The OSInstance Application Programming Interface for Optimization Problem Instances

Robert Fourer, Jun Ma

Industrial Engineering & Management Sciences
Northwestern University

[4er,maj]@iems.northwestern.edu

Kipp Martin

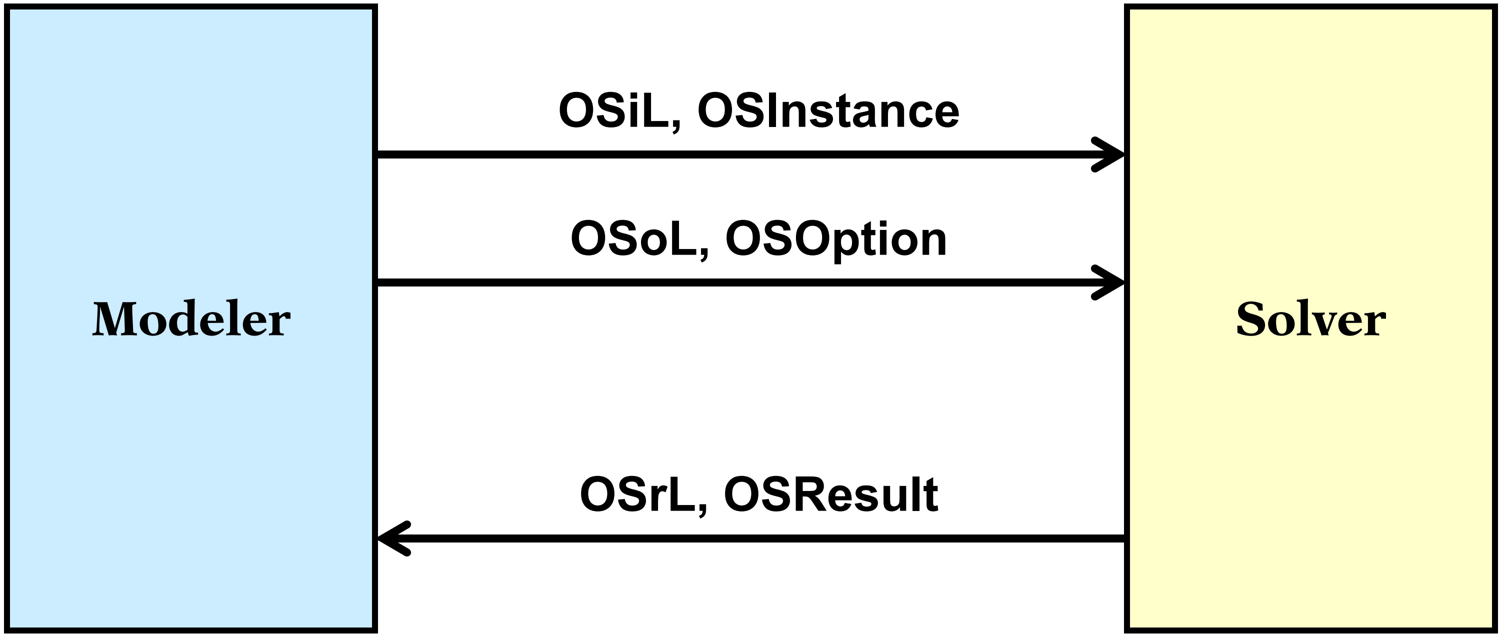
Graduate School of Business
University of Chicago

kmartin@gsb.uchicago.edu

INFORMS Annual Meeting

Pittsburgh — Wednesday, November 8, 2006 — WA02.1

Quick Overview



XML text files

- ➢ OSiL, OSoL, OSrL

In-memory data structures

- ➢ OSInstance, OSOption, OSResult

Aspects of the Interface

Motivation

- For any standard format
- For an XML-based format

Text files

- XML schema
- OSiL example
- Compression
- Extensions

In-memory data structures

- Objects and methods
- Writing a generator
- Translating from a modeling language

Motivation

XML Means “Tagged” Text Files . . .

Example: html for a popular home page

```
<html><head><meta http-equiv="content-type" content="text/html;
charset=UTF-8"><title>Google</title><style><!--
body,td,a,p,.h{font-family:arial,sans-serif;}
.h{font-size: 20px;}
.q{text-decoration:none; color:#0000cc;}
//-->
</style>
</head><body bgcolor=#ffffff text=#000000 link=#0000cc
vlink=#551a8b alink=#ff0000 onLoad=sf()><center><table border=0
cellspacing=0 cellpadding=0><tr><td><img src="/images/logo.gif"
width=276 height=110 alt="Google"></td></tr></table><br>
.......
<font size=-2>&copy;2003 Google - Searching 3,307,998,701 web
pages</font></p></center></body></html>
```

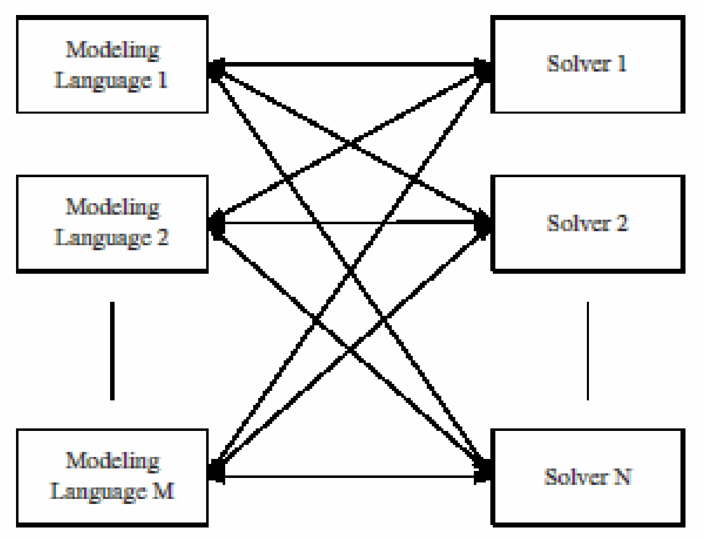
. . . a collection of XML tags is designed for a special purpose

. . . by use of a schema written itself in XML

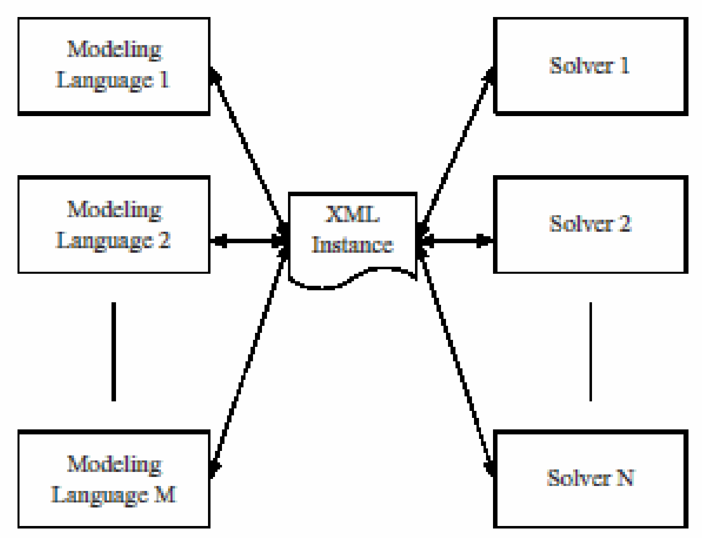
Motivation

Advantage of any standard

MN drivers
without a standard



M + N drivers
with a standard



Motivation

Advantages of an XML Standard

Specifying it

- Unambiguous definition via a *schema*
- Provision for *keys* and *data typing*
- Well-defined expansion to new *name spaces*

Working with it

- Parsing and validation via standard *utilities*
- Amenability to *compression* and *encryption*
- Transformation and display via XSLT *style sheets*
- Compatibility with *web services*

Motivation

What about “MPS Form”?

Weaknesses

- Standard only for LP and MIP, not for
  nonlinear, network, complementarity, logical, . . .
- Standard not uniform (especially for SP extension)
- Verbose ASCII form, with much repetition of names
- Limited precision for some numerical values

Used for

- Collections of (mostly anonymous) test problems
- Bug reports to solver vendors

Not used for

- **Communication between modeling systems and solvers**

Text files

Text from the OSiL Schema

```
<xs:complexType name="Variables">
  <xs:sequence>
    <xs:element name="var" type="Variable" maxOccurs="unbounded"/>
  </xs:sequence>
  <xs:attribute name="number" type="xs:positiveInteger" use="required"/>
</xs:complexType>
```

```
<xs:complexType name="Variable">
  <xs:attribute name="name" type="xs:string" use="optional"/>
  <xs:attribute name="init" type="xs:string" use="optional"/>
  <xs:attribute name="type" use="optional" default="C">
  <xs:simpleType>
    <xs:restriction base="xs:string">
      <xs:enumeration value="C"/>
      <xs:enumeration value="B"/>
      <xs:enumeration value="I"/>
      <xs:enumeration value="S"/>
    </xs:restriction>
  </xs:simpleType>
  </xs:attribute>
  <xs:attribute name="lb" type="xs:double" use="optional" default="0"/>
  <xs:attribute name="ub" type="xs:double" use="optional" default="INF"/>
</xs:complexType>
```

Text files

Example: A Problem Instance (in AMPL)

```
ampl: expand _var;

Coefficients of x[0]:
        Con1  1 + nonlinear
        Con2  7 + nonlinear
        Obj   0 + nonlinear

Coefficients of x[1]:
        Con1  0 + nonlinear
        Con2  5 + nonlinear
        Obj   9 + nonlinear

ampl: expand _obj;

minimize Obj:
        (1 - x[0])^2 + 100*(x[1] - x[0]^2)^2 + 9*x[1];

ampl: expand _con;

subject to Con1:
        10*x[0]^2 + 11*x[1]^2 + 3*x[0]*x[1] + x[0] <= 10;

subject to Con2:
        log(x[0]*x[1]) + 7*x[0] + 5*x[1] >= 10;
```

Text files

Example in OSiL

```
<instanceHeader>
   <name>Modified Rosenbrock</name>
   <source>Computing Journal3:175-184, 1960</source>
   <description>Rosenbrock problem with constraints</description>
</instanceHeader>

<variables number="2">
   <var lb="0" name="x0" type="C"/>
   <var lb="0" name="x1" type="C"/>
</variables>

<objectives number="1">
   <obj maxOrMin="min" name="minCost" numberOfObjCoef="1">
      <coef idx="1">9</coef>
   </obj>
</objectives>

<constraints number="2">
   <con ub="10.0"/>
   <con lb="10.0"/>
</constraints>
```

Text files

Example in OSiL *(continued)*

```
<linearConstraintCoefficients numberOfValues="3">
   <start>
      <el>0</el>
      <el>1</el>
      <el>3</el>
   </start>
   <rowIdx>
      <el>0</el>
      <el>1</el>
      <el>1</el>
   </rowIdx>
   <value>
      <el>1.0</el>
      <el>7.0</el>
      <el>5.0</el>
   </value>
</linearConstraintCoefficients>

<quadraticCoefficients numberOfQPTerms="3">
   <qpTerm idx="0" idxOne="0" idxTwo="0" coef="10"/>
   <qpTerm idx="0" idxOne="1" idxTwo="1" coef="11"/>
   <qpTerm idx="0" idxOne="0" idxTwo="1" coef="3"/>
</quadraticCoefficients>
```

Text files

Example in OSiL *(continued)*

```
<nl idx="-1">
   <plus>
      <power>
         <minus>
            <number type="real" value="1.0"/>
            <variable coef="1.0" idx="1"/>
         </minus>
         <number type="real" value="2.0"/>
      </power>
      <times>
         <power>
            <minus>
               <variable coef="1.0" idx="0"/>
               <power>
                  <variable coef="1.0" idx="1"/>
                  <number type="real" value="2.0"/>
               </power>
            </minus>
            <number type="real" value="2.0"/>
         </power>
         <number type="real" value="100"/>
      </times>
   </plus>
</nl>
```

Text files

Example in OSiL *(continued)*

```
<nl idx="1">
   <ln>
      <times>
         <variable idx="0"/>
         <variable idx="1"/>
      </times>
   </ln>
</nl>
```

Text files

Compression

Specific to OSiL

- Collapse sequences of row/column numbers
- Collapse repeated element values
- Encode portions using base-64 datatype

General for XML

- Compression schemes designed for XML files

Comparisons

- XML base-64 < MPS
- XML with multiple values collapsed < 2 × MPS
- Compressed XML < Compressed MPS

Other Features in OSiL . . .

In current specification

- Real-time data
- Functions defined by the user
- Logical / combinatorial expressions (or, if, all-different)

In process of design

- Stochastic programming / optimization under uncertainty
- Complementarity constraints
- Semidefinite / cone programming

In-Memory Data Structures

OSInstance object class

- Parallels the OSiL schema
- complexType in schema ←→ class in OSInstance
- attributes / children of an element ←→ members of a class
- choices / sequences in the schema arrays ←→ array members

OS expression tree

- Parallels the *nonlinear* part of the OSiL schema
- Designed to avoid lengthy "switch" statements

Creating an OSInstance

- Writing a generator
- Translating from AMPL

. . . ***similar handling of OSOption, OSResult***

Creating a Local OSInstance

Outline

```
#include "OSInstance.h"
#include "OSiLWriter.h"
#include "OSParameters.h"
#include "OSNlNode.h"
#include "LindoSolver.h"
#include <vector>
using namespace std;

int main(){
   try{
      OSInstance *osinstance;
      osinstance = new OSInstance();
      osinstance->setInstanceSource("LINDO samples directory");
      osinstance->setInstanceDescription("Simple nonlinear");
      ...
   }
   catch(const ErrorClass& eclass){
      cout << eclass.errormsg << endl;
   }
}
```

Data Structures

Creating a Local OSInstance *(cont'd)*

Variables

- `addVariable(int index, string name, double lowerBound, double upperBound, char type, double init, string initString);`
- `addVariables(...)`

```
osinstance->setVariableNumber(2);

osinstance->addVariable(0, "x0", -100, 100, 'C', OSNAN, "");
osinstance->addVariable(1, "x1", 0, 1, 'B', OSNAN, "");
```

Creating a Local OSInstance *(cont'd)*

Objective

- `bool addObjective(int index, string name, string maxOrMin, double constant, double weight, SparseVector* objectiveCoefficients);`

```
osinstance->setObjectiveNumber(1);

SparseVector *objcoeff;
objcoeff = new SparseVector(1);
objcoeff->indexes = new int[1];
objcoeff->values = new double[1];
objcoeff->indexes[0] = 1;
objcoeff->values[0] = .4;

osinstance->addObjective
   (-1, "objfunction", "max", 0.0, 1.0, objcoeff);
```

Data Structures

Creating a Local OSInstance *(cont'd)*

Constraints

- `bool addConstraint(int index, string name, double lowerBound, double upperBound, double constant);`
- `bool addConstraints(...)`

```
osinstance->setConstraintNumber(6);

osinstance->addConstraint(0, "row0", -OSINFINITY, 4, 0);
osinstance->addConstraint(1, "row1", -OSINFINITY, 6, 0);
osinstance->addConstraint(2, "row2", -OSINFINITY, 0, 0);
osinstance->addConstraint(3, "row3", 0 , OSINFINITY, 0);
osinstance->addConstraint(4, "row4", -OSINFINITY, 0, 0);
osinstance->addConstraint(5, "row5", -OSINFINITY, 0, 0);
```

Creating a Local OSInstance *(cont’d)*

Constraint coefficients

- `bool setLinearConstraintCoefficients(int numberOfValues, bool isColumnMajor, double* values, int valuesBegin, int valuesEnd, int* indexes, int indexesBegin, int indexesEnd, int* starts, int startsBegin, int startsEnd);`

```
double *values = new double[ 3];
int *indexes = new int[ 3];
int *starts = new int[ 3];
values[ 0] = 1.0;
values[ 1] = 1.0;
values[ 2] = 1.0;
indexes[ 0] = 0;
indexes[ 1] = 0;
indexes[ 2] = 1;
starts[ 0] = 0;
starts[ 1] = 2;
starts[ 2] = 3;

osinstance->setLinearConstraintCoefficients
   (3, true, values, 0, 2, indexes, 0, 2, starts, 0, 2);
```

Data Structures

Creating a Local OSInstance *(cont’d)*

Nonlinear expression setup

```
osinstance->instanceData
   ->nonlinearExpressions->numberOfNonlinearExpressions = 6;

osinstance->instanceData->nonlinearExpressions->nl = new Nl*[6];

OSnLNode *nlNodePoint;
OSnLNodeVariable *nlNodeVariablePoint;
OSnLNodeNumber *nlNodeNumberPoint;
OSnLNodeMax *nlNodeMaxPoint;

std::vector<OSnLNode*> nlNodeVec;
```

Data Structures

Creating a Local OSInstance *(cont'd)*

generate cos(x_2+1) in constraint 3

```
osinstance->instanceData->nonlinearExpressions->nl[0] = new Nl();
osinstance->instanceData->nonlinearExpressions->nl[0]->idx = 3;
osinstance->instanceData->nonlinearExpressions->nl[0]
   ->osExpressionTree = new OSExpressionTree();

nlNodeVariablePoint = new OSnLNodeVariable();
nlNodeVariablePoint->idx=2;
nlNodeVec.push_back(nlNodeVariablePoint);

nlNodeNumberPoint = new OSnLNodeNumber();
nlNodeNumberPoint->value = 1.0;
nlNodeVec.push_back(nlNodeNumberPoint);

nlNodePoint = new OSnLNodePlus();
nlNodeVec.push_back(nlNodePoint);

nlNodePoint = new OSnLNodeCos();
nlNodeVec.push_back(nlNodePoint);

osinstance->instanceData->nonlinearExpressions->nl[ 0]
   ->osExpressionTree->m_treeRoot =
      nlNodeVec[0]->createExpressionTreeFromPostfix(nlNodeVec);
```

Data Structures

Using a Local OSInstance

Writing OSiL to solve remotely

```
OSiLWriter *osilwriter;
osilwriter = new OSiLWriter();
cout << osilwriter->writeOSiL(osinstance);
```

Using OSInstance to solve locally

```
LindoSolver *lindo;
lindo = new LindoSolver();
lindo->osinstance = osinstance;

lindo->solve();
cout << lindo->osrl << endl;
```

Creating a Remote OSInstance

Reading OSiL to solve remotely

```
FileUtil *fileUtil = NULL;
std::string osilFileName;
std::string osil;

std::string dataDir;
dataDir = "../../data/" ;
osilFileName = dataDir + "CppADTestLag.osil";
fileUtil = new FileUtil();
osil = fileUtil->getFileAsString( &osilFileName[0] );

OSiLReader *osilreader = NULL;
OSInstance *osinstance = NULL;
try{
    osilreader = new OSiLReader();
    osinstance = osilreader->readOSiL( &osil );
    .......
    delete osilreader;
    osilreader = NULL;
}
```

Data Structures

Using a Remote OSInstance

Invoking `get()` *methods to build a LINDO expression tree*

```
allExpTrees = osinstance->getAllNonlinearExpressionTrees();

for(posTree = allExpTrees.begin();
    posTree != allExpTrees.end(); ++posTree){

   postFixVec = posTree->second->getPostfixFromExpressionTree();
}
```

Using a Remote OSInstance

Invoking `calculate( )` *methods to evaluate nonlinear functions and derivatives*

```
double *conVals = osinstance->
   calculateAllConstraintFunctionValues( &x[0], false );

double *objVals = osinstance->
   calculateAllObjectiveFunctionValues( &x[0], false );

double *objGrad = osinstance->
   calculateObjectiveFunctionGradient( -1, &x[0], false, false );

SparseJacobianMatrix *sparseJac = osinstance->
   getJacobianSparsityPattern();

// first sparseJac->conVals + idx rows of Jacobian are constant

sparseJac = osinstance->
   calculateAllConstraintFunctionGradients( &x[0], false, false );
```

Using a Remote OSInstance *(cont'd)*

Invoking `calculate( )` *methods to evaluate 2nd derivatives (Hessian) of Lagrangian*

```
SparseHessianMatrix *sparseHessian = osinstance->
   getLagrangianHessianSparsityPattern( );

sparseHessian = osinstance->
   calculateLagrangianHessian( x, y, w, false, false );

// different call for Hessian whose sparsity pattern
// varies with x, y, w
```

Data Structures

Translating from a Modeling Language

Sample model in AMPL

```
set ORIG;   # origins
set DEST;   # destinations

param supply {ORIG} >= 0;   # amounts available at origins
param demand {DEST} >= 0;   # amounts required at destinations

param vcost {ORIG,DEST} >= 0;  # variable shipment costs per unit
param limit {ORIG,DEST} > 0;   # limit on units shipped
var Trans {ORIG,DEST} >= 0;    # units to ship

param fcost {ORIG} >= 0;       # fixed costs for use of origins
var Use {ORIG} binary;         # = 1 iff origin is used

minimize Total_Cost:
   sum {i in ORIG, j in DEST}
      vcost[i,j] * Trans[i,j] / (1 - Trans[i,j]/limit[i,j]) +
   sum {i in ORIG} fcost[i] * Use[i];

subject to Supply {i in ORIG}:
   sum {j in DEST} Trans[i,j] <= supply[i] * Use[i];

subject to Demand {j in DEST}:
   sum {i in ORIG} Trans[i,j] = demand[j];
```

Data Structures

Translating from AMPL *(cont’d)*

AMPL session

```
ampl: model nltrans.mod;
ampl: data nltrans.dat;

ampl: option solver amplclient;
ampl: option amplclient_options "solver lindo";
ampl: option lindo_options "...";

ampl: solve;

LINDO 12.1
LOCALLY OPTIMAL SOLUTION FOUND ...

ampl: display Trans;

...
```

Translating from AMPL *(cont'd)*

OSiL derived from AMPL's output format

```
<osil xmlns="os.optimizationservices.org"
xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
    xsi:schemaLocation=
        "os.optimizationservices.org ../schemas/OSiL.xsd">
    <instanceHeader>
        <description>Generated from AMPL nl file</description>
    </instanceHeader>
    <instanceData>
        <variables numberOfVariables="24">
            <var name="_svar[1]"/>
            <var name="_svar[2]"/>
            ...
            <var name="_svar[22]" type="B" ub="1"/>
            <var name="_svar[23]" type="B" ub="1"/>
            <var name="_svar[24]" type="B" ub="1"/>
        </variables>
        ....
    </instanceData>
</osil>
```

Data Structures

Translating from AMPL *(cont'd)*

OSiL derived from AMPL's output format

```
<objectives numberOfObjectives="1">
    <obj maxOrMin="min" numberOfObjCoef="24">
        <coef idx="21">50000</coef>
        <coef idx="22">3.94e+06</coef>
        <coef idx="23">370000</coef>
    </obj>
</objectives>
<constraints numberOfConstraints="10">
    <con name="_scon[1]" ub="-0"/>
    <con name="_scon[2]" ub="-0"/>
    <con name="_scon[3]" ub="-0"/>
    <con name="_scon[4]" lb="900" ub="900"/>
    <con name="_scon[5]" lb="1200" ub="1200"/>
    <con name="_scon[6]" lb="600" ub="600"/>
    <con name="_scon[7]" lb="400" ub="400"/>
    <con name="_scon[8]" lb="1700" ub="1700"/>
    <con name="_scon[9]" lb="1100" ub="1100"/>
    <con name="_scon[10]" lb="1000" ub="1000"/>
</constraints>
```

Data Structures

Translating from AMPL *(cont'd)*

OSiL derived from AMPL's output format

```
<linearConstraintCoefficients numberOfValues="45">
    <start>
        <el>0</el>
        <el>2</el>
        <el>4</el>
        ...
    </start>
    <rowIdx>
        <el>0</el>
        <el>3</el>
        <el>0</el>
        <el>4</el>
        <el>0</el>
        <el>5</el>
        ...
    </rowIdx>
    <value>
        <el>1</el>
        ...
```

Data Structures

Translating from AMPL *(cont'd)*

OSiL derived from AMPL's output format

```
<linearConstraintCoefficients numberOfValues="45">
    <start>
        ...
    </start>
    <rowIdx>
        ...
    </rowIdx>
    <value>
        <el>1</el>
        <el>1</el>
        <el>1</el>
        <el>1</el>
        <el>1</el>
        ...
        <el>-2800</el>
        <el>-5200</el>
        <el>-5800</el>
    </value>
</linearConstraintCoefficients>
```

Translating from AMPL *(cont'd)*

OSiL derived from AMPL's output format

```
<nonlinearExpressions numberOfNonlinearExpressions="1">
    <nl idx="-1">
        <sum>
            <divide>
                <times>
                    <number value="39" type="real"/>
                    <variable idx="0" coef="1"/>
                </times>
                <minus>
                    <number value="1" type="real"/>
                    <divide>
                        <variable idx="0" coef="1"/>
                        <number value="1300" type="real"/>
                    </divide>
                </minus>
            </divide>
            ...
        </sum>
    </nl>
</nonlinearExpressions>
```

Data Structures

Translating from AMPL *(cont'd)*

OSrL derived from solver's results

```
<osrl xmlns:os="os.optimizationservices.org"
    xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
    xsi:schemaLocation="os.optimizationservices.org
    ../schemas/OSiL.xsd">

    <resultHeader>
        <generalStatus type="success"/>
        <serviceName>Solved using a LINDO service</serviceName>
    </resultHeader>

    <resultData>
        <optimization numberOfSolutions="1" numberOfVariables="24"
            numberOfConstraints="10" numberOfObjectives="1">
            ...
        </optimization>
    </resultData>

</osrl>
```

Data Structures

Translating from AMPL *(cont'd)*

OSrL derived from solver's results

```
<solution objectiveIdx="-1">
    <status type="optimal"/>
    <variables>
        <values>
            <var idx="0">36.8552</var>
            <var idx="1">563.142</var>
            <var idx="2">122.355</var>
            <var idx="3">0</var>
            <var idx="4">991.065</var>
            ...
        </values>
        <other name="reduced costs">
            <var idx="0">0</var>
            <var idx="1">0</var>
            <var idx="2">0</var>
            <var idx="3">8.5573</var>
            <var idx="4">-2.51902e-09</var>
            ...
        </other>
    </variables>
```

Data Structures

Translating from AMPL *(cont'd)*

OSrL derived from solver's results

```
    <objectives>
        <values>
            <obj idx="-1">722383</obj>
        </values>
    </objectives>
    <constraints>
        <dualValues>
            <con idx="0">-12.4722</con>
            <con idx="1">-98.9784</con>
            <con idx="2">0</con>
            <con idx="3">53.7812</con>
            <con idx="4">35.7967</con>
            <con idx="5">25.5129</con>
            <con idx="6">17.9149</con>
            <con idx="7">82.3857</con>
            <con idx="8">193.978</con>
            <con idx="9">29.3393</con>
        </dualValues>
    </constraints>
</solution>
```

For More Information

- R. Fourer, L.B. Lopes and K. Martin, LPFML: A W3C XML Schema for Linear and Integer Programming. *INFORMS Journal on Computing* **17** (2005) 139–158.
- R. Fourer, J. Ma and K. Martin, OSiL: An Instance Language for Optimization. `www.optimization-online.org/DB_HTML/2006/03/1353.html`.