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<td><strong>GAMS Development / GAMS Software</strong></td>
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<td>GAMS at a Glance</td>
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<tr>
<td>An illustrative Example: The Mean Variance Model</td>
</tr>
<tr>
<td>Grid Computing</td>
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</tbody>
</table>
• Roots: Research project
World Bank 1976
• Pioneer in Algebraic
Modeling Systems
used for economic modeling
• Went commercial in 1987
• Offices in Washington, D.C
and Cologne

• Professional software tool
provider, not a consulting company
• Operating in a segmented
niche market
• Broad academic &
commercial user base
and network
Typical Application Areas *

- Agricultural Economics
- Chemical Engineering
- Econometrics
- Environmental Economics
- Finance
- International Trade
- Macro Economics
- Management Science/OR
- Micro Economics
- Applied General Equilibrium
- Economic Development
- Energy
- Engineering
- Forestry
- Logistics
- Military
- Mathematics
- Physics

* Illustrative examples in the GAMS Model Library
GAMS Solutions Specialists Network

Details at: http://www.gams.com/specialists/

Companies with wide experience in GAMS modeling
## Agenda

- GAMS Development/GAMS Software
- **GAMS at a Glance**
- An illustrative Example: The Mean Variance Model
- Grid Computing
GAMS at a Glance

**General Algebraic Modeling System:**

**Design Principles:**
- Balanced mix of declarative and procedural elements
- Open architecture and interfaces to other systems
- Different layers with separation of:
  - model and data
  - model and solution methods
  - model and operating system
  - model and interface
More GAMS Features

- State of art professional modeling technology
- Increased productivity
- Robust and scalable
- Rapid development
- Broad Network
- Large model libraries with templates
- Multiple Model Types
- Platform / Solver independence:
  - Protection of investments
  - Maintainable models
**System Overview**

**Connectivity Tools**
- Uniform Data Exchange:
  - ASCII
  - GDX (ODBC, SQL, XLS, XML)
- GDX Tools
- Data API
- Ext. programs
  - EXCEL
  - MATLAB
  - GNUPLOT, ...
  - C, Delphi, ...

**GAMS Language Compiler and Execution System**

**Solvers**
- LP-MIP-QCP-MIQCP-NLP-MINLP-CNS-MCP-MPEC
- MPSGE, global, and stochastic optimization

**Productivity Tools**
- Integrated Development Environment
- Model Debugger and Profiler
- Model Libraries
- Data Browser
- Charting Engine
- Benchmarking
- Deployment System
- Quality Assurance and Testing

**User Interfaces**

**Interactive**

**API / Batch**

**Productivity Tools**
- BARON, COIN, CONOPT, CPLEX, DECIS, DICOPT, KNITRO, LGO, MINOS, MOSEK, OQNLP, PATH, SNOPT, XA, XPRESS, ...
## Multiple Solvers & Platforms

<table>
<thead>
<tr>
<th>Solver/Platform availability - 22.2</th>
<th>April 21, 2006</th>
</tr>
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<tr>
<td><strong>x86</strong> MS Windows</td>
<td><strong>x86 64</strong> MS Windows</td>
</tr>
<tr>
<td>BARON 7.5</td>
<td>✓</td>
</tr>
<tr>
<td>BDMLP</td>
<td>✓</td>
</tr>
<tr>
<td>COIN</td>
<td>✓</td>
</tr>
<tr>
<td>CONOPT 3</td>
<td>✓</td>
</tr>
<tr>
<td>CPLEX 10.0</td>
<td>✓</td>
</tr>
<tr>
<td>DECIS</td>
<td>✓</td>
</tr>
<tr>
<td>DICOPT</td>
<td>✓</td>
</tr>
<tr>
<td>KNITRO 4.0</td>
<td>✓</td>
</tr>
<tr>
<td>LGO</td>
<td>✓</td>
</tr>
<tr>
<td>MILES</td>
<td>✓</td>
</tr>
<tr>
<td>MINOS</td>
<td>✓</td>
</tr>
<tr>
<td>MOSEK 3.2</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>
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<td>OQNLP</td>
<td>✓</td>
</tr>
<tr>
<td>OSL V3</td>
<td>✓</td>
</tr>
<tr>
<td>OSLSE</td>
<td>✓</td>
</tr>
<tr>
<td>PATH</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 16.10</td>
<td>✓</td>
</tr>
</tbody>
</table>

For backward compatibility we maintain older versions of operating systems and solvers. Please call.
Integrated Development Environment
Interfacing with different Applications
Gams Data eXchange

Binary Data Exchange

- complements ASCII data exchange
- Data exchange at any stage
  - Supports ODBC and XML
  - Direct Excel connectivity
  - General API
  - Visual Data Inspector
  - Scenario Management Support
  - Full Support of Batch Runs

GDX Tools

GDX

GDX Viewer
GDXRank
GDXMerge
GDXDump
GDXDiff
IDE
GDX API
GAMS
GDXxrw (MS Office)
GDX Viewer
GDXDiff
GDXMerge
GDXRank
GDXDump
GDXDiff
IDE
GDX API
GAMS
GDXxrw (MS Office)
Interfacing with GIS Applications

Increase in Ktons Per Year
- Less Than 0
- 0-199
- 200-1000
- 1000-3000
Interfacing with MATLAB

Figure 1: US dollar short rate scenarios

Figure 2: Short vs. long rates
Interfacing with GNUPLOT
<table>
<thead>
<tr>
<th>SeqNr</th>
<th>Name</th>
<th>Application Area</th>
<th>Type</th>
<th>Contributor</th>
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Dynamic open pit mining extraction (OPENFPl, SEQ=309)

This is an example of how to model material extractions that have sequencing requirements with a multi-period decision process. A segment has to be extracted completely before we can start on the next segment. Segments not completely extracted have to be extracted in the next time period or remain partially extracted in the last time period. The requirement of full extraction adds complications to the modeling within the multi-period framework.

Reference:
GAMS Development corporation, formulation and Language Example.

... currently more than 316 models from various areas
Benchmarking

- BENCH -"solver":

```
Benchmark Summary:
Solver     Modstat solstat  objective  ResUsd  Examiner
---------- --------------- ---------- ------- -------
BDMLP      1               1  153.6750  0.000   P/P
COINCBC    1               1  153.6750  0.000   P/P
COINGLPK   1               1  153.6750  0.047   P/P
CONOPT     1               1  153.6750  0.015   P/P
Cplex      1               1  153.6750  0.016   P/P
MINOS      1               1  153.6750  0.141   P/P
MOSEK      1               1  153.6750  0.093   P/P
PAMPLP     1               1  153.6750  0.000   P/P
SNOPRT     1               1  153.6750  0.015   P/P
XA         1               1  153.6750  0.031   P/P
XPRESS     1               1  153.6750  0.000   P/P

--- Restarting execution
--- trnsport.gms(66) 0 Mb
--- Reading solution for model transport
--- Executing after solve
--- trnsport.gms(67) 3 Mb
*** Status: Normal completion
--- Job trnsport.gms stop 05/26/06 11:00:25 elapsed 0:00:02.110
```
System Overview

Connectivity Tools
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  - EXCEL
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  - C, Delphi, ...

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GAMS Language Compiler and Execution System

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BARON, COIN, CONOPT, CPLEX, DECIS, DICOPT, KNITRO, LGO, MINOS, MOSEK, OQNLP, PATH, SNOPT, XA, XPRESS, ...
Agenda

GAMS Development/GAMS Software

GAMS at a Glance

An illustrative Example: The Mean Variance Model

Grid Computing
The Mean-Variance Model

Markowitz (1952), Nobel prize 1990

**Given**

Some investments $x_i$ with historical data

- **Rewards** = Expected returns of investments: $\mu_i$
  (Mean of historical returns)
- Risk: **Variance** of investments $Q_{i,j}$

**Goal**

Balance risk $r$ of portfolio against expected returns of portfolio

Minimize variance $\nu$ of portfolio for a given target return $r$
MV Model Algebra

Variance of Portfolio

\[ \text{Min} \sum_{i=1}^{I} \sum_{j=1}^{J} x_i Q_{i,j} x_j \]

Target return

\[ \text{s.t.} \quad \sum_{i=1}^{I} \mu_i x_i \geq r \]

Budget constraint

\[ \sum_{i=1}^{I} x_i = 1 \]

No short sales

\[ x_i \geq 0 \]

Talk: Wednesday, 18:00, Geb. 11.40, R. 202
Declarative Model and some Data

GAMS

Model Type: QCP
Procedural Elements

$gdxin data  # get data & setup model
$load i mu q
q(i,j) = 2*q(j,i) ;  q(i,i) = q(i,i)/2;
Model var / all /;
set p      points for efficient frontier /minv, p1*p8, maxr/,
  pp(p) points used for loop     /      p1*p8      /;
parameter minr, maxr,rep(p,*), repx(p,i);

# get bounds for efficient frontier
solve var minimizing v using miqcp;       #find portfolio with minimal variance
minr = r.l; rep('minv','ret') = r.l;
rep('minv','var') = v.l; repx('minv',i) = x.l(i);

solve var maximizing r using miqcp;      #find portfolio with maximal return
maxr = r.l; rep('maxr','ret') = r.l;
rep('maxr','var')=v.l;repx('maxr',i)= x.l(i);

loop(pp,  #calculate efficient frontier
    r.fx = minr + (maxr-minr)/(card(pp)+1)*ord(pp);
solve var minimizing v using miqcp;
  rep(pp,'ret') =r.l;rep(pp,'var') = v.l;repx(pp,i)= x.l(i);
);

Execute_Unload 'results.gdx',rep, repx;   # export results to GDX & Excel
Execute 'GDXXRW.EXE results.gdx par=repx rng=Portfolio!a1 Rdim=1';
Execute 'GDXXRW.EXE results.gdx par=rep  rng=Frontier!a1  Rdim=1';
Efficient Frontier and Portfolios

- Return of portfolio (%)
  - Variance of portfolio

- Share of portfolio (%)
  - Solution Points
  - Share labels: cn, gr, jp, uk, us
  - Solution points: minv, p1, p2, p3, p4, p5, p6, p7, p8, maxr
Imagine...

.. you have to solve 1,000’s of independent scenarios..
.. and you can do this very rapidly for little additional money…
.. without having to do lots of cumbersome programming work..

```gams
loop(pp,
    r.fx = minr + (maxr-minr)/(card(pp)+1)*ord(pp);
    solve var minimizing v using miqcp;
    rep(pp,'ret') = r.l; rep(pp,'var') = v.l; repx(pp,i)= x.l(i);
);
```

**Grid Computing**
What is Grid Computing?

A pool of connected computers managed and available as a common computing resource

- Effective sharing of CPU power
- Massive parallel task execution
- Scheduler handles management tasks
- E.g. Condor, Sun Grid Engine, Globus
- Can be rented or owned in common
- Licensing & security issues
**Advantages of Grid Computing**

- Solve a certain number of scenarios faster, e.g.:
  - sequential: 50 hours
  - parallel (200 CPUs): ~15 minutes
    $\Rightarrow$ Cost is $100 (2$ CPU/h)

- Get better results by running more scenarios*:

<table>
<thead>
<tr>
<th>#SIM</th>
<th>VaR error</th>
<th>CVaR error</th>
</tr>
</thead>
<tbody>
<tr>
<td>1000</td>
<td>5.42%</td>
<td>6.74%</td>
</tr>
<tr>
<td>20,000</td>
<td>1.21%</td>
<td>1.49%</td>
</tr>
</tbody>
</table>

Economics of Grid Computing

- Yearly cost, 2-CPU workstation: $5200
  - Hardware: $1200
  - Software: $4000
- Hourly cost on the grid: $2/cpu
  - $1/hour for CPU time (to grid operator)
  - $1/hour for software (GAMS, model owner)
- 1 workstation:
  - ~ 2600 hrs grid time or
  - ~ 50 hrs/week grid time
- Up-front vs. deferred, as-needed costs
GAMS & Grid Computing

• **Scalable:**
  - support of massive grids, **but also**
  - multi-cpu / multiple cores desktop machines
  - “1 CPU - Grid”

• Platform **independent**

• Only **minor changes** to model required

• **Separation** of model and solution method
  → Model stays **maintainable**
Simple Serial Solve Loop

\textbf{Loop} (p(pp),

\texttt{ret.fx = rmin +(rmax-rmin) / (card(pp)+1)*ord(pp) ;}

\texttt{Solve minvar min var using miqcp;}
\texttt{xres(i,p) = x.l(i);}
\texttt{report(p,i,'inc') = xi.l(i);} \texttt{report(p,i,'dec') = xd.l(i)};

How do we get to parallel and distributed computing?
Simple Serial Solve Loop

\[
\text{Loop}(p(pp), \\
\quad \text{ret.fx} = \text{rmin} + (\text{rmax-\text{rmin}}) \\
\quad \quad / (\text{card(pp)+1}) \times \text{ord(pp)} \\
\quad \text{Solve minvar min var using miqcp;}
\]

\[
\text{xres}(i,p) = x.l(i); \\
\text{report}(p,i,'inc') = \text{xi.l}(i); \\
\text{report}(p,i,'dec') = \text{xd.l}(i)
\]

How do we get to parallel and distributed computing?
GRID Specific Enhancements

1. Submission of jobs
2. “Grid Middleware”
   - Distribution of jobs
   - Job execution
3. Collection of solutions
4. Processing of results
Job Submission Loop

Parameter \( h(p) \) store the instance handle;

\[ \text{minvar}.\text{solvelink} = 3; \quad \# \text{turn on grid option} \]

Loop(p(pp),

\[
\text{ret.fx} = \text{rmin} + (\text{rmax}-\text{rmin}) \big/ (\text{card}(pp)+1) \ast \text{ord}(pp) ;
\]

Solve minvar min var using miqcp ;

\[ h(pp) = \text{minvar.handle} \); \# save instance handle

LOG:

--- LOOPS pp = p1
--- 46 rows 37 columns 119 non-zeroes
--- 311 nl-code 7 nl-non-zeroes
--- 14 discrete-columns
--- grid_qmeanvar.gms(150) 3 Mb
--- Submitting model minvar with handle grid137000002
--- grid_qmeanvar.gms(148) 3 Mb
--- Generating MIQCP model minvar...
"Grid" - Middleware (PC)

: gams grid submission script
: arg1 solver executable
: 2 control file
: 3 scratch directory
: gmscr_nx.exe processes the solution and produces 'gmsgrid.gdx'
: note: %3 will be the short name, this is needed because
: the START command cannot handle spaces or "...">
: before we use %~3 will strip surrounding "..."
: makes the name short
: gmsrerun.cmd will resubmit runit.cmd

echo @echo off > %3runit.cmd
echo %1 %2 >> %3runit.cmd
echo gmsc
r_nx.exe %2 >> %3runit.cmd
echo mkdir%3finished >> %3runit.cmd
echo exit >> %3runit.cmd

echo @start /b /BELOWNORMAL %3runit.cmd ^> nul >> %3gmsrerun.cmd
start /b /BELOWNORMAL %3runit.cmd > nul
exit
Solution Collection Loop

Repeat
loop(p(pp)$h(p),
    if(handlestatus(h(p))=2,
        minvar.handle = h(p); execute_loadhandle minvar;
        xres(i,p)=x.l(i); report(p,i,'inc')=xi.l(i);
        report(p,i,'dec')= xd.l(i)
        display$handedle(h(p))'Could not remove handle';
        h(p) = 0)
    );
    # indicate solution is loaded
    if(card(h), execute 'sleep 1');
    until card(h) = 0 or timeelapsed > 100;

LOG: ...
    --- GDXin=c:\work\mod\225b\grid137000002\gmsgrid.gdx
    --- grid_qmeanvar.gms(154) 3 Mb
    --- Removing handle grid137000002
    --- GDXin=c:\work\mod\225b\grid137000003\gmsgrid.gdx
    --- Removing handle grid137000003
    --- GDXin=c:\work\mod\225b\grid137000007\gmsgrid.gdx
    ...
Results for 4096 MIPS on Condor Grid

- Submission started Jan 11, 16:00
- All jobs submitted by Jan 11, 23:00
- All jobs returned by Jan 12, 12:40
  - 20 hours wall time, 5000 CPU hours
  - Peak number of CPU's: 500
More Developments

→ http://www.gams.com/docs/release/release.htm

Release Notes

Each new release incorporates numerous fixes and improvements to the core GAMS system and its many components. A selected list of improvements and new components is given below.

If you are interested in receiving the latest information about new GAMS releases and trying out beta releases, please subscribe to our release email list.

Distribution 22.2  Apr 21, 2006

Distribution 22.2 is a maintenance release to correct some performance issues in the GAMS system and include newly available solver libraries.

Acknowledgements

We would like to thank all of our users who have reported problems and made suggestions for improving this release. In particular, we thank Wolfgang Britz (Bonn University), Paritosh Desai (DemandTec), Michael Ferris (UW-Madison), Edgar Ramirez (at hotmail.com), and Rich Roberts (SRS Technologies).

GAMS System

- The limit on nonlinear instructions in a single block has been raised from 16 million to 64 million instructions.
- Performance improvements for very large and complicated loop structures.
- International characters in file and path names are now handled correctly.
- GAMS IDE:
  - GD data browser is faster and can sort indices by name vs. entry order
  - A symbol shown in the GD data browser can be written to an Excel file

Solvers

- CONOPT: New libraries are included which address minor fixes.
- CPLEX: New libraries (version 10.0.1, a maintenance release)
- LGO: New libraries
  - The built-in stochastic searches have been improved.
  - Some internal limits were increased to allow larger models to be solved.

Distribution 22.1  Mar 15, 2006

GAMS System

- Relaxation of discrete variables (prior=Inf):

The priority attribute of a discrete variable can be used to relax a specific variable instance. The priority attribute .prior establishes in what order variables are to be fixed to integral values while searching for a solution. Variables with a specific .prior value will remain relaxed until all variables with a lower .prior values have been fixed. Setting the .prior value to -Inf will relax this variable.