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

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Technology Tutorials — Monday, 2:10-3:00 pm
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 until you get it right!

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
- Solver’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
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

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

```AMPL
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  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 12.7.0.0: 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 7.0.0: 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)

Solver choice independent of model and data

```
ampl: model cut.mod;
ampl: data cut.dat;
ampl: option solver gurobi;
ampl: solve;
Xpress 29.01: Best integer solution found 20
3 integer solutions have been found; 1 branch and bound node
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

Optimization on demand
- NEOS Server

Optimization by subscription
- Gurobi Instant Cloud

Building optimization apps
- QuanDec

... more AMPL alternatives on the way!
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
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 \approx 100 \text{ per minute}

45000/\text{month} \approx \text{one per minute}
**NEOS Server**

**Impact: Recent Submissions**

*Monthly rates for past year*

45000/month $\approx$ 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
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
  - BDMPLP (GAMS Input)
  - bpmip (AMPL Input, LP Input, MPS Input)
  - Clp (MPS Input)
  - CPLEX (AMPL Input, GAMS Input, LP Input, MPS Input)
  - FICO-Xpress (AMPL Input, GAMS Input, MOSEL Input, MPS Input)
  - Gurobi (AMPL Input, GAMS Input, MPS Input)
  - MOSEK (AMPL Input, GAMS Input, LP Input, MPS Input)
  - OOQP (AMPL Input)
  - SoPlex 8.0 (LP Input, MPS Input)

- Mathematical Programs with Equilibrium Constraints
  - filterMPEC (AMPL Input)
  - Knitro (GAMS Input)
  - NLPEC (GAMS Input)

- 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)
  - FICO-Xpress (AMPL Input, GAMS Input, MOSEL Input, MPS Input)
  - Gurobi (AMPL Input, GAMS Input, MPS Input)
  - MINTO (AMPL Input)
  - MOSEK (AMPL Input, GAMS Input, LP Input, MPS Input)
  - proxy (CPLEX Input, MPS Input)
  - qsopt_ex (AMPL Input, LP Input, MPS Input)
  - scip (AMPL Input, CPLEX Input, GAMS Input, MPS Input)
  - SYMPHONY (MPS Input)

- Mixed Integer Nonlinearly Constrained Optimization
  - AlphaECP (GAMS Input)
  - BARON (AMPL Input, GAMS Input)
  - Bonmin (AMPL Input, GAMS Input)
NEOS Server

AMPL Input Page

NEOS Server: CPLEX

NEOS Interfaces to CPLEX
WWW Form & Sample Submissions Email XML-RPC

CPLEX
The NEOS Server offers the IBM ILOG CPLEX Optimizer for the solution of mixed-integer linear programming (MILP) 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 mixed-integer linear program. The examples section of the AMPL website provides examples of models in AMPL format.
The MILP 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.
The commands file may include option settings for CPLEX. To specify solver options, add
**NEOS Server**

**AMPL Input Page**
NEOS Server
AMPL Input Page

![NEOS Server AMPL Input Page](image-url)
**NEOS Server**

**Impact: Modeling Languages**

*Monthly rates since 2011*

![Bar chart showing monthly rates for AMPL+GAMS and All Other from 2011 to 2016]
NEOS Server

APIs

Application programming interfaces
- Access NEOS from a local program

Implementations
- Version 1: XML-RPC remote procedure call
- Version 5: full Python API

Uses
- NEOS submission tool
- NEOS option in Solver Studio for Excel
- NEOS as a “solver” for modeling systems
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.
```
### AMPL Interactive Session

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

Job submitted to NEOS HTCondor pool.

CPLEX 12.6.2.0: optimal integer solution; objective 265.9999999999943
135348 MIP simplex iterations
17430 branch-and-bound nodes

ampl: option omit_zero_rows 1, display_1col 0;

ampl: display Work;

Work [*] :=

<p>| | | | | | | | | | | | | | | | |</p>
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</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: Back up to 100,000 submissions
NEOS Server

Kestrel Assessment

Strengths
- Powerful local client for modeling
- NEOS facilities for solving

Weaknesses
- 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
- Limited support & development
Recent Developments

Intensified support

- Shift to HTCondor “high-throughput” platforms
- Updated Kestrel client
- Updated solver offerings

User accounts

- Higher priority for job scheduling
- “My Jobs” tab listing recent jobs & links to results
Other Offerings Like NEOS

IBM Decision Optimization on Cloud

- “DropSolve” service similar to NEOS
- “DOcplexcloud API” like NEOS API

Satalia

- Chooses a solver for you
- Pays royalties to clients and to solvers
- Currently sold on subscription . . .
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

An easier way to make better decisions

The state-of-the-art mathematical programming solver for prescriptive analytics

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Gurobi builds and supports the best math programming solvers available for all major problem types. It’s all we do...

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We are offering two free training events for commercial users, one presented in English and another presented in German.

In these hands-on and interactive training events you will:

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Gurobi Instant Cloud for AMPL

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Get Gurobi License File

# 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=0v9XdWrDQLiE3EiAAEKtFw
CLOUDHOST=ngcloud.gurobi.com
**Gurobi Instant Cloud for AMPL**

**Use with AMPL: Setup**

```
ampl: model multip3.mod;
ampl: data multip3.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
ampl: model multmip3.mod;
ampl: data multmip3.dat;
ampl: option solver gurobi;
ampl: option gurobi_options
ampl? 'cloudid=fedf3901-04f1-44d7-9725-e36c1c3f70f6 \nampl?   cloudkey=0v9XdWrDQLiE3EiAAEktFw';
ampl: solve;
Gurobi 7.0.0: cloudid=fedf3901-04f1-44d7-9725-e36c1c3f70f6
cloudkey=0v9XdWrDQLiE3EiAAEktFw
Waiting for cloud server to start...........
```
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=0v9XdWrDQLiE3EiAAEkTfW';
ampl: solve;

Gurobi 7.0.0: cloudid=fedf3901-04f1-44d7-9725-e36c1c3f70f6
cloudkey=0v9XdWrDQLiE3EiAAEkTfW

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:
Use with AMPL: Continue

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 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: clouid=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

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.
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…
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
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
### Scenario comparison

All variables can be compared

Display of relative difference

Custom reports
Sensitivity analysis

For both parameters AND variables

All variables can be compared

Display of relative difference
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