <xsd:enumeration value="VW"/>
  </xsd:restriction>
</xsd:simpleType>
```

Restricting the value space of a simple type (regular expression)

```
<xsd:simpleType name="AreaCode">
  <xsd:restriction base="xsd:string">
    <xsd:pattern value="0[0-9]+"/>
    <xsd:minLength value="3"/>
    <xsd:maxLength value="5"/>
  </xsd:restriction>
</xsd:simpleType>
```

- Other **facets**: `length`, `maxInclusive` (upper bound for numeric values)...

Other XML Schema Concepts

- **Fixed** and **default** element content,
- support for **null values**,
- uniqueness constraints, arbitrary **keys** (specified via XPath)
- ...

Intermediate Outline

- Processing XML Documents
- Parsing
    - Two radically different approaches: DOM and SAX
    - Advantages and drawbacks

XML Processing Model

Validation is good

- Validation is better than writing code
- Remember the promise:

  “**you will never have to write a parser again during your lifetime**”

  → instead, you will spend your lifetime trying to encode the right grammar ☺...
- Virtually all XML applications operate on the logical tree view which is provided to them by an XML parser
- An XML parser can be validating or non-validating
- XML parsers are widely available (*e.g.* Apache’s Xerces).
- How is the XML parser supposed to communicate the XML tree structure to the application?

XML Parsers

- Two different approaches:
  1. Parser stores document into a fixed (standard) data structure (*e.g.* DOM)

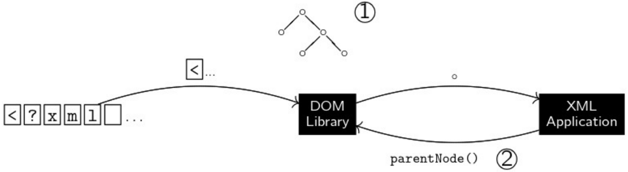
     ```
     parser.parse("foo.xml");
     doc = parser.getDocument();
     ```

  2. Parser triggers events. Does not store! User has to write own code on how to store / process the events triggered by the parser.

Next slides on DOM & SAX by Marc H. Scholl (Uni KN)...

DOM—Document Object Model

- With **DOM**, W3C has defined a **language-** and **platform-neutral** view of XML documents.
- DOM APIs exist for a wide variety of—predominantly object-oriented—programming languages (Java, C++, C, Perl, Python, . . .).
- The DOM design rests on two major concepts:
  1. An **XML Processor** offering a DOM interface parses the XML input document, and constructs the **complete XML document tree** (in-memory).
  2. The **XML application** then issues DOM library calls to **explore** and **manipulate** the XML document, or **generate** new XML documents.



- The DOM approach has some obvious advantages:
  - Once DOM has build the XML tree structure, (tricky) issues of XML grammar and syntactical specifics are void.
  - **Constructing** an XML document using the DOM instead of serializing an XML document manually (using some variation of `print`), ensures **correctness** and **well-formedness**.
    - No missing/non-matching tags, attributes never owned by attributes, ...
  - The DOM can simplify document **manipulation** considerably.
    - Consider transforming

Weather forecast (English)

```xml
<?xml version="1.0"?>
<forecast date="Thu, May 16">
  <condition>sunny</condition>
  <temperature unit="Celsius">23</temperature>
</forecast>
```

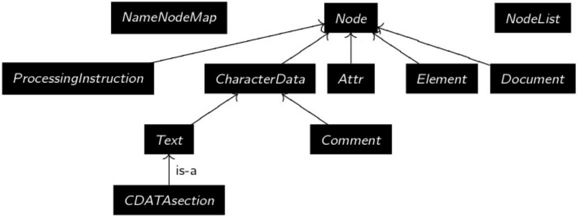
into

Weather forecast (German)

```xml
<?xml version="1.0"?>
<vorhersage datum="Do, 16. Mai">
  <wetterlage>sonnig</wetterlage>
  <temperatur skala="Celsius">23</temperatur>
</vorhersage>
```

DOM Level 1 (Core)

- To operate on XML document trees, DOM Level 1[4] defines an inheritance hierarchy of node objects—and methods to operate on these—as follows (excerpt):



- Character strings (DOM type *DOMString*) are defined to be encoded using UTF-16 (*e.g.*, Java DOM represents type *DOMString* using its `String` type).

[4] `http://www.w3.org/TR/REC-DOM-Level-1/`

- (The complete DOM interface is too large to list here.) Some methods of the principal DOM types *Node* and *Document*:

DOM Type	Method		Comment
Node	*nodeName*	:: *DOMString*	redefined in subclasses, *e.g.*, tag name for *Element*, `"#text"` for *Text* nodes, ...
	parentNode	:: *Node*	
	firstChild	:: *Node*	leftmost child node
	nextSibling	:: *Node*	returns `NULL` for root element or last child or attributes
	childNodes	:: *NodeList*	see below
	attributes	:: *NameNodeMap*	see below
	ownerDocument	:: *Document*	
	replaceChild	:: *Node*	replace new for old node, returns old
Document	*createElement*	:: *Element*	creates element with given tag name
	createComment	:: *Comment*	creates comment with given content
	getElementsByTagName	:: *NodeList*	list of all *Elem* nodes in document order

Some DOM Details

- Creating an element (or attribute) using *createElement* (*createAttribute*) does *not* wire the new node with the XML tree structure yet.

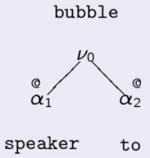
  Call *insertBefore*, *replaceChild*, . . . to wire a node at an explicit position.

- DOM type *NodeList* (node sequence) makes up for the lack of collection datatypes in most programming languages.

  Methods: *length*, *item* (node at specific index position).

- DOM type *NameNodeMap* represents an *association table* (nodes may be accessed by name).

  Example:



Apply method *attributes* to *Element* object ν_0 to obtain this *NameNodeMap*:

name		node
"speaker"	$\mapsto$	α_1
"to"	$\mapsto$	α_2

Methods: *getNamedItem*, *setNamedItem*, . . .

DOM Example Code

- The following slide shows C++ code written against the Xerces C++ DOM API[5].
- The code implements a variant of the *content* :: *Doc* → (*Char*):
  - Function `collect ()` decodes the UTF-16 text content returned by the DOM and prints it to standard output directly (`transcode ()`, `cout`).

N.B.

- A W3C DOM node type named τ is referred to as `DOM_`τ in the Xerces C++ DOM API.
- A W3C DOM property named *foo* is—in line with common object-oriented programming practice—called `getFoo()` here.

[5] `http://xml.apache.org/`

Example: C++/DOM Code

content.cc (1)

```
// Xerces C++ DOM API support
#include <dom/DOM.hpp>
#include <parsers/DOMParser.hpp>

void collect (DOM_NodeList ns)
{
  DOM_Node n;

  for ( unsigned long i = 0;
        i < ns.getLength ();
        i++){
    n = ns.item (i);

    switch (n.getNodeType ()) {
    case DOM_Node::TEXT_NODE:
      cout << n.getNodeValue ().transcode ();
      break;
    case DOM_Node::ELEMENT_NODE:
      collect (n.getChildNodes ());
    }
  }
}
```

content.cc (2)

```

void content (DOM_Document d)
{
  collect (d.getChildNodes ());
}

int main (void)
{
  XMLPlatformUtils::Initialize ();

  DOMParser parser;
  DOM_Document doc;

  parser.parse ("foo.xml");
  doc = parser.getDocument ();

  content (doc);

  return 0;
}
```

Now: Find all occurrences of `Dogbert` speaking (attribute `speaker` of element `bubble`) . . .

dogbert.cc (1)

```
// Xerces C++ DOM API support
#include <dom/DOM.hpp>
#include <parsers/DOMParser.hpp>

void dogbert (DOM_Document d)
{
  DOM_NodeList     bubbles;
  DOM_Node         bubble, speaker;
  DOM_NamedNodeMap attrs;

  bubbles = d.getElementsByTagName ("bubble");

  for (unsigned long i = 0; i < bubbles.getLength (); i++) {
    bubble = bubbles.item (i);

    attrs = bubble.getAttributes ();
    if (attrs != 0)
      if ((speaker = attrs.getNamedItem ("speaker")) != 0)
        if (speaker.getNodeValue ().
              compareString (DOMString ("Dogbert")) == 0)
          cout << "Found Dogbert speaking." << endl;
  }
}
```

dogbert.cc (2)

```
int main (void)
{
  XMLPlatformUtils::Initialize ();

  DOMParser parser;
  DOM_Document doc;

  parser.parse ("foo.xml");
  doc = parser.getDocument ();

  dogbert (doc);

  return 0;
}
```

DOM—A Memory Bottleneck

- The two-step processing approach (① parse and construct XML tree, ② respond to DOM property function calls) enables the DOM to be "**random access**":

  The XML application may explore and update any portion of the XML tree at any time.

- The inherent memory hunger of the DOM may lead to

  1. heavy **swapping** activity
     (partly due to unpredictable memory access patterns, `madvise()` less helpful)
     or
  2. even "`out-of-memory`" failures.
     (The application has to be extremely careful with its own memory management, the very least.)

Numbers

DOM and random node access

Even if the application touches a single element node only, the DOM API has to maintain a data structure that represents the **whole XML input document** (all sizes in kB):[6]

XML size	**DOM process size DSIZ**	$\frac{\texttt{DSIZ}}{\text{XML size}}$	**Comment**
7480	47476	6.3	(Shakespeare's works) many elements containing small text fragments
113904	552104	4.8	(Synthetic eBay data) elements containing relatively large text fragments

[6] The random access nature of the DOM makes it hard to provide a truly "lazy" API implementation.

To remedy the memory hunger of DOM-based processing . . .

- Try to **preprocess** (*i.e.*, filter) the input XML document to reduce its overall size.
  - Use an XPath/XSLT processor to preselect *interesting* document regions,
  - *no updates* to the input XML document are possible then,
  - make sure the XPath/XSLT processor is *not* implemented on top of the DOM.

Or

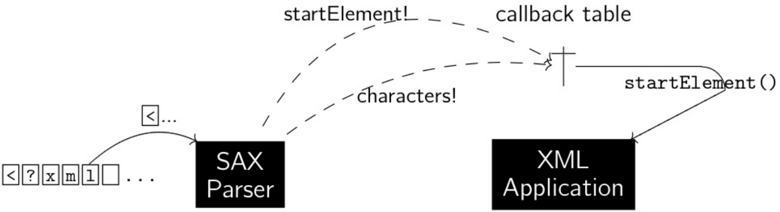
- Use a **completely different** approach to XML processing (→ **SAX**).

SAX—Simple API for XML

- **SAX**[7] (**Simple API for XML**) is, unlike DOM, *not* a W3C standard, but has been developed jointly by members of the `XML-DEV` mailing list (*ca.* 1998).
- SAX processors use **constant space**, regardless of the XML input document size.
  - Communication between the SAX processor and the backend XML application does *not* involve an intermediate tree data structure.
  - Instead, the **SAX parser sends events** to the application whenever a certain piece of XML text has been recognized (*i.e.*, parsed).
  - The **backend acts on/ignores events** by populating a **callback function table**.

[7] `http://www.saxproject.org/`

Sketch of SAX's mode of operations



- A SAX processor reads its input document **sequentially** and **once** only.
- No memory of what the parser has seen so far is retained while parsing. As soon as a *significant bit of XML text* has been recognized, an **event** is sent.
- The application is able to act on events **in parallel** with the parsing progress.

SAX Events

- To meet the constant memory space requirement, SAX reports **fine-grained parsing events** for a document:

Event	**. . . reported when seen**	**Parameters sent**
startDocument	`<?xml...?>`[8]	
endDocument	⟨EOF⟩	
startElement	<*t* a_1=v_1 . . . a_n=v_n>	$t, (a_1, v_1), \ldots, (a_n, v_n)$
endElement	</*t*>	*t*
characters	*text content*	Unicode buffer ptr, length
comment	<!--*c*-->	*c*
processingInstruction	<?*t* *pi*?>	*t*, *pi*
	⋮	

[8]**N.B.**: Event *startDocument* is sent even if the optional XML text declaration should be missing.

dilbert.xml

```
<?xml encoding="utf-8"?> ⋆1
<bubbles> ⋆2
  <!-- Dilbert looks stunned --> ⋆3
  <bubble speaker="phb" to="dilbert"> ⋆4
    Tell the truth, but do it in your usual engineering way
    so that no one understands you. ⋆5
  </bubble> ⋆6
</bubbles> ⋆7 ⋆8
```

Event[9] [10]		Parameters sent
$\star_1$	*startDocument*	
$\star_2$	*startElement*	t = "bubbles"
$\star_3$	*comment*	c = "␣Dilbert looks stunned␣"
$\star_4$	*startElement*	t = "bubble", ("speaker","phb"), ("to","dilbert")
$\star_5$	*characters*	buf = "Tell the...understands you.", $len = 99$
$\star_6$	*endElement*	t = "bubble"
$\star_7$	*endElement*	t = "bubbles"
$\star_8$	*endDocument*	

[9] Events are reported in **document reading order** $\star_1, \star_2, \ldots, \star_8$.

[10] **N.B.**: Some events suppressed (white space).

SAX Callbacks

- To provide an efficient and tight **coupling** between the SAX **frontend** and the application **backend**, the SAX API employs **function callbacks**:[11]
  1. Before parsing starts, the application **registers function references** in a table in which each event has its own slot:

Event	*Callback*
⋮	
startElement	?
endElement	?
⋮	

$\longrightarrow$ *SAX register*(*startElement*, `startElement ()`) *SAX register*(*endElement*, `endElement ()`)

Event	*Callback*
⋮	
startElement	`startElement ()`
endElement	`endElement ()`
⋮	

  2. The application alone decides on the implementation of the functions it registers with the SAX parser.
  3. **Reporting an event** $\star_i$ then amounts to call the function (with parameters) registered in the appropriate table slot.

[11] Much like in event-based GUI libraries.

Java SAX API

In Java, populating the callback table is done via implementation of the SAX `ContentHandler` interface: a `ContentHandler` object represents the callback table, its methods (*e.g.*, `public void endDocument ()`) represent the table slots.

Example: Reimplement *content.cc* shown earlier for DOM (find all XML text nodes and print their content) using SAX (pseudo code):

```
content (File f)

// register the callback,
// we ignore all other events
SAXregister (characters, printText);
SAXparse (f);
return;
```

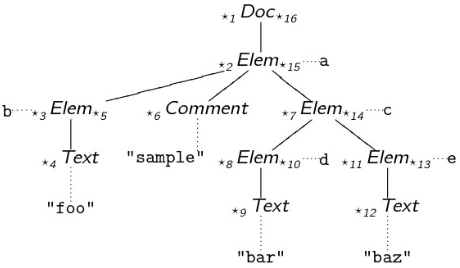
```
printText ((Unicode) buf, Int len)

Int i;

foreach i ∈ 1 ... len do
    print (buf[i]);
return;
```

SAX and the XML Tree Structure

- Looking closer, the **order** of SAX events reported for a document is determined by a **preorder traversal** of its document tree[12]:

Sample XML document

```
⋆1
<a>⋆2
   <b>⋆3 foo⋆4 </b>⋆5
   <!--sample-->⋆6
   <c>⋆7
     <d>⋆8 bar⋆9 </d>⋆10
     <e>⋆11 baz⋆12 </e>⋆13
   </c>⋆14
</a>⋆15 ⋆16
```



N.B.: An *Elem* [*Doc*] node is associated with two SAX events, namely *startElement* and *endElement* [*startDocument*, *endDocument*].

[12] Sequences of sibling *Char* nodes have been collapsed into a single *Text* node.

Challenge

- This **left-first depth-first** order of SAX events is well-defined, but appears to make it hard to answer certain queries about an XML document tree.

✎ Collect all direct children nodes of an *Elem* node.

In the example on the previous slide, suppose your application has just received the *startElement*($t =$ `"a"`) event $\star_2$ (*i.e.*, the parser has just parsed the opening element tag `<a>`).

With the remaining events $\star_3 \ldots \star_{16}$ still to arrive, can your code detect all the immediate children of *Elem* node `a` (*i.e.*, *Elem* nodes `b` and `c` as well as the *Comment* node)?

The previous question can be answered more generally:

> *SAX events are sufficient to* **rebuild the complete XML document tree** *inside the application. (Even if we most likely don't want to.)*

SAX-based tree rebuilding strategy (sketch):

1. [*startDocument*]
   Initialize a **stack** S of **node IDs** (*e.g.* $\in \mathbb{Z}$). **Push** first ID for this node.
2. [*startElement*]
   Assign a **new ID** for this node. **Push** the ID onto S.[13]
3. [*characters*, *comment*, ...]
   Simply assign a new node ID.
4. [*endElement*, *endDocument*]
   Pop S (no new node created).

Invariant: The **top of** S holds the identifier of the current **parent node**.

[13] In callbacks ② and ③ we might wish to store further node details in a table or similar summary data structure.

Final Remarks on SAX

- For an XML document fragment shown on the left, SAX might actually report the events indicated on the right:

XML fragment

```
<affiliation>
  AT&amp;T Labs
</affiliation>
```

XML + SAX events

```
<affiliation>★1
  AT★2&amp;★3T Labs
★4</affiliation>★5
```

$\star_1$	*startElement*(`affiliation`)
$\star_2$	*characters*(`"\n␣␣AT"`, 5)
$\star_3$	*characters*(`"&"`, 1)
$\star_4$	*characters*(`"T␣Labs\n"`, 7)
$\star_5$	*endElement*(`affiliation`)

White space is reported.

Multiple *characters* **events** may be sent for text content (although adjacent).
(Often SAX parsers break text on entities, but may even report each character on its own.)

Concluding Remarks

We have seen:

- Motivation for XML (where XML originates from and what it is aimed for)
- How the XML meta-language works
- What is new/important with XML: standard, independence from processors, well-formed documents can be processed as trees, users may agree on a dialect and save coding effort, they can exchange valid documents and the schemas...
- How to define your own XML dialect (using DTD or XML Schema, but other schema languages exist, e.g. Relax NG)
- How/when to use the 2 different kinds of XML parsers (DOM, SAX)

→ Welcome to the world of XML!