LPFML: A W3C XML Schema for Linear and Integer Programming

Robert Fourer
Northwestern University
4er@iems.northwestern.edu

Leonardo Lopes
University of Arizona
leo@sie.arizona.edu

Kipp Martin
University of Chicago
kipp.martin@gsb.uchicago.edu

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OUTLINE

1. Introduction and motivation

2. Model versus Instance

3. Why XML?

4. The LPFML Schema

5. Compression

6. The libraries

7. Testing under loosely and tightly coupled scenarios

8. The license
There is a proliferation of modeling languages and solvers

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Consequence: a lot of drivers are needed for every modeling language to talk to every solver
It would be nice to have an instance representation language.
A MODEL

set PROD;  # products
set DEP;   # processing departments

param hours {DEP};   # time available in each department
param rate {DEP,PROD}; # hours used in each dept per product unit made
param profit {PROD};  # profit per unit of each product made

var Make {PROD} >= 0;   # number of units of each product to be made

maximize TotalProfit:
   sum {j in PROD} profit[j] * Make[j];

subject to HoursAvailable {i in DEP}:
   sum {j in PROD} rate[i,j] * Make[j] <= hours[i];

This is a model. It is symbolic, general, concise, and understandable (Fourer, 1983).
DATA

param: PROD: profit :=
    std  10
    del  9 ;

param: DEP: hours :=
    cutanddye  630
    sewing     600
    finishing  708
    inspectandpack 135 ;

param: rate: std del :=
    cutanddye  0.7  1.0
    sewing     0.5  0.8333
    finishing  1.0  0.6667
    inspectandpack 0.1  0.25 ;
MODEL + DATA = INSTANCE

maximize TotalProfit:
10*Make[‘std’] + 9*Make[‘del’];

subject to HoursAvailable[‘cutanddye’]:
0.7*Make[‘std’] + Make[‘del’] <= 630;

subject to HoursAvailable[‘sewing’]:
0.5*Make[‘std’] + 0.8333*Make[‘del’] <= 600;

subject to HoursAvailable[‘finishing’]:
Make[‘std’] + 0.6667*Make[‘del’] <= 708;

subject to HoursAvailable[‘inspectandpack’]:
0.1*Make[‘std’] + 0.25*Make[‘del’] <= 135;

**Objective**: represent a model instance using XML.
Why not MPS?

NAME PRODMIX
ROWS
  N  TPROFIT
  L  HRSCUT
  L  HRSSEW
  L  HRSFIN
  L  HRSINS
COLUMNS
  MAKESTD  TPROFIT  10
  MAKESTD  HRSCUT  0.7  HRSSEW  0.5
  MAKESTD  HRSFIN  1  HRSINS  0.1
  MAKEDEL  TPROFIT  9
  MAKEDEL  HRSCUT  1  HRSSEW  0.8333
  MAKEDEL  HRSFIN  0.6667  HRSINS  0.25
RHS
  RHS1  HRSCUT  630
  RHS1  HRSSEW  600
  RHS1  HRSFIN  708
  RHS1  HRSINS  135
ENDATA
The Case for XML

1. Validation against a schema provides for error checking

2. Validation against a schema promotes stability of a standard

3. The schema can restrict data values to appropriate types, e.g. row names to `string`, indices to `integer`, coefficients to `double`

4. The schema can define keys to insure, for example, no row or column name is used more than once.

5. The schema can be extended to include new constraint types or solver directives

6. There is a lot of open source software to make parsing easy.
1. When instances are stored in XML format, optimization technology solutions are more readily integrated into broader IT infrastructures

2. XML is used for Web Services – important for distributed computing

3. The XML format lends itself well to compression – more on this later

4. The XML format can be combined with other technologies, e.g. XSLT to present results in human readable formats

5. Encryption standards are emerging for XML – possibly important in a commercial setting.
XML Concepts

XML (Extensible Markup Language) – an XML file contains both data and Markup (Elements (tags) and Attributes)

The tags are organized in a tree like structure. The closing tag of a child element preceding the closing tag of its parent.

<rows>
  <row rowName="cutanddye" rowUB="630"/>
  <row rowName="sewing" rowUB="600"/>
  <row rowName="finishing" rowUB="708"/>
  <row rowName="inspectandpack" rowUB="135"/>
</rows>
XML Concepts

Key idea – a **schema**. Similar to the concept of a class in object orient programming.

We need a schema to represent an instance.
<xs:element name="rows">
  <xs:complexType>
    <xs:sequence>
      <xs:element name="row" minOccurs="0" maxOccurs="unbounded">
        <xs:complexType>
          <xs:attribute name="rowName" type="xs:string" use="optional"/>
          <xs:attribute name="rowUB" type="xs:double" use="optional"/>
          <xs:attribute name="rowLB" type="xs:double" use="optional"/>
          <xs:attribute name="mult" type="xs:int" use="optional"/>
        </xs:complexType>
      </xs:element>
    </xs:sequence>
  </xs:complexType>
</xs:element>
XML Concepts – a Row Object

<rows>
    <row rowName="cutanddye" rowUB="630"/>
    <row rowName="sewing" rowUB="600"/>
    <row rowName="finishing" rowUB="708"/>
    <row rowName="inspectandpack" rowUB="135"/>
</rows>
LPFML Schema

1. Information about the instance
LPFML Schema

2. The instance data
2. The instance data (rows and columns)

```xml
<rows>
    <row rowName="HoursAvailable[‘cutanddye’]" rowUB="630"/>
    <row rowName="HoursAvailable[‘sewing’]" rowUB="600"/>
    <row rowName="HoursAvailable[‘finishing’]" rowUB="708"/>
    <row rowName="HoursAvailable[‘inspectandpack’]" rowUB="135"/>
</rows>

<columns>
    <col objVal="10" colName="Make[‘std’]" colType="C" colLB="0.0"/>
    <col objVal="9" colName="Make[‘del’]" colType="C" colLB="0.0"/>
</columns>
```
LPFML Schema

2. The instance data (the A matrix)
LPFML Schema

2. The instance data (the A matrix)

```
<sparseMatrix>
  <pntANonz>
    <el>2</el><el>4</el>
  </pntANonz>
  <rowIdx>
    <el>1</el><el>2</el> <el>0</el><el>1</el>
  </rowIdx>
  <nonz>
    <el>1</el><el>2</el> <el>-3</el><el>4</el>
  </nonz>
</sparseMatrix>
```

```
0  -3
1   4
2   0
```
3. Information about the solution
Compression – Base 64

\[
\begin{align*}
&<\text{nonz}>
& <\text{el}>.7</el><\text{el}>.5</el>
& <\text{el}>1.0</el><\text{el}>0.1</el>
& <\text{el}>1.0</el><\text{el}>0.8333</el>
& <\text{el}>0.6667</el><\text{el}>0.25</el>
& </nonz>

<nonz>
<base64BinaryData numericType="double" sizeOf="8">
ZmZmZmZm5j8AAAAAAADgPwAAAAAAAAPA/mpmZmZmZuT8AAAAAAAADwP7U3+MJkquo/S8gHPZtV5T8AAAAAAAADQPw==</base64BinaryData>
</nonz>
Compression – Structural

Min $x_1 + x_2 + x_3 + x_4 + x_5 + x_6$

s.t.

$x_1 + x_2$ $\geq 1$
$x_1 + x_2 + x_6$ $\geq 1$
$+ x_3 + x_4$ $\geq 1$
$+ x_3 + x_4 + x_5$ $\geq 1$
$+ x_4 + x_5 + x_6$ $\geq 1$
$+ x_2 + x_5 + x_6$ $\geq 1$

<nonz><el mult="16">1</el></nonz>

<rowIdx>
<el>0</el><el>1</el><el>0</el><el>0</el><el>1</el><el>1</el>
<el>5</el><el>2</el><el>3</el><el>5</el><el>1</el>
<el mult="3" incr="1">2</el>
<el mult="3" incr="1">3</el>
<el>1</el><el>4</el><el>5</el><el>1</el><el>4</el><el>5</el>
</rowIdx>
The LPFML Libraries

A set of open source libraries for reading and writing LP instances in XML format.

**Objective**: hide all of the parsing and writing of XML in the library

**Corollary**: library users should only have to deal with optimization concepts such as objectives, constraints, etc.

**Objective**: allow changes and extensions to the schema without any solver or modeling language code to be rewritten
The LPFML Libraries - Parsing

Current C++ library based on SAX (Simple API for XML).

Our libraries use the Apache Xerces libraries.

Key classes are FMLHandler and FMLParser.

FMLHandler inherits from SAX2 ContentHandler.

The FMLHandler “gets the data” from the XML file when elements and attributes are read.
The LPFML Libraries - Parsing

FMLParser is solver independent. It instantiates an FMLHandler Object and passes to the constructor an FMLParser object.

```
handler = new FMLHandler(this, encodingName, expandNamespaces)
```

Provides numerous “dummy” methods:

- `onVariableCount()`
- `onObjectiveSense()`
- `onAMatrix()`
- `etc`

The handler object calls these methods when reading elements and attributes.
The LPFML Libraries - Parsing

It is up to the user to implement their own solver specific FMLParser class. For example, in FMLLINDOParser we have

```cpp
void FMLLINDOParser::onObjectiveSense(const bool isMin)
{
    if(isMin) nDir_ = LS_MIN;
    else nDir_ = LS_MAX;
    // make sure objConstant_ gets initialized
    objConstant_ = 0.;
}
```

There is no XML involved in writing the solver specific FMLParser that inherits from the FMLParser. It is hidden from the solver developer.
The LPFML Libraries - Parsing

Current open source FMLParses include:

OSI/COIN

LINDO

FORTMP

lp_solve (coming soon)

OSI/COIN – low level API for solvers. If a solver supports OSI/COIN they can read FML. For example, CLP and GLPK.
The LPFML Libraries - Parsing

- FMLParser
  - FMLHandler
    + FMLHandler()
    + characters()
    + endDocument()
    + startElement()
    + error()
    + fatalError()
    + getTag()
    + ignoreWhitespace()
    + processColumn()
    + processE()
    + processRow()
    + processSolutionValues()
    + processingInstruction()
    + startDocument()
    + startElement()
    + warning()
    + ~FMLHandler()

FMLParser is the main class the solver developer deals with. FMLCINParser adds only the convenience method onCINMatrix().

FMLCINParser
- FMLCINParser
  + FMLCINParser()
  + onAMatrix()
  + onCINMatrix()
  + onConstraintCount()
  + onVariablesCount()
  + ~FMLCINParser()

FMLAMPLParser
- FMLAMPLParser
  + FMLAMPLParser()
  + onConstraintCount()
  + onDualSolution()
  + onMaximalSolution()
  + onVariableCount()
  # parseToDense()
  + write()
  + ~FMLAMPLParser()

FMLINDOParser
- FMLINDOParser
  + FMLINDOParser()
  + onConstraintCount()
  + onConstraints()
  + onPrimalSolution()
  + onObjectiveConstant()
  + onObjectiveSense()
  + onSource()
  + onVariableCount()
  + onVariables()
  + solve()
  + write()
  + ~FMLINDOParser()

FMLOSIParser
- FMLOSIParser
  + FMLOSIParser()
  + getSolver()
  + onConstraintCount()
  + onConstraints()
  + onObjectiveConstant()
  + onObjectiveSense()
  + onSource()
  + onVariableCount()
  + onVariables()
  + solve()
  + write()
  + ~FMLOSIParser()

FMLHandler does all the XML parsing. A solver developer should not have to deal with this class.

These classes are examples of what an user of the library typically needs to do inherit from FMLParser and provide implementations of the on* methods specific to the solver.
The LPFML Libraries - Writing

**FMLLPToXML**
- + FMLLPToXML()
  - # createBase64Tag()
  - # createBase64Tag()
  - + createDOM()
  - # createLPDataSection()
  - # createLPDescriptionSection()
  - + setAMatrix()
  - + setAMatrix()
  - + setAMatrix()
  - + setColumns()
  - + setColumns()
  - + setColumns()
  - + setLPDescription()
  - + setLPDescription()
  - + setRows()
  - + setRows()
  - + setRows()
  - + setlinearProgramSolution()
  - + setlinearProgramSolution()
  - + useBase64()
  - + useCompress()
  - + write()
  - + ~FMLLPToXML()

**FMLCOINMPSToXML**
- + FMLCOINMPSToXML()
  - + writelinearProgramData()
  - + writelinearProgramDescription()
  - + writelinearProgramFinish()
  - + writelinearProgramSolution()
  - + ~FMLCOINMPSToXML()

These classes use the functionality in FMLLPToXML and the functionality in their respective libraries to convert MPS files to LPFML files.

**FMLLINDOToXML**
- + FMLLINDOToXML()
  - + writelinearProgramData()
  - + writelinearProgramDescription()
  - + writelinearProgramFinish()
  - + writelinearProgramSolution()
  - + ~FMLLINDOToXML()
Basic scenarios:

1. Tightly coupled scenario where modeling system and solver communicate directly with each other on same machine. Performance important here.

2. Loosely coupled environments where modeling system and solver on different machines. File size important here.

3. Pre and post-processing environments. Flexibility key here.
Scenario – Pre and Post Processing
Scenario – Pre and Post Processing

**Linear Program Solution**

<table>
<thead>
<tr>
<th>PRIMAL SOLUTION</th>
<th>DUAL SOLUTION</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Variable</strong></td>
<td><strong>Constraint</strong></td>
</tr>
<tr>
<td>Make ['std']</td>
<td>HoursAvailable['cutanddye']</td>
</tr>
<tr>
<td>Make ['del']</td>
<td>HoursAvailable['sewing']</td>
</tr>
<tr>
<td></td>
<td>HoursAvailable['finishing']</td>
</tr>
<tr>
<td></td>
<td>HoursAvailable['inspectandpack']</td>
</tr>
<tr>
<td>Value</td>
<td>Dual Value</td>
</tr>
<tr>
<td>539.984</td>
<td>4.37457</td>
</tr>
<tr>
<td>252.011</td>
<td>6.9378</td>
</tr>
</tbody>
</table>
Conclusion and Extension

1. The libraries are open source. See http://gsbkip.chicagogsb.edu/fml/fml.html

2. Libraries licensed under a non-copyleft license

3. Obvious extensions in the linear area include networks, SOS, quadratic, and stochastic programming.

4. For more general extensions into nonlinear and optimization services framework see Jun Ma (SB16.4), “A Unified XML-Based Framework for Optimization Services.”