GAMS: A High Performance Modeling System for Large-Scale Modeling Applications

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Agenda

• Overview of Modeling Systems
  – Why use Modeling Systems? (Past and Present)
  – Language Syntax
  – GAMS Features?
  – Solvers and Other Features

• Illustrative Examples
  – Solving Models and Quick Modifications
  – Interfacing with Office Applications
  – Full Web Integration Example

• Conclusions
Modeling Systems

Software systems for decision making:

- **Optimization** problems (max profit/min cost)
- **Simplify** the model building and solution process
- Create **maintainable** models
- **Adapt** models quickly to new situations
Modeling: Past

In the early years: Implementation (software) was cumbersome:
• Problem-specific
• Platform-specific
• Required high technical skills
• Models not easily maintainable or adaptable

Today: modeling languages are (roughly)
• a means of describing problems to a computer system in the same way that people describe those problems to each other.
Modeling Systems: Present

Real World Problem

Focus is on application

Analyst

Focus is on technical details

GAMS
Data ↔ Model ↔ Solution

Focus is on technical details

Operating System
Computer Languages
Solution Packages

Decision-making problem

Formulate as GAMS model

Solve on any platform using any solver

Formulate as GAMS model
Basic Technical Principles

GAMS principles:

- **Separation** of model and solution methods
- Computing **platform independence**
- **Multiple** model types, solvers, platforms
- Balanced mix of declarative and procedural approaches
- Model is a **data base operator** and/or object
GAMS Language Example

Transport:

Minimize: Transportation cost (distance & units)
Subject to: Demand satisfaction at markets
            Supply constraints

San Diego  650
           / 2.5  1.4 1.8
           /      / 2.5 1.8
           /      /      1.7
 Seattle  350  
           New York 325
           Topeka 275
           Chicago 300
Transport Model (IDE)

Sets
i   canning plants / seattle, san-diego /
j   markets / new-york, chicago, topeka / ;

Parameters
a(i)  capacity of plant i in cases,
b(j)  demand at market j in cases;

Parameter c(i,j)  transport cost in thousands of dollars per case ;

Variables
x(i,j)  shipment quantities in cases
z  total transportation costs in thousands of dollars ;
Positive Variable x ;

Equations
cost       define objective function
supply(i)  observe supply limit at plant i
demand(j)  satisfy demand at market j ;

cost ..  
  
  z =e=  sum(i,j), c(i,j)*x(i,j)) ;
supply(i) ..  
  
  sum(j, x(i,j)) =e=  a(i) ;
demand(j) ..  
  
  sum(i, x(i,j)) =e=  b(j) ;

Model m1 /cost, supply, demand/ ;
Solve m1 using lp minimizing z ;
Display x.l, x.m ;
Transport Model With Data

Sets
i  canning plants / seattle, san-diego / 
j  markets / new-york, chicago, topeka / ;

Parameters
a(i) capacity of plant i in cases 
    seattle 350
    san-diego 600 /

b(j) demand at market j in cases
    new-york 325
    chicago 300
    topeka 275 / ;

Table d(i,j) distance in thousands of miles
       new-york  |  chicago  |  topeka  |
seattle     2.5  |   1.7   |   1.8   |
san-diego   2.5   |   1.8   |   1.4   |

Scalar f freight in dollars per case per thousand miles /90/ ;
Parameter c(i,j) transport cost in thousands of dollars per case ;
c(i,j) = f * d(i,j) / 1000 ;

Variables
x(i,j) shipment quantities in cases
z  total transportation costs in thousands of dollars ;

Positive Variable x ;

Equations
cost  define objective function
supply(i) observe supply limit at plant i
demand(j) satisfy demand at market j ;
Features

GAMS:

- Offers **single point of support**
- Large number of **model types**
- Multiple platforms
- State of the art **solvers**
- Large user base (10,000 of customers in over 100 countries)
- Large **model library** and public models
- GAMS **User List**
Multiple Model Types

Includes:

- **LP** - Linear Programming
- **MIP** - Mixed Integer Programming
- **QCP** - Quadratically Constrained Programming
- **NLP** - Nonlinear Programming
- **CNS** – Constrained Nonlinear Systems
- **MINLP** - Mixed Integer Nonlinear Programming
- **MPEC** - NLP with Complementarity Constraints
- **MPSGE** - General Equilibrium Models
- **Stochastic Optimization**
# Supported Platforms

<table>
<thead>
<tr>
<th>Solver/Platform availability - 21.4</th>
<th>September 6, 2004</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Intel</strong></td>
<td><strong>Sun Sparc</strong></td>
</tr>
<tr>
<td>Windows 95/98/Me/NT/2000/XP</td>
<td>Linux</td>
</tr>
<tr>
<td>BARON 7.2</td>
<td>✓</td>
</tr>
<tr>
<td>BDMLP</td>
<td>✓</td>
</tr>
<tr>
<td>CONOPT 3</td>
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</tr>
<tr>
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<td>✓</td>
</tr>
<tr>
<td>CPLEX 9.0</td>
<td>✓</td>
</tr>
<tr>
<td>DECIS</td>
<td>✓</td>
</tr>
<tr>
<td>DICOPT</td>
<td>✓</td>
</tr>
<tr>
<td>LGO</td>
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</tr>
<tr>
<td>MILES</td>
<td>✓</td>
</tr>
<tr>
<td>MINOS</td>
<td>✓</td>
</tr>
<tr>
<td>MOSEK 3.0</td>
<td>✓</td>
</tr>
<tr>
<td>MPSGE</td>
<td>✓</td>
</tr>
<tr>
<td>MSNLP</td>
<td>✓</td>
</tr>
<tr>
<td>NLPEC</td>
<td>✓</td>
</tr>
<tr>
<td>OQNLP</td>
<td>✓</td>
</tr>
<tr>
<td>OSL V3</td>
<td>✓</td>
</tr>
<tr>
<td>PATH</td>
<td>✓</td>
</tr>
<tr>
<td>PATHNLCP</td>
<td>✓</td>
</tr>
<tr>
<td>SBB</td>
<td>✓</td>
</tr>
<tr>
<td>SNOPT</td>
<td>✓</td>
</tr>
<tr>
<td>XA</td>
<td>✓</td>
</tr>
<tr>
<td>XPRESS 2004</td>
<td>✓</td>
</tr>
</tbody>
</table>

For backward compatibility we maintain older versions of operating systems and solvers. Please call.
### Supported Solvers

<table>
<thead>
<tr>
<th>Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>BARON</td>
<td>Branch-And-Reduce Optimization Navigator for proven global solutions from The Optimization Firm.</td>
</tr>
<tr>
<td>EDMPLP</td>
<td>LP solver that comes with any GAMS system</td>
</tr>
<tr>
<td>COIN</td>
<td>Link to the solvers in the COIN-OR project (Computational Infrastructure - Operations Research).</td>
</tr>
<tr>
<td>CONOPT</td>
<td>Large scale NLP solver from ARKI Consulting and Development</td>
</tr>
<tr>
<td>CONVERT</td>
<td>Framework for translating models into scalar models of other languages</td>
</tr>
<tr>
<td>CPLEX</td>
<td>High-performance LP/MIP solver from ILOG</td>
</tr>
<tr>
<td>DECIS</td>
<td>Large scale stochastic programming solver from Stanford University</td>
</tr>
<tr>
<td>DICOPT</td>
<td>Framework for solving MINLP models, from Carnegie Mellon University</td>
</tr>
<tr>
<td>EXAMINER</td>
<td>A tool for examining solution points and assessing their merit</td>
</tr>
<tr>
<td>GAMSBSAS</td>
<td>A Program for Saving an Advanced Basis for GAMS</td>
</tr>
<tr>
<td>GAMSCHK</td>
<td>A System for Examining the Structure and Solution Properties of Linear Programming Problems Solved using GAMS</td>
</tr>
<tr>
<td>LGO</td>
<td>Lipschitz global optimizer from Fister Consulting Services</td>
</tr>
<tr>
<td>MILES</td>
<td>MCP solver from University of Colorado at Boulder that comes with any GAMS system.</td>
</tr>
<tr>
<td>MINOS</td>
<td>NLP solver from Stanford University</td>
</tr>
<tr>
<td>MOSEK</td>
<td>Large scale LP/MIP plus conic and convex non-linear programming system from BKA Consulting</td>
</tr>
<tr>
<td>MPSGE</td>
<td>Modeling Environment for CGE models from University of Colorado at Boulder</td>
</tr>
<tr>
<td>MPSWRITE</td>
<td>MPS file generator that comes with any GAMS System</td>
</tr>
<tr>
<td>MSNLPH</td>
<td>Multi-start method for global optimization from Optimal Methods Inc.</td>
</tr>
<tr>
<td>NLPEC</td>
<td>MPBSC to NLP translator that uses other GAMS NLP solvers</td>
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</tr>
<tr>
<td>OSL</td>
<td>High performance LP/MIP solver from IBM</td>
</tr>
<tr>
<td>OSLSR</td>
<td>OSL Stochastic Extensions for solving stochastic models</td>
</tr>
<tr>
<td>PATH</td>
<td>Large scale MCP solver from University of Wisconsin at Madison</td>
</tr>
<tr>
<td>PATHNLPL</td>
<td>Large scale NLP solver for convex problems from University of Wisconsin at Madison</td>
</tr>
<tr>
<td>SBB</td>
<td>Branch-and-Bound algorithm from ARKI for solving MINLP models</td>
</tr>
<tr>
<td>SCENRED</td>
<td>A tool for the reduction of scenarios modeling the random data processes</td>
</tr>
<tr>
<td>SNOPT</td>
<td>Large scale SQP based NLP solver from Stanford University</td>
</tr>
<tr>
<td>XA</td>
<td>Large scale LP/MIP system from Sunset Software</td>
</tr>
<tr>
<td>XPRESS</td>
<td>High performance LP/MIP solver from Dash</td>
</tr>
</tbody>
</table>

29 supported solvers (including global solvers) plus several contributed plug and play solvers.
• Using the GAMS IDE
• Modifying models to handle new situations
Sets
i  canning plants / seattle, san-diego /
j  markets / new-york, chicago, topeka /;

Parameters
a(i)  capacity of plant i in cases
/  seattle 350
    san-diego 600 /

b(j)  demand at market j in cases
/  new-york 325
    chicago 300
    topeka 275 /

Table d(i,j)  distance in thousands of miles

<table>
<thead>
<tr>
<th></th>
<th>new-york</th>
<th>chicago</th>
<th>topeka</th>
</tr>
</thead>
<tbody>
<tr>
<td>seattle</td>
<td>2.5</td>
<td>1.7</td>
<td>1.8</td>
</tr>
<tr>
<td>san-diego</td>
<td>2.5</td>
<td>1.8</td>
<td>1.4</td>
</tr>
</tbody>
</table>

Scalar f  freight in dollars per case per thousand miles /90/ ;

Parameter c(i,j)  transport cost in thousands of dollars per case ;

\[ c(i,j) = f \times d(i,j) / 1000 ; \]
Min/Max Shipments – MIP

Add additional constraints: (m2.gms)

Min/max shipments

Scalars xmin / 100 /,
    xmax / 275 /;

Binary variables ship(i,j) decision variable to ship

Equations minship(i,j) minimum shipments
    maxship(i,j) maximum shipments ;

Minship(i,j)... x(i,j) =g= xmin*ship(i,j);
Maxship(i,j)... x(i,j) =l= xmax*ship(i,j);

Model m2 / cost, supply, demand, minship, maxship /;

Solve m2 using mip minimizing z;

Restart using "r=m1" option
Nonlinear Cost – NLP

Change objective function: (m3.gms)

Scalar 
beta;

Equations nlcost) Nonlinear cost function ;

Nlcost... z =e= sum( (i,j), c(I,j)*x(i,j)**beta); 

Model m3 / nlcost, supply, demand /;

Beta = 1.5;
Solve m3 using nlp minimizing z;

Beta = 0.6;
Solve m3 using nlp minimizing z;

Restart using “r=m1” option
Min/max and NL Cost – MINLP

Add both the nonlinear function nlcost and the max/min shipment constraints:
(m4.gms)

Model m4 / nlcost, supply, demand, minship, maxship /;

Option minlp = baron;
Solve m4 using minlp minimizing z;

Option minlp = sbb; Option nlp=snopt;
Option optcr=0;
Solve m4 using minlp minimizing z;

Restart using “r=m1” option
[ Done With Demo ]
Other Language Features

- For and while loops
- If – else constructs
- Unix-like data manipulation utilities for Windows (grep, awk, sed, etc.)
- Statistical functions (distributions)
## Change in Focus (Future)

### Computation

**Past**
- Algorithm limits applications
- Problem representation is low priority
- Large costly projects
- Long development times
- Centralized expert groups
- High computational cost, mainframes
- Users left out

**Present**
- Modeling skill limits applications
- Algebraic model representation
- Smaller projects
- Rapid development
- Decentralized modeling teams
- Low computational cost, workstations
- Machine independence
- Users involved

### Model

**Present**
- Modeling skill limits applications
- Algebraic model representation
- Smaller projects
- Rapid development
- Decentralized modeling teams
- Low computational cost, workstations
- Machine independence

### Application

**Present/Future**
- Domain expertise limits application
- Off-the-shelf graphical user interfaces
- Links to other types of models
- Models embedded in business applications
- New computing environments
- User hardly aware of model

---

User hardly aware of model

---
New Challenges

Model only *small component* of a complex application:

Particular emphasis on

- Need to *interface* with databases
- Interface with other *analytic/visualization engines*
- Embed in *web-based applications*
Interfacing

GAMS offers full range of **interfacing capabilities**:

- Data Import/Export from *Standard Applications*
  - MS Office, Databases, Text Files,...
- Execute programs from within GAMS (including another GAMS job itself)
- Call GAMS from complex applications
- Visualization tools
Scenario: Import/Export Data

- External Database
  - Text Files
  - Direct Interface (Office Appl.)
- GAMS
  - Text Files
  - Direct Interface (Office Appl.)

Import

Export
Embedding

- External Application
  - Call GAMS
  - Call external program (including GAMS)

GAMS

- Programming Language or other Application

Application
Examples – MapInfo

Increase in Ktons Per Year

- Less Than 0
- 0 - 199
- 200-1000
- 1000-3000
Examples - GnuPlot

Relative objective difference within 0 (wrt to best value) - data file: profile_0.txt
Examples – GAMS/MATLAB
Total average yearly $\text{NO}_x$ immission

Coupling GIS databases with models permits efficient data handling, preparation of scenarios, displays of results, animations.

GIS computations permit the evaluation of spatially related costs or technical coefficients.

scale: $10 \ \mu g/m^3$-$200 \ \mu g/m^3$
Various Front Ends

Client Model: Electricity Market
Various Front Ends

Client Model: Gasoline Blending
Illustrative Examples

- Writing to Excel
- Reading from Access
- Embedding in another application

Real-world scenario

- Likely will involve the model being only a small component of the application
# Excel Example

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>seattle</td>
<td></td>
<td>mip</td>
<td>nlp-convex</td>
<td>nlp-noncon</td>
<td>minlp</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>new-york</td>
<td>50</td>
<td>150</td>
<td>142.38408</td>
<td>300</td>
<td>117.4423</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>chicago</td>
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<td>200</td>
<td>130.92994</td>
<td>300</td>
<td>117.4423</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>topeka</td>
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<td></td>
<td>100</td>
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<tr>
<td>5</td>
<td>new-york</td>
<td>275</td>
<td>175</td>
<td>182.61592</td>
<td>325</td>
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<tr>
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<td>182.5577</td>
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<tr>
<td>7</td>
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<td>275</td>
<td>175</td>
<td></td>
</tr>
</tbody>
</table>
Fully Embedded Application

WEB CLIENT

Web Front End

Communication via HTML/JAVA Servlets

Graph Solution as HTML (JAVA Servlets)

SERVER

Server

Get data using JDBC (.txt file)

JAVA Servlet Calls GAMS (batch file)

Return Solution (.txt file)

BACK END APPLICATION

GAMS

Get data using GAMS interface

Access / Excel Database

Access Database
Communication via .txt files

Comma-delimited format most common for large scale applications:

Call GAMS using batch file (runit.cmd)
Sample File Formats

runit.cmd (Server executes GAMS)

```bash
cd C:\gamsprojects\conferences\informs2004\models\C:\gams\21.4\gams portfolio_%1.gms lo=3 pf=pf.inc
REM in case of problems send zip file to administrator
C:\gams\21.4\gmszip log.zip portfolio_%1.gms portfolio_%1.lst *.log *.inc
```

value.jdbc.inc (Database sample input to GAMS)

```plaintext
GAB,951127,9.25
GAB,951128,9.25
GAB,951129,9.25
GAB,951130,9.5
```

results.txt (GAMS solution input to server)

```plaintext
MODELSTATUS,2.00
SOLVERSTATUS,1.00
GAB,28.05
GAP,0.00
GDW,0.00
GE,0.00
```
• Writing to Excel (m5.gms)
• Reading from Access (portfolio_access.gms)
• Web application (portfolio.htm using a local server)
User may specify:

- Expected Return
- Investment Period (Days)
- Number of Stocks
- Solver
- Database (Excel or Access using GAMS interface or Access using JAVA JDBC)

Portfolio Optimization Using GAMS

This application illustrates embedding GAMS into a real-world web-based financial application. The model used is the financial optimization model `portfolio.gms`, which minimizes the risk given a user-specified expected return.

The submitted data is passed on to the server, which solves the model using GAMS and returns the results in real-time back to the client browser.

Minimum Return (in %): 25
Period (in days): 30 Days
Number of Stocks (1-170): 10
Solver: MINOS
Back-end Database: Excel

Background

A standard formulation for the optimal portfolio problem looks like:

\[
\begin{align*}
\min & \quad x'Qx \\
\text{subject to} & \quad r'x \geq R \\
& \quad Ax = b \\
& \quad x \geq 0
\end{align*}
\]

The Q matrix is often a variance-covariance matrix, r(i) is the return on investment instrument i and R is the required return on the portfolio.
Output:

- User input parameters
- Real-time GAMS output of model solve
Output:

- GAMS Return Codes
- Investment distribution
- Graphical output
[ Done With Demo ]
Download GAMS

Free fully functional demo available for download

www.gams.com/download

Contains all available GAMS solvers.
Contacting GAMS

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Phone +49 (221) 949-9170
Information/Sales/ Technical Support: info@gams.de