Optimization Via the Internet: NEOS 5 and Beyond

Robert Fourer

Industrial Engineering & Management Sciences
Northwestern University
Evanston, Illinois 60208-3119, U.S.A.

4er@iems.northwestern.edu — www.iems.northwestern.edu/~4er/

and many others . . .

19th International Symposium on Mathematical Programming
Rio de Janeiro, July 30 – August 4, 2006
Session WE1-R15, Software Services and Distribution

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

Jorge J. Moré, Todd S. Munson, Jason Sarich

Mathematics and Computer Science Division
Argonne National Laboratory

[more,tmunson,sarich]@mcs.anl.gov

Dominique Orban

Mathematics and Industrial Engineering Department
École Polytechnique de Montréal

dominique.orban@polymtl.ca

NEOS www-neos.mcs.anl.gov/neos/

A general-purpose optimization server

- Over 45 solvers in all
  - Linear, linear network, linear integer
  - Nonlinear, nonlinear integer, nondifferentiable & global
  - Stochastic, semidefinite, semi-infinite, complementarity
- Commercial as well as experimental solvers
- Central scheduler with distributed solver sites

A research project

- Currently free of charge
- Supported through the Optimization Technology Center of Northwestern University and Argonne National Laboratory

NEOS Design

Flexible architecture

- Central controller and scheduler machine
- Distributed solver sites

Numerous formats

- Low-level formats: MPS, SIF, SDPA
- Programming languages: C/ADOL-C, Fortran/ADIFOR
- High-level modeling languages: AMPL, GAMS

Varied submission options

- E-mail
- Web form
- Direct call via XML-RPC
  - from AMPL or GAMS client
  - from user's client program using NEOS's API

. . . server processes submissions of new solvers, too

NEOS Frequently Asked Questions

Who uses it?

- Where are its users from?
- How much is it used?

What kinds of solvers does it offer?

- Who supplies them?
- Which are most heavily used?
- Where are they hosted?

How is it supported?

- Who answers user questions?

Who Uses NEOS? *(a sample)*

- We are using NEOS services for duty-scheduling for ground handling activities in a regional airport environment.
- We used NEOS to solve nonlinear optimization problems associated with models of physical properties in chemistry.
- Our company is working with various projects concerning R&D of internal combustion engines for cars and brakes for heavy vehicles.
- We are working on bi-dimensional modeling of earth's conductivity distribution.
- I am dealing with ultimate limit-state analyses of large dams by means of a non-standard approach ("direct method"); this requires solving problems of linear and non-linear programming. The NEOS server is an extraordinary tool to perform parametric tests on small models, in order to choose the best suited solver.
- I have used NEOS with LOQO solver to optimize an interpolator. . . . My domain is digital receivers where the receiver clock is not changed to match the transmitter clock.

Who Uses NEOS? *(more)*

- I have been able to build and solve a prototype combinatorial auction MIP model using AMPL and NEOS in a fraction of the time it would have required me to do this had I needed to requisition a solver and install it locally.
- Our idea is trying to design antennas by using the computer. . . . We have tried various solvers on NEOS to see if this is possible at all.
- I am using the LOQO solver and code written in AMPL to perform numerical optimization of a spinor Bose-Einstein condensate.
- We are using the NEOS Server for solving linear and nonlinear complementarity problems in engineering mechanics and in robotics.
- I have been working on a system for protein structure prediction. . . . I had need to incorporate a nonlinear solver to handle packing of sidechain atoms in the protein.

Who Uses NEOS? *(academic)*

- I am regularly suggesting my students to use NEOS as soon as their projects in AMPL cannot be solved with the student edition. **So they debug their AMPL models locally . . . and then they run their real-life projects thanks to NEOS.**
- I didn't even know what nonlinear programming was and after I discovered what it was, it became clear how enormous a task it would be to solve the problems assigned to me. . . . I had extremely complicated objective functions, both convex and nonconvex, an armload of variables, and an armload of convex, nonconvex, equality and inequality constraints, but when I sent off the information via the web submission form, within seconds I received extremely accurate and consistent results. **The results were used for verifying a certain theory in my professor's research** and so accuracy was extremely important.
- NEOS has been a very valuable tool in the two graduate optimization courses that I teach. **NEOS allows students to see a broader variety of solvers than we have available . . .**

. . . more at **`www-neos.mcs.anl.gov/neos/stories.html`**

NEOS Users

Where are They From?

June 2005 through May 2006:
Identifiable domain and >= 20 submissions

(com)	12575
(edu)	69648
(gov)	34547
(net)	21204
(mil)	277
(org)	374

Argentina (ar)	26
Australia (au)	434
Austria (at)	171
Belgium (be)	5973
Brazil (br)	2183
Bulgaria (bg)	60
Canada (ca)	11247
Chile (cl)	2745
Colombia (co)	1201
Croatia (hr)	223
Cyprus (cy)	179
Czech Republic (cz)	1012
Denmark (dk)	94
Finland (fi)	46
France (fr)	2162
Germany ...	

NEOS Users

What Countries are They From?

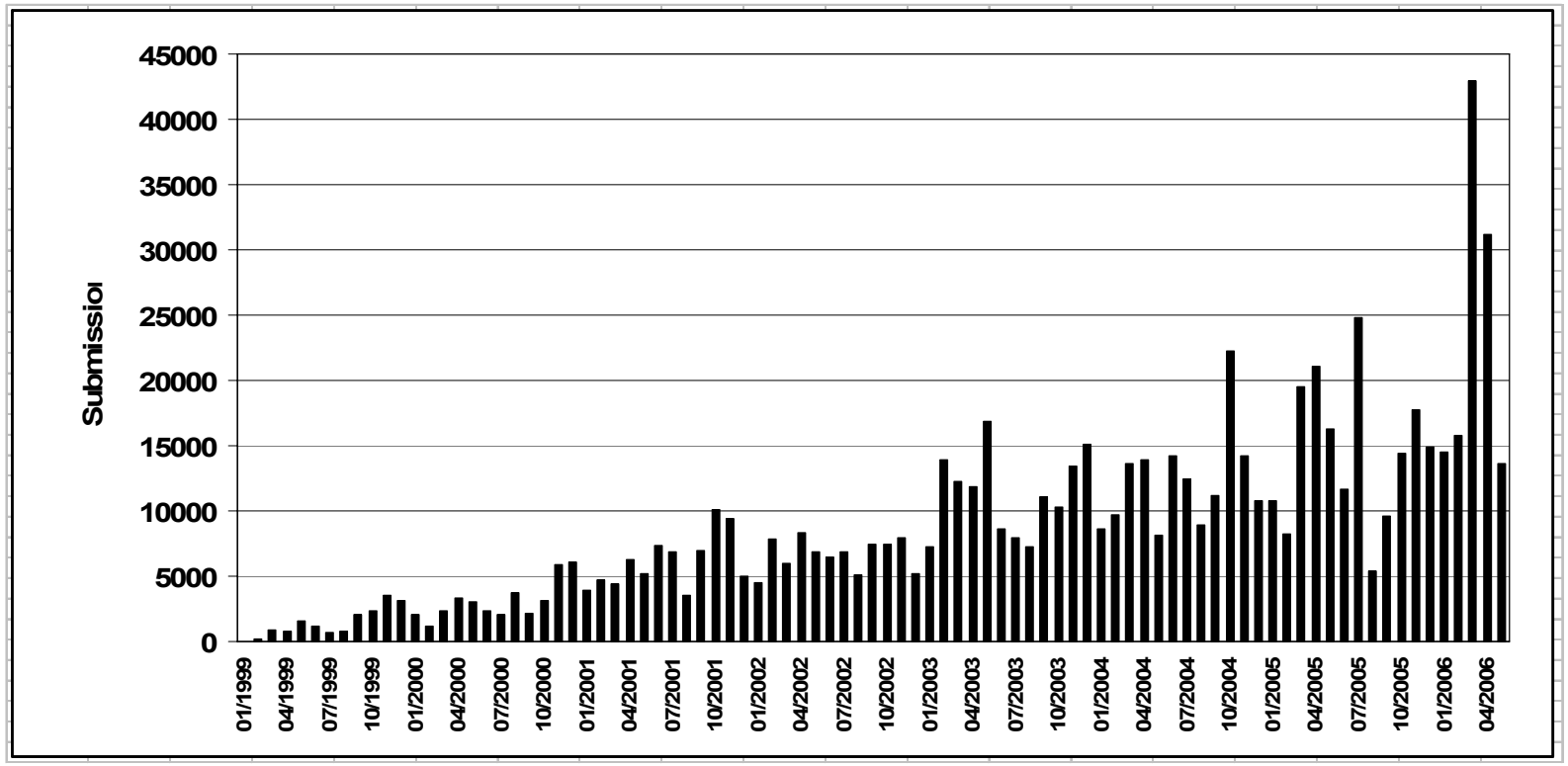
Argentina (ar)	26
Australia (au)	434
Austria (at)	171
Belgium (be)	5973
Brazil (br)	2183
Bulgaria (bg)	60
Canada (ca)	11247
Chile (cl)	2745
Colombia (co)	1201
Croatia (hr)	223
Cyprus (cy)	179
Czech Republic (cz)	1012
Denmark (dk)	94
Finland (fi)	46
France (fr)	2162
Germany (de)	3694
Hong Kong (hk)	45
Hungary (hu)	34
India (in)	704
Ireland (ie)	24
Italy (it)	2401

Japan (jp)	1376
Korea (kr)	35
Malaysia (my)	640
Mexico (mx)	163
Netherlands (nl)	5026
New Zealand (nz)	299
Norway (no)	156
Poland (pl)	195
Portugal (pt)	1257
Russia (ru)	178
Singapore (sg)	1324
Spain (es)	1265
Sweden (se)	3442
Switzerland (ch)	518
Taiwan (tw)	53
Turkey (tr)	1432
Ukraine (ua)	398
United Kingdom (uk)	2084
Uruguay (uy)	292
Uzbekistan (uz)	98

NEOS Users

How Much Do They Use It?

Submissions by month, 1/1999 through 5/2006



. . . 25 / hour over past year

. . . 50 / hour in peak months

What Solvers Does NEOS Offer?

For familiar problem types

- Linear programming
- Linear network optimization
- Linear integer programming
- Nonlinear programming
- Stochastic linear programming
- Complementarity problems

For emerging problem types

- Nondifferentiable optimization
- Semi-infinite optimization
- Global optimization
- Nonlinear integer programming
- Semidefinite & 2nd-order cone programming

. . . virtually every published semidefinite programming code

Who Supplies Them?

Some commercial solver vendors

- Xpress, FortMP (mixed integer)
- CONOPT, KNITRO, MOSEK (nonlinear)

Universities and their researchers

- BonsaiG (mixed integer)
- DONLP2, FILTER, LANCELOT, LOQO, MINOS, SNOPT (nonlinear)

Open-Source Enthusiasts

- GLPK (mixed integer)

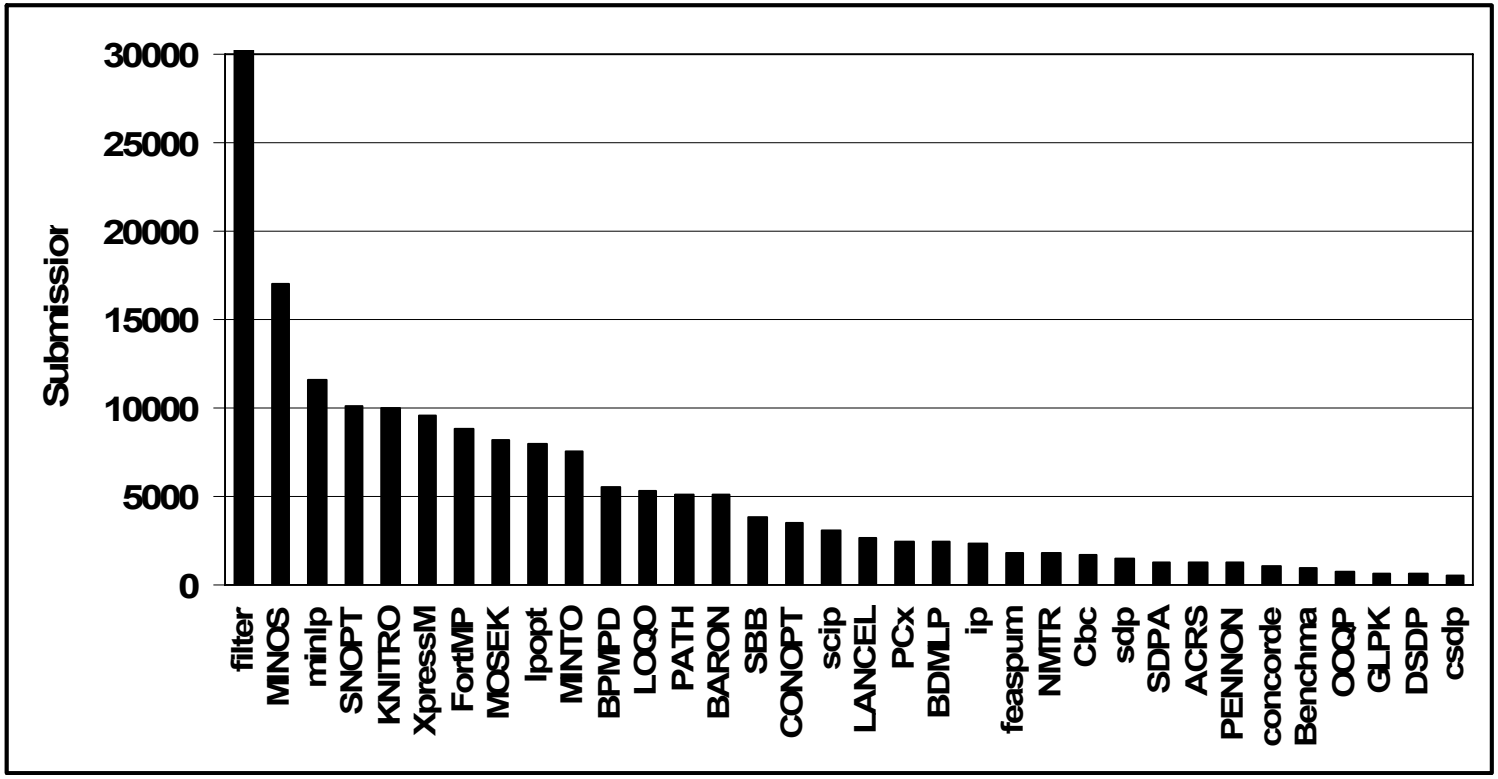
with thanks to . . .

- ***AMPL*** and ***GAMS*** developers
- ***Hans Mittelmann,*** Arizona State

NEOS Solvers

Which are Most Heavily Used?

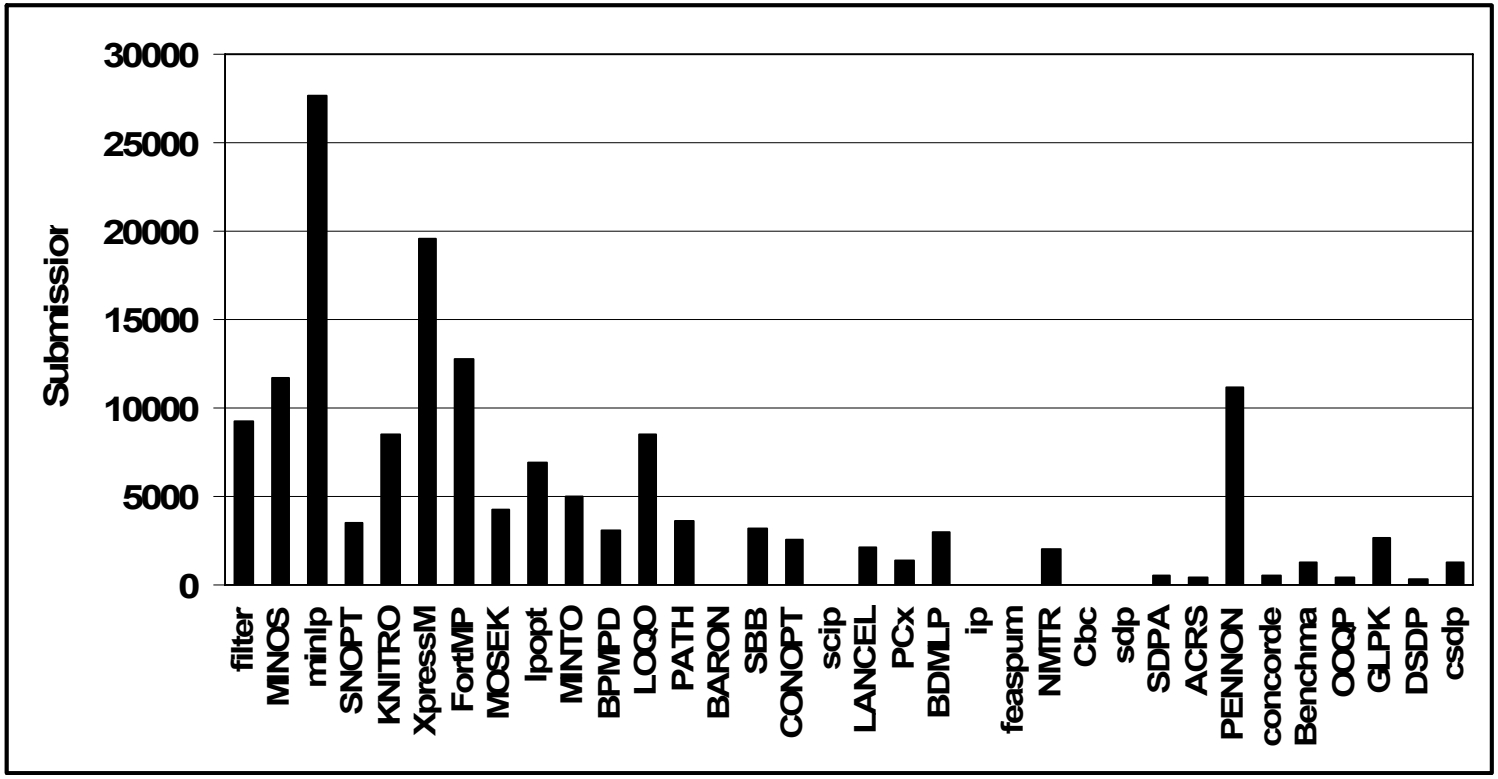
Totals for June 2005 to May 2006



NEOS Solvers

Which are Most Heavily Used?

Totals for June 2004 to May 2005



NEOS Solvers

Where are They Hosted?

Varied workstations at

- Aachen University of Technology
- Argonne National Laboratory
- Arizona State University
- Lehigh University
- National Taiwan University
- Northwestern University *(with support from Sun Microsystems)*
- University of Wisconsin at Madison

. . . new hosts are readily added anywhere on the Internet

How is NEOS Supported?

Grants

- National Science Foundation, Operations Research Program, grant DMI-0322580
- National Science Foundation, Information Technology Research Program, grant CCR-0082807
- U.S. Department of Energy, Office of Advanced Scientific Computing, Mathematical, Information, and Computational Sciences Division subprogram, Contract W-31-109-Eng-38
- National Science Foundation, Challenges in Computational Science Program, grant CDA-9726385

Donations

- Processor cycles
- Many people's time

. . . no user charges as yet

Who Answers Users' Questions?

Large mailing list for support questions

- NEOS developers
- Solver developers

Support request buttons on every page

New in Version 5

Callable interface

XML-based communications

Short-job queue

New solver submission procedures

Callable Interface

Server

- `http://neos.mcs.anl.gov:3332`
- at Argonne National Laboratory

Clients

- in Python, Perl, C, C++, Java, *and others*
- new Kestrel clients for AMPL and GAMS

. . . see Python example later in this talk

Methods

- for getting information from NEOS
- for submitting and retrieving jobs on NEOS
- for maintaining solvers on NEOS

Callable Interface

Getting Information

"get" methods

- `getSolverTemplate(category, solvername, inputMethod)`
- `getXML(category, name, input)`

"list" methods

- `listAllSolvers()`
- `listCategories()`
- `listSolversInCategory(category)`

Utilities

- `help()`
- `emailHelp()`
- `welcome()`
- `version()`
- `ping()`
- `printQueue()`

Callable Interface

Submitting and Retrieving Jobs

Submission methods

- `submitJob(xmlstring, user='', interface='', id=0)`
- `killJob(jobNumber, password, killmsg='')`

Intermediate retrieval methods

- `getJobStatus(jobNumber, password)`
- `getIntermediateResults(jobNumber, password, offset)`
- `getIntermediateResultsNonBlocking(jobNumber, password)`

Final retrieval methods

- `getFinalResults(jobNumber, password)`
- `getFinalResultsNonBlocking(jobNumber, password)`

Callable Interface

Maintaining Solvers

Solver setup methods

- `pingHost(user, hostname)`
- `validateSolverXML(xmlString)`
- `registerSolver(xmlString)`

Solver management methods

- `disableSolver(category, solvername, input, password)`
- `enableSolver(category, solvername, input, password)`
- `removeSolver(category, solvername, input, password)`

Example methods

- `registerExample(xmlstring, password)`
- `removeExample(category, solvername, input, password, examplename)`

XML-Based Communications

```
<document>
<category>nco</category>
<solver>KNITRO</solver>
<inputMethod>AMPL</inputMethod>

<model><![CDATA[
...Insert Value Here...
]]></model>

<data><![CDATA[
...Insert Value Here...
]]></data>

<commands><![CDATA[
...Insert Value Here...
]]></commands>

<comments><![CDATA[
...Insert Value Here...
]]></comments>

</document>
```

XML

Submissions

By e-mail

- Insert actual files
- Send as text file
- Receive results via e-mail

From XML-RPC client

- Insert file names
- Submit file using **`submitJob()`** method
- Check status and intermediate results using appropriate methods
- Retrieve results using **`getFinalResults()`** method

. . . results include everything sent to standard output

XML

Example: Python Client

```
#!/usr/bin/env python
import sys
import xmlrpclib
import time

from config import Variables

if len(sys.argv) < 2 or len(sys.argv) > 3:
  sys.stderr.write
     ("Usage: NeosClient <xmlfilename | help | queue> ")
  sys.exit(1)

neos=xmlrpclib.Server
  ("http://%s:%d" % (Variables.NEOS_HOST, Variables.NEOS_PORT))

if sys.argv[1] == "help":
  sys.stdout.write(neos.help())

elif sys.argv[1] == "queue":
  msg = neos.printQueue()
  sys.stdout.write(msg)

else: ...
```

XML

Example: Python Client *(cont'd)*

```
xmlfile = open(sys.argv[1],"r")
xml=""
buffer=1

while buffer:
  buffer =  xmlfile.read()
  xml+= buffer
xmlfile.close()

(jobNumber,password) = neos.submitJob(xml)
sys.stdout.write("jobNumber = %d " % jobNumber)

offset=0

while status == "Running" or status == "Waiting":
  (msg,offset) =
     neos.getIntermediateResults(jobNumber,password,offset)
  sys.stdout.write(msg.data)
  status = neos.getJobStatus(jobNumber, password)
  time.sleep(2)

msg = neos.getFinalResults(jobNumber, password).data
sys.stdout.write(msg)
```

Short-Job Queue

5-minute limit

- A few machines dedicated to this purpose
- Jobs exceeding limit are terminated

. . . prevents blocking of short jobs by long ones

New Solver-Submission Procedures

Downloading the NEOS software

- `www-neos.mcs.anl.gov/neos/Installation.html`

Installing the NEOS software

- Client tools for problem submission
- **Solver tools for hooking up new solvers**
- Installing a new NEOS Server

Solver Submission

Hooking Up a New Solver

Register with NEOS

- Create an XML file to . . .
  - Describe your solver
  - Describe your solver's input
  - Designate your workstation(s)
- Send the file to NEOS

Write a "driver" for your solver

Start a "server" for your solver on your workstation

Example: "HelloNEOS" solver . . .

Solver Submission

Describing Your Solver

```
<neos:SolverDescription xmlns:neos="http://www.mcs.anl.gov/neos">

<neos:category>test</neos:category>
<neos:solver>HelloNEOS</neos:solver>
<neos:inputMethod>basic</neos:inputMethod>
<neos:password>hello</neos:password>
<neos:contact>fakeperson@mcs.anl.gov</neos:contact>
```

Solver Submission

Describing the Solver's Input

Input types available

- Text field
  - one line of text
- Text area
  - multiple lines of text
- File
  - name of a local file
- Check box
- Radio button

Example continued . . .

Solver Submission

Describing the Solver's Input

```
<neos:input TYPE="textfield">
  <neos:token>num1</neos:token>
  <neos:filename>num1</neos:filename>
  <neos:prompt>First Number</neos:prompt>
</neos:input>

<neos:input TYPE="textfield">
  <neos:token>num2</neos:token>
  <neos:filename>num2</neos:filename>
  <neos:prompt>Second Number</neos:prompt>
</neos:input>

<neos:input TYPE="radio">
  <neos:token>operation</neos:token>
  <neos:filename>operation</neos:filename>
  <neos:prompt>Which Operation</neos:prompt>
  <neos:option value="Multiplication"
      default="true">Multiplication</neos:option>
  <neos:option value="Addition">Addition</neos:option>
</neos:input>
```

Solver Submission

Designating Workstations

```
<neos:machine>
  <neos:hostname>lully.mcs.anl.gov</neos:hostname>
  <neos:user>neos</neos:user>
</neos:machine>

</neos:SolverDescription>
```

Registering with NEOS

```
register.py HelloNEOS.txt
```

Solver Submission

Writing a "Driver" for the Solver

```
#!/usr/bin/env python
import os
print ("Hello NEOS!");

f = open('num1','r')
num1 = float(f.read())
f.close()

f = open('num2','r')
num2 = float(f.read())
f.close()

f = open('operation','r')
operation=f.read()
f.close()

if operation=="Multiplication":
  print "%.5f * %.5f = %.5f" % (num1, num2, num1*num2)
else:
  print "%.5f + %.5f = %.5f" % (num1, num2, num1+num2)
```

Solver Submission

Starting a "Server" on the Workstation

List solvers in **`/home/neos/driverlist.txt`**

- **`test:HelloNEOS:basic /path/to/hello.py`**

Edit **`SolverTools/config.py`**

- **`class Variables: NEOS_HOST="neos.mcs.anl.gov"`**
  `NEOS_PORT=3332`
  `JOBSDIR="/home/neos/HelloNEOS/jobs"`
  `LOGDIR="/home/neos/HelloNEOS/logs"`
  `TESTDIR="/home/neos/HelloNEOS/test"`
  `DRIVER_FILE="/home/neos/driverlist.txt"`

Start up

- **`SolverTools/SolverDaemon.py`**

Open up a port (if behind a firewall)

- **`SolverDaemon.py 4000`**

Optimization Services

Decentralized framework

- *Centralized repository, but decentralized . . .*
- Sources for solver information and problem analysis
- Services for optimization

Optimization cyberinfrastructure

- XML-based standards for representation
- Benchmarking and verification services
- High-performance computing on demand

What's special about optimization?

- Independence of modeling, data, and solver software
- Choice of solver based on mathematics
- Huge variation in solver performance

XML-Based Standard Formats

Motivation

- for any standard format
- for an XML-based format

"OSxL" standards

- OSiL: problem instances
- OSoL: solver options
- **OSrL: results**

. . . and a host of others
(see www.optimizationservices.org)

Components of OSiL

- XML schema for text file format, *and*
- Corresponding in-memory data structures
- Libraries for reading and writing the above

Standards

XML Means "Tagged" Text Files . . .

Example: html for a popular home page

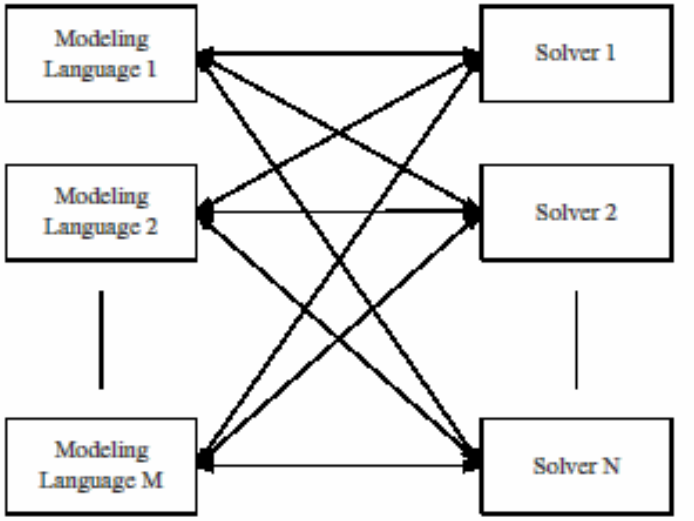
```
<html><head><meta http-equiv="content-type" content="text/html;
charset=UTF-8"><title>Google</title><style><!--
body,td,a,p,.h{font-family:arial,sans-serif;}
.h{font-size: 20px;}
.q{text-decoration:none; color:#0000cc;}
//-->
</style>
</head><body bgcolor=#ffffff text=#000000 link=#0000cc
vlink=#551a8b 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

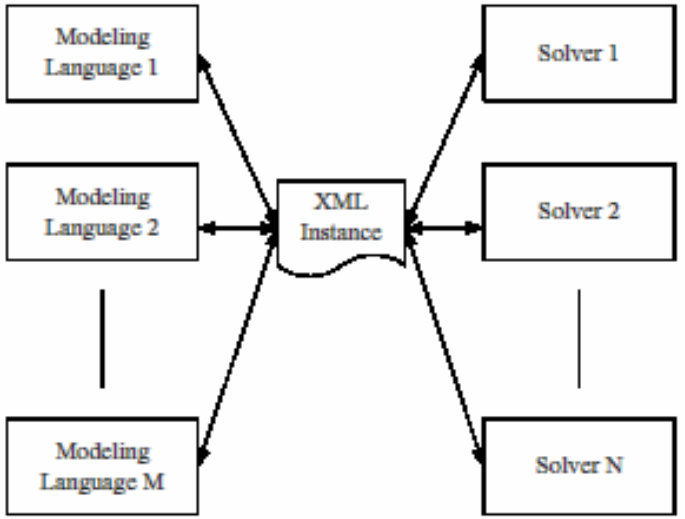
. . . by use of a schema written itself in XML

Advantage of any standard

MN drivers without a standard



M + N drivers with a standard



Standards

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*

Standards

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**

Standards

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>
```

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;
```

Standard formats

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>
```

Example in OSiL *(continued)*

```
<linearConstraintCoefficients numberOfValues="3">
   <start>
      <el>0</el>
      <el>2</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>
```

Standard formats

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>
```

Standard formats

Example in OSiL *(continued)*

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

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

Other Features in OSiL . . .

In current specification

- Real-time data
- Functions defined by the user

In process of design

- Stochastic programming / optimization under uncertainty
- Logical / combinatorial constraints
- Semidefinite / cone programming

Associated languages

- OSoL for communicating options to solvers
- OSrL for communicating results from solvers

. . . broader family of "optimization services" languages

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

Advantages

- One standard instead of two
- Complements COIN-OR's OSI

Libraries (APIs, Interfaces)

Use by client

- OSInstance `set()` methods generate instance in memory
- `OSiLWriter` writes instance to a file in OSiL format
- Using SOAP over HTTP, instance is sent to a solver

Use by solver

- OSiLReader in solver interface
  reads instance from OSiL format back to memory
- OSInstance `get()` methods extract instance data
  as needed by solver
- Solver works on the problem
- Results are sent back similarly, using OSrL

. . . OSiL can be skipped
when instance is passed in memory

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 data

```
param: ORIG:  supply fcost:=
        GARY 2800 50000  CLEV 5200 3940000  PITT 5800 370000 ;

param: DEST:  demand :=
        FRA     900    DET    1200    LAN     600
        WIN     400    STL    1700    FRE    1100
        LAF    1000 ;

param vcost : FRA  DET  LAN  WIN  STL  FRE  LAF :=
        GARY   39   14   11   14   16   82    8
        CLEV   27    9   12    9   26   95   17
        PITT   24   14   17   13   28   99   20 ;

param limit :  FRA  DET  LAN  WIN  STL  FRE  LAF :=
        GARY  1300 2500 1500 1500 1900 1700 1700
        CLEV   800  900  800  800  500  700 1700
        PITT  2600 1700 2600 2700 1700 1900 2700 ;
```

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)*

AMPL's "nl" output format (beginning)

```
g3 2 1 0     # problem nltrans
 24 10 1 0 7 # vars, constraints, objectives, ranges, eqns
 0 1         # nonlinear constraints, objectives
 0 0         # network constraints: nonlinear, linear
 0 21 0      # nonlinear vars in constraints, objectives, both
 0 0 0 1     # linear network variables; functions; arith, flags
 3 0 0 0 0   # discrete vars: binary, integer, nonlinear (b,c,o)
 45 24       # nonzeros in Jacobian, gradients
 0 0         # max name lengths: constraints, variables
 0 0 0 0 0   # common exprs: b,c,o,c1,o1
C0       #Supply['GARY']
n0
C1       #Supply['CLEV']
n0
C2       #Supply['PITT']
n0
C3       #Demand['FRA']
n0
C4       #Demand['DET'] ...
```

Translating from AMPL *(cont'd)*

AMPL's "nl" output format (nonlinear objective)

```
O0 0     #Total_Cost
o54      #sumlist
21
o3       #/
o2       #*
n39
v0       #Trans['GARY','FRA']
o1       # -
n1
o3       #/
v0       #Trans['GARY','FRA']
n1300
o3       #/
o2       #*
n14
v1       #Trans['GARY','DET']
o1       # -
n1
o3       #/
v1       #Trans['GARY','DET']
N2500 ...
```

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>
```

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>
```

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>
        ...
```

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>
```

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

- E.D. Dolan, R. Fourer, J.J. Moré and T.S. Munson, Optimization on the NEOS Server. SIA*M News* **35:**6 (July/August 2002) 4, 8–9. `www.siam.org/siamnews/07-02/neos.pdf`
- NEOS Server: `www-neos.mcs.anl.gov/neos`
- 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`.