# An Open Interface for Hooking Solvers to Modeling Systems

## Part 2: The Modeling System Interface

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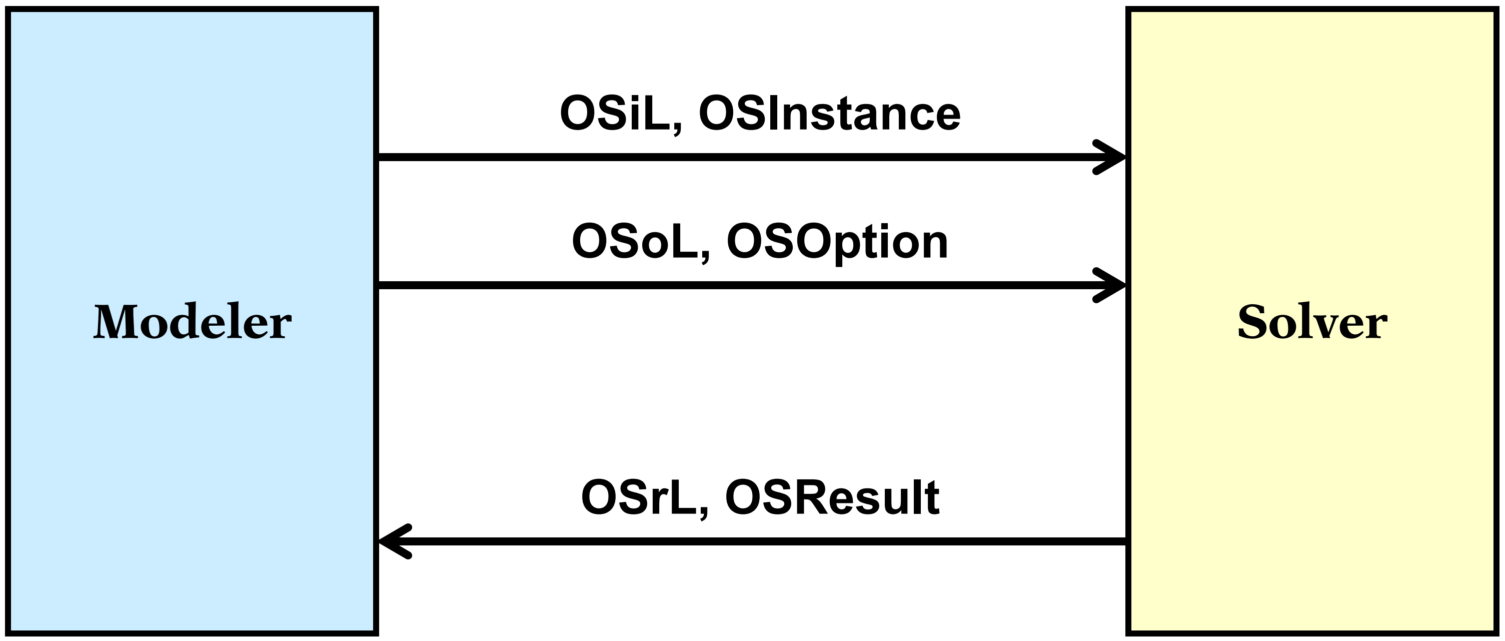
## An Open Interface for Hooking Solvers to Modeling Systems

Every optimization modeling system has developed its own way of representing problem instances. Hence each solver package for optimization problems must have a separate “driver” for every modeling system that it supports.

We describe a new open standard that, once adopted by modeling systems, will require each solver to have only one driver. The components of our proposal include OSiL, a new XML-based representation for optimization problem instances, and OSInstance, a corresponding in-memory representation. An open source library provides application programming interfaces for reading and writing OSiL and OSInstance and for converting between them. Related languages and libraries handle the passing of options to solvers and the retrieval of results, as well as protocols for facilitating solver registration, client and scheduler discovery, and communication between the various components of the optimization process.

This session will emphasize the practical aspects of using our tools to hook solvers to modeling systems, focusing on our overall Optimization Services framework (Ma), the modeling system interface to our library (Fourer), and the solver interface to our library (Martin).

## Quick Overview



*XML text files*

- ➢OSiL, OSoL, OSrL

*In-memory data structures*

- ➢OSInstance, OSOption, OSResult

## The Modeling System 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***

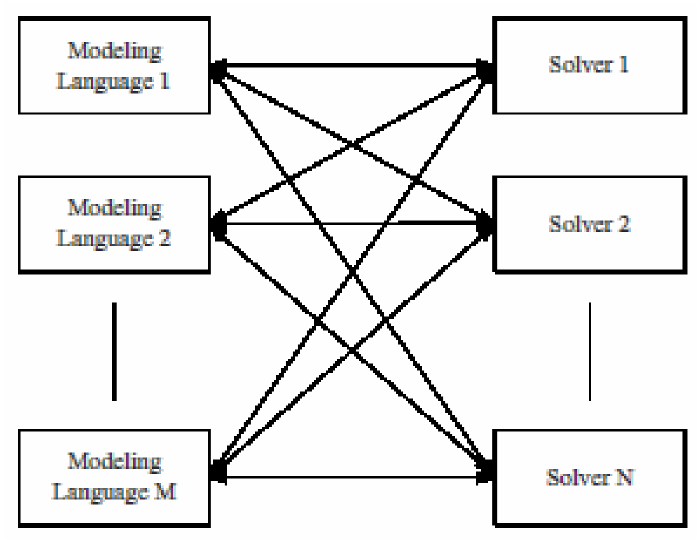
***. . . by use of a schema written itself in XML***

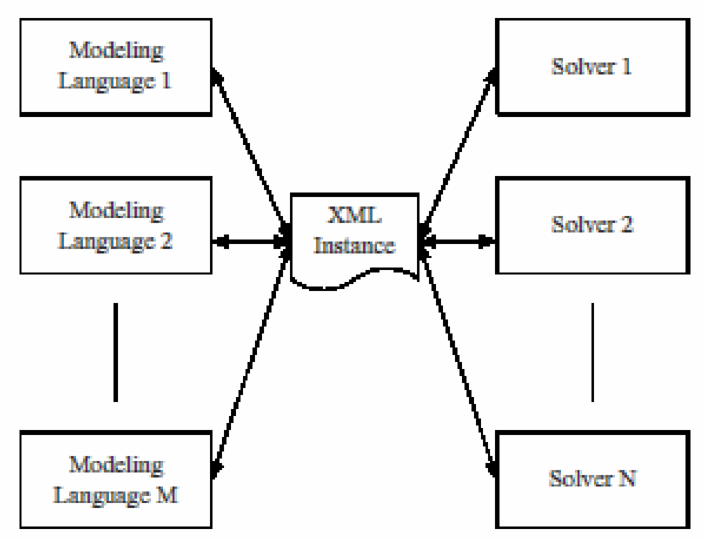
*Motivation*

## 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**

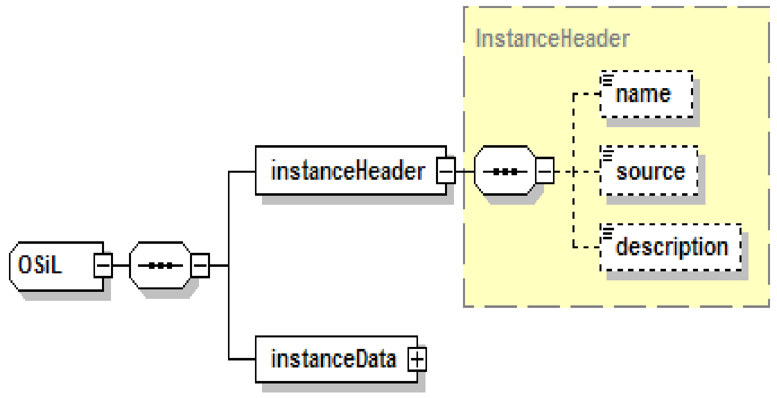
## Text from the OSiL Schema

```
<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>
```

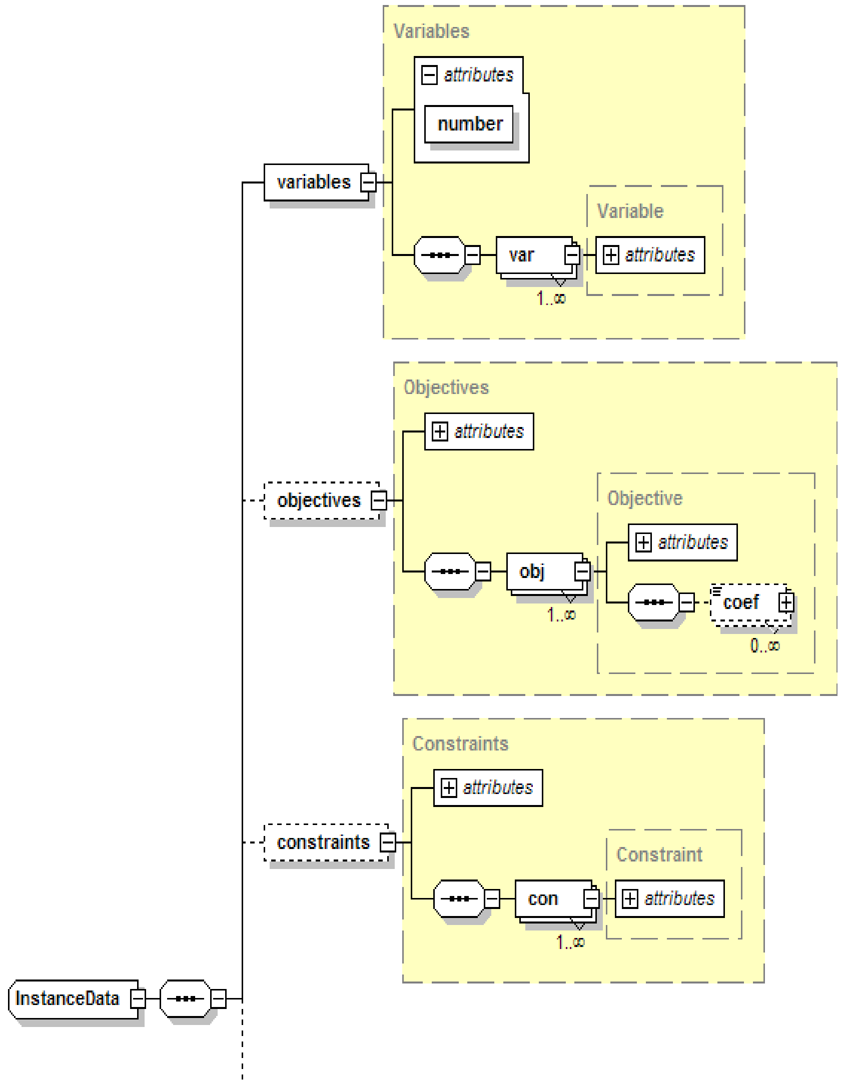
*Text files*

## Diagram of the OSiL Schema



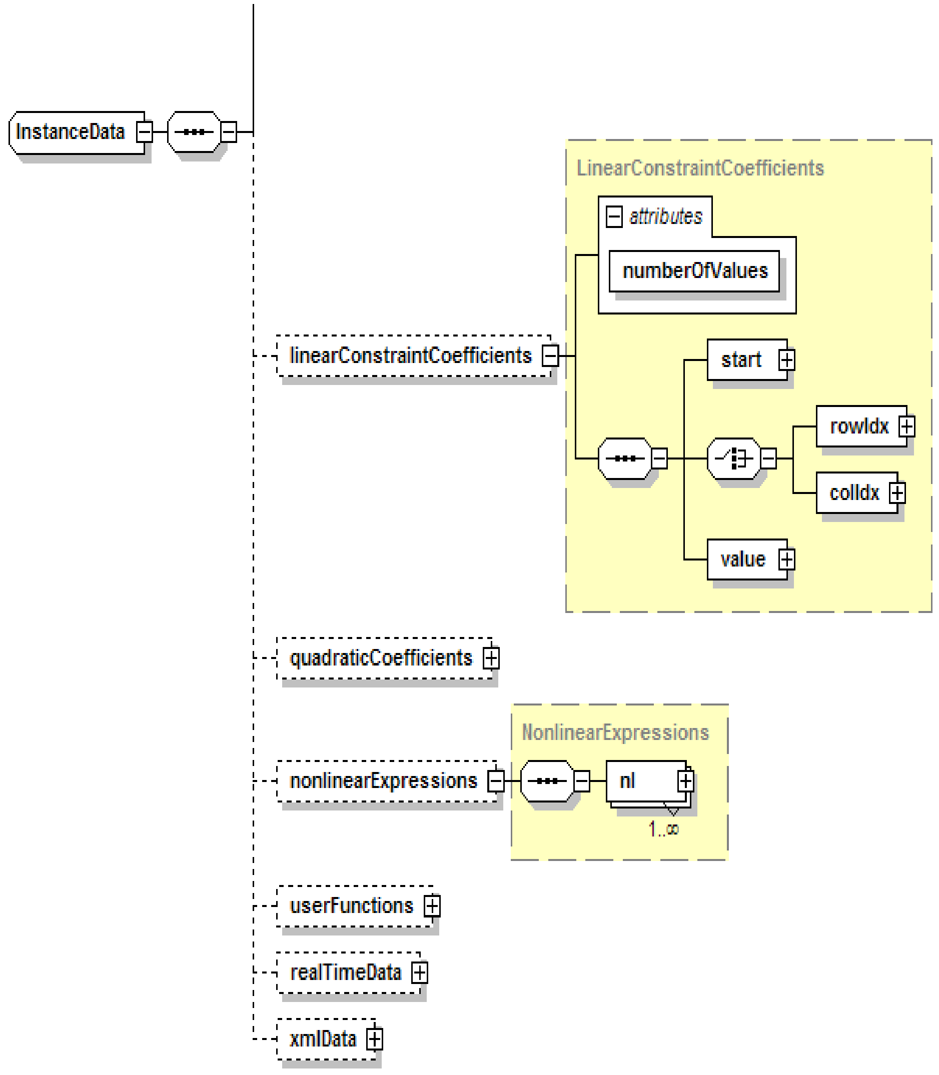
*Text files*

# Details of OSiL’s instanceData Element



*Text files*

## Details of OSiL’s instanceData Element



*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 $< 2 \times$ MPS
- Compressed XML < Compressed MPS

*Text files*

## 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***

## Writing a Generator for an 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;
   }
}
```

## Generator for an 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, "");
```

## Generator for an 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*

## Generator for an 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);
```

# Generator for an 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*

## Generator for an 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;
```

## Generator for an 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);
```

## Generator for an OSInstance *(cont'd)*

### *Writing in OSiL for remote solution*

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

### *Solving locally in memory*

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

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

## Generator for an 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*

## 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];
```

## 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>
```

*Data Structures*

## 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>
```

## 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>
```

## 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`.