AMPL in the Cloud
Using Online Services to Develop and Deploy Optimization Applications through Algebraic Modeling

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AMPL in the Cloud

Using Online Services to Develop and Deploy Optimization Applications through Algebraic Modeling

Optimization modeling systems first appeared online almost 20 years ago, not long after web browsers came into widespread use. This presentation describes the evolution of optimization alternatives in what has come to be known as cloud computing, with emphasis on the role of the AMPL modeling language in making models easy to develop and deploy. We start with the pioneering free NEOS Server, and then compare more recent commercial offerings such as Gurobi Instant Cloud; the benefits of these solver services are readily leveraged through their use with the AMPL modeling tools. We conclude by introducing QuanDec, which creates web-based collaborative applications from an AMPL models.
Word cloud, exhibitor descriptions
The Optimization Modeling Cycle

Steps

- Communicate with problem owner
- Build model
- Prepare data
- Generate optimization problem
- Submit problem to solver
  * Gurobi, Knitro, CPLEX, Xpress, CONOPT, MINOS, . . .
- Report & analyze results
- Repeat!

Goals for optimization software

- Do this quickly and reliably
- Get results before client loses interest
- Deploy for application
Optimization Modeling Languages

Two forms of an optimization problem

- Modeler’s form
  - Mathematical description, easy for people to work with
- Algorithm’s form
  - Explicit data structure, easy for solvers to compute with

Idea of a modeling language

- A computer-readable modeler’s form
  - You write optimization problems in a modeling language
  - Computers translate to algorithm’s form for solution

Advantages of a modeling language

- Faster modeling cycles
- More reliable modeling
- More maintainable applications
Algebraic Modeling Languages

Formulation concept

- Define data in terms of sets & parameters
  - Analogous to database keys & records
- Define decision variables
- Minimize or maximize a function of decision variables
- Subject to equations or inequalities that constrain the values of the variables

Advantages

- Familiar
- Powerful
- Proven
Features

- Algebraic modeling language
- Built specially for optimization
- Designed to support many solvers

Design goals

- Powerful, general expressions
- Natural, easy-to-learn modeling principles
- Efficient processing that scales well with problem size

3 ways to use . . .
3 Ways to Use AMPL

Command language

- Browse results & debug model interactively
- Make changes and re-run

Scripting language

- Bring the programmer to the modeling language

Programming interface (API)

- Bring the modeling language to the programmer
Example: Roll Cutting

Motivation

- Fill orders for rolls of various widths
  - by cutting raw rolls of one (large) fixed width
  - using a variety of cutting patterns

Optimization model

- Decision variables
  - number of raw rolls to cut according to each pattern
- Objective
  - minimize number of raw rolls used
- Constraints
  - meet demands for each ordered width
Roll cutting

Mathematical Formulation

Given

- \( W \) set of ordered widths
- \( n \) number of patterns considered

and

- \( a_{ij} \) occurrences of width \( i \) in pattern \( j \), for each \( i \in W \) and \( j = 1, \ldots, n \)
- \( b_i \) orders for width \( i \), for each \( i \in W \)
Roll cutting

Mathematical Formulation (cont’d)

Determine

\[ X_j \] number of rolls to cut using pattern \( j \),
for each \( j = 1, \ldots, n \)

to minimize

\[ \sum_{j=1}^{n} X_j \]

total number of rolls cut

subject to

\[ \sum_{j=1}^{n} a_{ij} X_j \geq b_i, \quad \text{for all } i \in W \]

number of rolls of width \( i \) cut
must be at least the number ordered
Roll Cutting

AMPL Formulation

Symbolic model

```AMPL
set WIDTHS;
param orders {WIDTHS} > 0;
param nPAT integer >= 0;
param nbr {WIDTHS,1..nPAT} integer >= 0;

var Cut {1..nPAT} integer >= 0;

minimize Number:
  sum {j in 1..nPAT} Cut[j];

subj to Fulfill {i in WIDTHS}:
  sum {j in 1..nPAT} nbr[i,j] * Cut[j] >= orders[i];
```

\[ \sum_{j=1}^{n} a_{ij} X_j \geq b_i \]
Roll Cutting

AMPL Formulation (cont’d)

Explicit data (independent of model)

```
param: WIDTHS: orders :=
  6.77 10
  7.56 40
  17.46 33
  18.76 10;

param nPAT := 9;

param nbr:  1  2  3  4  5  6  7  8  9 :=
  6.77 0 1 1 0 3 2 0 1 4
  7.56 1 0 2 1 1 4 6 5 2
  17.46 0 1 0 2 1 0 1 1 1
  18.76 3 2 2 1 1 0 0 0;
```
Command Language

Model + data = problem instance to be solved

ampl: model cut.mod;
ampl: data cut.dat;
ampl: option solver cplex;
ampl: solve;

CPLEX 12.6.3.0: optimal integer solution; objective 20
3 MIP simplex iterations

ampl: option omit_zero_rows 1;
ampl: option display_1col 0;
ampl: display Cut;
4 13 7 4 9 3
Command Language (cont’d)

Solver choice independent of model and data

ampl: model cut.mod;
ampl: data cut.dat;
ampl: option solver gurobi;
ampl: solve;
Gurobi 6.5.0: optimal solution; objective 20
3 simplex iterations
ampl: option omit_zero_rows 1;
ampl: option display_1col 0;
ampl: display Cut;
4 13 7 4 9 3
Command Language (cont’d)

Results available for browsing

ampl: display {j in 1..nPAT, i in WIDTHS: Cut[j] > 0} nbr[i,j];
:  4  7  9 :=                      # patterns used
  6.77  0  0  4
  7.56  1  6  2
  17.46  2  1  1
  18.76  1  0  0

ampl: display {j in 1..nPAT} sum {i in WIDTHS} i * nbr[i,j];
1  63.84  3  59.41  5  64.09  7  62.82  9  59.66         # pattern
2  61.75  4  61.24  6  62.54  8  62.0           # total widths

ampl: display Fulfill.slack;
  6.77  2                        # overruns
  7.56  3
  17.46  0
  18.76  3
IDE for Command Language
Computing in the Cloud

Client side

- Local computing device owned by the user
  - Company, organization, university, individual
- Client application run by the user on the local device

Server side

- Remote computing facility owned by a provider
  - Company, organization, university
- Service running automatically at the remote facility
Optimization in the Cloud

Local modeling system, remote solver
- NEOS Server
- Gurobi Instant Cloud

Local analysis tools, remote model
- QuanDec

... a variety of AMPL interface alternatives
NEOS Server www.neos-server.org

Network Enabled Optimization System

- Originated 1995 at Argonne National Laboratory
  * U.S. Department of Energy
- Since 2011 at Wisconsin Institutes for Discovery
  * University of Wisconsin, Madison

Free “optimization on demand”

- Over 40 solvers
- Several optimization modeling languages
NEOS Server

Architecture

Distributed workstations
- Offer varied inputs & solvers
- Process submissions on demand
- Contributed by varied organizations

Central scheduler
- Receives and queues submissions
- Sends submissions to appropriate workstations
- Returns results

Minimal hands-on management
- Distributed: Install NEOS software on workstations
- Central: Update server database of workstation locations and abilities
NEOS Server

Original Facilities

Local submission clients
- Email
- Website
- NEOS submission tool

Problem description formats
- Linear: MPS and other solver files
- Nonlinear: Fortran or C programs
  * automatic differentiation of programs


Impact: Total Submissions

Monthly rates since 1999

Peak day: 29 Sep 2013
144890 ≈ 100 per minute

45000/month ≈ one per minute
NEOS Server

Impact: Recent Submissions

Monthly rates for past year

45000/month ≈ one per minute
NEOS Server

Assessment

Strengths

- Free
- Choice of solvers
  - Every popular solver available
- Easy to use
  - No account setup
  - No advance scheduling

Weaknesses

- Stand-alone focus: submission of “solve jobs”
- Non-profit management
  - Limited support & development
  - No guarantee of confidentiality
  - No guarantee of performance
Recent Enhancements

More flexible server infrastructure
  ➢ Based on HTCondor “high-throughput computing”

Secure user authentication
  ➢ Option to register and sign in when submitting
  ➢ Potential advantages for registered clients
    * priority job execution
    * data security
    * “more services and better customized experiences”
NEOS Server

Modeling Languages in NEOS

Modeling language inputs
- AMPL model, data, commands files
- GAMS model, options, gdx files

Modeling language operation
- User chooses a solver and a language
- NEOS scheduler finds a compatible workstation
- NEOS workstation invokes modeling language system with given inputs
- Modeling language system invokes solver

NEOS Server

Solver & Language Listing

- Linear Programming
  - BDMLP [GAMS Input]
  - bpmip [AMPL Input][LP Input][MPS Input][QPS Input]
  - Cip [MPS Input]
  - CPLEX [AMPL Input][GAMS Input][LP Input][MPS Input]
  - Gurob [AMPL Input][GAMS Input][MPS Input]
  - MOSEK [AMPL Input][GAMS Input][LP Input][MPS Input]
  - OOQP [AMPL Input]
  - SoPlex80bit [LP Input][MPS Input]
  - XpressMP [AMPL Input][GAMS Input][MOSEL Input][MPS Input]

- Model Analyzers
- Mixed Integer Linear Programming
  - Cbc [AMPL Input][GAMS Input][MPS Input]
  - CPLEX [AMPL Input][GAMS Input][LP Input][MPS Input]
  - feaspump [AMPL Input][CPLEX Input][MPS Input]
  - Gurob [AMPL Input][GAMS Input][MPS Input]
  - MINTO [AMPL Input]
  - MOSEK [AMPL Input][GAMS Input][LP Input][MPS Input]
  - proxy [CPLEX Input][MPS Input]
  - qospt_ex [AMPL Input][LP Input][MPS Input]
  - scip [AMPL Input][CPLEX Input][GAMS Input][MPS Input][OSIL Input][ZIMPL Input]
  - SYMPHONY [MPS Input]
  - XpressMP [AMPL Input][GAMS Input][MOSEL Input][MPS Input]

- Mixed Integer Nonlinearly Constrained Optimization
  - AlphaECP [GAMS Input]
  - BARON [AMPL Input][GAMS Input]
  - Bonmin [AMPL Input][GAMS Input]
  - Couenne [AMPL Input][GAMS Input]
  - DICOPT [GAMS Input]
  - FIMINT [AMPL Input]
  - Knitro [AMPL Input][GAMS Input]
  - LINDOGLOBAL [GAMS Input]
  - MINLP [AMPL Input]
NEOS Server

AMPL Input Page

CPLEX

The NEOS Server offers the IBM ILOG CPLEX Optimizer for the solution of linear programming (LP) problems that can be modeled in AMPL format.

For information on IBM Decision Optimization products, including the CPLEX Optimizer, visit IBM Decision Optimization.

For information on all IBM software available to academics, visit the IBM Academic Initiative.

Using the NEOS Server with AMPL/CPLEX

The user must submit a model in AMPL format to solve a linear program. The examples section of the AMPL website provides examples of models in AMPL format. The LP problem must be specified by a model file with the options of a data file and a commands file. If the commands file is specified, it must contain the AMPL solve command. However, the command file must not contain the model or data commands. The model and data files are renamed internally by NEOS.

Note: An email address is required for any submissions that use CPLEX. This email address will be forwarded to IBM and may be used by IBM for promotional purposes. If using the XML-RPC interface, you must add the line <email>your.address@email.edu</email> into the XML file that is sent to NEOS.
NEOS Server

AMPL Input Page

Enter the location of the AMPL model file (local file)
Model File: Browse...

Enter the location of the AMPL data file (local file)
Data File: Browse...

Enter the location of the AMPL commands file (local file)
Commands File: Browse...

Comments:
NEOS Server

AMPL Input Page
NEOS Server

Impact: Modeling Languages

Monthly rates since 2011
NEOS Server

Modeling Systems as NEOS Clients

New “solvers”
- Kestrel for AMPL
- Kestrel for GAMS

Familiar operation
- Choose Kestrel as the local “solver”
- Set an option to choose a real solver on NEOS
- Initiate a solve and wait for results

**NEOS Server**

**AMPL Interactive Session**

```ampl
ampl: model sched1.mod;
ampl: data sched.dat;
ampl: let least_assign := 16;
ampl: option solver kestrel;
ampl: option kestrel_options 'solver=cplex';
ampl: solve;
```

Connecting to: neos-server.org:3332
Job 4679195 submitted to NEOS, password='JMNRQoTD'

Check the following URL for progress report:

http://neos-server.org/neos/cgi-bin/nph-neos-solver.cgi?admin=results&jobnumber=4679195&pass=JMNRQoTD

Job 4679195 dispatched
password: JMNRQoTD

---------- Begin Solver Output ----------

Job submitted to NEOS HTCondor pool.
**NEOS Server**

**AMPL Interactive Session**

------------- Begin Solver Output -------------</br>
Job submitted to NEOS HTCondor pool.

CPLEX 12.6.2.0: optimal integer solution; objective 265.9999999999943</br>135348 MIP simplex iterations</br>17430 branch-and-bound nodes</br>
ampl: option omit_zero_rows 1, display_1col 0;</br>
ampl: display Work;</br>
Work [*] :=</br>

<table>
<thead>
<tr>
<th>Work [ ] :=</th>
<th>1 16</th>
<th>11 16</th>
<th>36 19</th>
<th>72 20</th>
<th>82 20</th>
<th>106 16</th>
<th>114 20</th>
<th>125 20</th>
<th>3 16</th>
<th>29 16</th>
<th>66 17</th>
<th>79 19</th>
<th>104 19</th>
<th>112 16</th>
<th>121 16</th>
</tr>
</thead>
<tbody>
<tr>
<td>;</td>
<td></td>
<td>121 16</td>
<td>106 16</td>
<td>114 20</td>
<td>125 20</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

ampl:
NEOS Server

Kestrel Impact

Some success

- 2013 and 2014: Peaked at over 500,000 submissions
- 2015: Dropped to only about 30,000 submissions
- 2016: Up to over 100,000 submissions so far
**NEOS Server**

**Kestrel Assessment**

**Strengths**

- Powerful local client for modeling
- NEOS facilities for solving

**Weaknesses**

- Limited support & development
- Not all NEOS solvers available
- Local solver software is strong competition . . .
  * Bundled with modeling languages
  * Free for trial use
  * Free for course and academic use
More Recently . . .

**NEOS in Solver Studio**
- Excel add-in using AMPL/GAMS models, NEOS solvers

**Optimization Services**
- Fully distributed, decentralized alternative to NEOS

**IBM Decision Optimization on Cloud**
- “DropSolve” service similar to NEOS
- “DOcplexcloud API” like NEOS API

**Gurobi Cloud Services for Optimization**
- Gurobi cloud for Amazon Web Services
- *Gurobi instant cloud*
Gurobi 7.0 Instant Cloud cloud.gurobi.com

Client side
- Standard Gurobi installation
- Cloud license

Server side
- Compute server for Gurobi solver
  - Single-machine solves
  - Distributed MIP solves
  - Distributed tuning
- Server pools with load balancing

. . . hosted on Amazon Web Services

“Cloud computing technology is changing quickly. Please check these documents periodically to ensure you have the latest instructions for the Gurobi Cloud.”
Gurobi Instant Cloud for AMPL

Client side
- AMPL installation (command-line or IDE)
- Standard Gurobi-for-AMPL installation

Server side
- Gurobi compute server
- Gurobi optimizer
Gurobi Instant Cloud for AMPL

www.gurobi.com
Gurobi Instant Cloud for AMPL

www.gurobi.com
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ngcloud.gurobi.com
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View Available Licenses
# This is a license file created by the Gurobi Instant Cloud
# Created on Mon, 17 Oct 2016 20:46:26 GMT
# License Id: 142032
# Place this file in your home directory or one of the following locations where XXX is the Gurobi Optimizer version you are using:
#   * C:\gurobi\ or C:\gurobiXXX\ on Windows
#   * /opt/gurobi/ or /opt/gurobiXXX/ on Linux
#   * /Library/gurobi/ or /Library/gurobiXXX/ on Mac OS X
# Or set environment variable GRB_LICENSE_FILE to point to this file
# Do not share this license file because it contains your secret key

CLOUDACCESSID=fedf3901-04f1-44d7-9725-e36c1c3f70f6
CLOUDKEY=0v9XdWrDQLiE3iAAEKtFw
CLOUDHOST=ngcloud.gurobi.com
Gurobi Instant Cloud for AMPL

Use with AMPL: Setup

```bash
ampl: model multmip3.mod;
ampl: data multmip3.dat;
ampl: option solver gurobi;
ampl: option gurobi_options
ampl?  'cloudid=fedf3901-04f1-44d7-9725-e36c1c3f70f6 \
ampl?    cloudkey=0v9XdWrDQLiE3EiAAEKtFw';
ampl:
```
Use with AMPL: Startup

ampl: model multmip3.mod;
ampl: data multmip3.dat;
ampl: option solver gurobi;
ampl: option gurobi_options
ampl?  'cloudid=fedf3901-04f1-44d7-9725-e36c1c3f70f6 \
ampl?  cloudkey=0v9XdWrDQLiE3EiAAEKFw';
ampl: solve;

Gurobi 7.0.0: cloudid=fedf3901-04f1-44d7-9725-e36c1c3f70f6
cloudkey=0v9XdWrDQLiE3EiAAEKFw

Waiting for cloud server to start............
Gurobi Instant Cloud for AMPL

Use with AMPL: Solve

ampl: model multmip3.mod;
ampl: data multmip3.dat;
ampl: option solver gurobi;
ampl: option gurobi_options
ampl? 'cloudid=fedf3901-04f1-44d7-9725-e36c1c3f70f6 \ ampl? cloudkey=0v9XdWrDQLiE3EiAAEkFw';
ampl: solve;
Gurobi 7.0.0: cloudid=fedf3901-04f1-44d7-9725-e36c1c3f70f6 cloudkey=0v9XdWrDQLiE3EiAAEkFw
Waiting for cloud server to start.............
Capacity available on 'default' cloud pool - connecting...
Established 256-bit AES encrypted connection
Gurobi 7.0.0: optimal solution; objective 235625
289 simplex iterations
25 branch-and-cut nodes
plus 35 simplex iterations for intbasis
ampl:
Gurobi Instant Cloud for AMPL

Use with AMPL: Continue

```ampl
ampl: display {i in ORIG, j in DEST} sum {p in PROD} Trans[i,j,p];

:    DET  FRA  FRE  LAF  LAN  STL  WIN  :=
CLEV  625   375   550  0    500  550  0        
GARY  0     0     400  0    625  375            
PITT  525   525   625  600  0    625  0        
;

ampl: reset data;
ampl: data multmip3a.dat;
ampl: solve;

Gurobi 7.0.0: cloudid=fedf3901-04f1-44d7-9725-e36c1c3f70f6
cloudkey=0v9XdWrDQLiE3EiAAEKtFw

Capacity available on 'default' cloud pool - connecting...
Established 256-bit AES encrypted connection

Gurobi 7.0.0: optimal solution; objective 238450
163 simplex iterations
plus 33 simplex iterations for intbasis

ampl:
```
Gurobi Instant Cloud for AMPL

Manage Server Configuration
Gurobi Instant Cloud for AMPL

Check Costs

Cost Estimate

1 compute server will be launched.

You will be charged $0.838 per hour for the machine costs.

You will be charged $0 per hour for the Gurobi license.

OK
Gurobi Cloud Costs

**Commercial plans**
- Annual subscription fee, *plus*
- Hourly rates for use:
  - Gurobi rate for compute servers
  - Amazon rate for distributed workers

**Trials, academic use, special grants**
- Amazon rate only
  
  ... set up through sales rep
Gurobi Cloud for AMPL: Assessment

Strengths

- Security
- Reliability (via Amazon)
- Support for multi-server and/or multi-worker pools
- Support for local modeling clients

Drawbacks (compared to NEOS)

- Not free
  - Budgeting can be complicated
- Solver-specific
- Not quite “optimization on demand”
QuanDec

Server side
- AMPL model and data
- Standard AMPL-solver installations

Client side
- Interactive tool for collaboration & decision-making
- Runs on any recent web browser
- Java-based implementation
  - AMPL API for Java
  - Eclipse Remote Application Platform

...developed / supported by Cassotis Consulting
The web-based graphical interface that turns optimization models written in AMPL into decision-making tools.
Features

Server application
Centralized data
Several models on a single server

Web-based
Multi-users
Concurrent access
Secure access

Scenario-based
Sharing between users
Sharing rights
(edit / comment / view)

And much more…

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**Getting started**

**step 1:** install QuanDec on a server

**step 2:** copy & paste your model files (.mod and .dat) into QuanDec’s workspace

**step 3:** create AMPL tables and link them to QuanDec explorer
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Web-application
Multi-user
Secure access
Concurrent access
Scenario-based environment

Sharing system

Permission: Edit – Comment - View
3 levels:
- Report
- Input parameters
- Variables

Chart and tables

Colored values for easier analysis

Constraint (min/max) on any variable
Collaborative work
Notification system
Comments between users
Scenarios with changes history
Traceability and undo system
### Scenarios comparison

All variables can be compared

Display of relative difference

Custom reports

<table>
<thead>
<tr>
<th>Variable</th>
<th>Unit</th>
<th>BUDGET 2016</th>
<th>My Scenario</th>
<th>Diff</th>
</tr>
</thead>
<tbody>
<tr>
<td>Net production level</td>
<td>kt</td>
<td>1763.98</td>
<td>1764.25</td>
<td>0.02%</td>
</tr>
<tr>
<td>'PLT' CO</td>
<td>kt</td>
<td>4085.77</td>
<td>4084.46</td>
<td>-0.03%</td>
</tr>
<tr>
<td>'PLT' SI</td>
<td>kt</td>
<td>5063.62</td>
<td>5060.51</td>
<td>-0.05%</td>
</tr>
</tbody>
</table>

Select the scenarios to compare:

- BUDGET 2015
- BUDGET 2016
- My Scenario
- FORECAST 2017
Sensitivity analysis

For both parameters AND variables

All variables can be compared

Display of relative difference

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Predefined analyses

Script parameters
QuanDec Availability

*Ready now for commercial applications*
- Free trials available
- Pricing keyed to number of models & users

*First year’s support included*
- Tailored setup support from Cassotis Consulting
- Customizations possible

... contact sales@AMPL.com for details