Fundamentals and Recent Developments of the GAMS System

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GAMS Software GmbH

www.gams.com

Huntington Beach, CA  April 2012
Agenda

- What is GAMS?
- What is special?
- What is new?
Agenda

What is GAMS?
  - GAMS at a Glance
  - A simple Example
  - Applications
What’s that?

http://en.wikipedia.org/wiki/Algebraic_modeling_language

- High-level **computer programming languages** for the formulation of **complex mathematical optimization problems**

- **Notation similar to algebraic notation**: Concise and readable definition of problems in the domain of optimization

- **Do not solve problems directly**, but ready-for-use links to state-of-the-art algorithms
Algebraic Modeling Languages

Core Elements:

• A modeling language interpreter
• Solver links
• User interfaces
• Data exchange facilities
GAMS Development at a Glance

- Roots: World Bank, 1976
- Went commercial in 1987
- GAMS Development Corp. (US)
- GAMS Software GmbH (Europe)

Technical tool provider (Software)

- Broad academic & commercial user community and network
  - GAMS is used in more than 120 countries
  - Half of licenses commercially used
Broad Network

5177 visits from 19 Mar 2012 to 26 Mar 2012

- distance in which individuals are clustered
- Total number of visits depicted above = 4275

Dot sizes:
- = 1000 +
- = 100 - 999
- = 10 - 99
- = 1 - 9
Downloads (March 2012)

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<th>GB用量</th>
<th>月下载量</th>
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Total: 495 GB ~ 5,500 monthly downloads
General Algebraic Modeling System

Timeline at:

http://en.wikipedia.org/wiki/General_Algebraic_Modeling_System

- 1976 GAMS idea is presented at the ISMP Budapest
- 1978 Phase I: GAMS supports linear programming. Supported platforms: Mainframes and Unix Workstations
- 1979 Phase II: GAMS supports nonlinear programming.
- 1987 GAMS becomes a commercial product
- 1988 First PC System (16 bit)
- 1988 Alex Meeraus, the initiator of GAMS and founder of GAMS Development Corporation, is awarded INFORMS Computing Society Prize
- 1990 32 bit Dos Extender
- 1990 GAMS moves to Georgetown, Washington, D.C.
- 1991 Mixed Integer Non-Linear Programs capability (DICOPT)
- 1994 GAMS supports mixed complementarity problems
- 1995 MPSGE language is added for CGE modeling

... 

- 2005 Support for 64 bit PC Operating systems
- 2006 GAMS supports parallel grid computing
- 2007 GAMS supports open-source solvers from COIN-OR
- 2008 Support for 32 and 64 bit Mac OS X
- 2009 GAMS supports extended mathematical programs (EMP)
- 2010 GAMS is awarded the company award of the German Society of Operations Research (GOR)
Agenda

- What is GAMS?
- GAMS at a Glance
- A simple Example
- Applications
GAMS at a Glance

Fundamentals:

• Balanced mix of declarative and procedural elements
• Platform independence
• Hassle-free switch of solution methods and solvers
• Open architecture and interfaces to other systems
• Independent layers
GAMS at a Glance

- Balanced mix of declarative and procedural elements
- Platform independence
- Hassle-free switch of solution methods
- Open architecture and interfaces to other systems
- Independent Layers

<table>
<thead>
<tr>
<th>Declarative elements</th>
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<tr>
<td>Parameters</td>
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<td>Variables</td>
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<td>Equations</td>
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<td>Models</td>
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<table>
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<th>combined with procedural elements</th>
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<tr>
<td>Loops</td>
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<td>If-then-else</td>
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<tr>
<td>Macros</td>
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<td>User defined functions</td>
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<td>...</td>
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GAMS at a Glance

• Balanced mix of declarative and procedural elements

• Platform independence

• Hassle-free switch of solution methods

• Open architecture and interfaces to other systems

• Independent Layers

10+ Supported Platforms

- Solaris 64
- Solaris Sparc
- AXU
- AIX
- Linux 32
- Linux 64
- Mac
- HP
- Windows 64
- Windows 32
GAMS at a Glance

• Balanced mix of declarative and procedural elements

• Platform independence

• Hassle-free switch of solution methods

• Open architecture and interfaces to other systems

• Independent Layers
GAMS at a Glance

- Balanced mix of declarative and procedural elements
- Platform independence
- Hassle-free switch of solution methods
- Open architecture and interfaces to other systems
- Independent Layers

- ASCII
- Gams Data eXchange (Binary)
  - MS Excel, MS Access
  - Databases
  - Matlab, R, ….
- API’s
- Component Libraries
- .NET Integration (Alpha)
GAMS at a Glance

Independence of
• Model and data
• Model and solution methods (solver)
• Model and operating system
• Model and user interface

→ Models benefit from
• Advancing hardware
• Enhanced / new solver technology
• Improved / upcoming interfaces to other systems

GAMS IDE

- Project management
- Editor / Syntax coloring / Spell checking
- Launching and monitoring of (multiple) GAMS processes
- Listing file / Tree view / Syntax-error navigation
- Solver selection / Option selection
- GDX viewer
  - Data cube
  - Data export (e.g. to MS Excel)
  - Charting facilities
- Model libraries
- Documentation
GAMS at a Glance: Model Libraries

- **GAMS Model Library**
  - Example and user-contributed models
  - Very often used as templates

- **GAMS Test Library**
  - Transparent and reproducible quality assurance tests

- **Practical Financial Optimization Models**
  - Models of the book ““PRACTICAL FINANCIAL OPTIMIZATION – A Library of GAMS Models” by Consiglio, Nielsen and Zenios
User Contributed Tools and Extensions

• Complement GAMS system:
  – Bruce Mc Carl: GAMSCHK, data exchange tools http://agecon2.tamu.edu/people/faculty/mccarl-bruce/GAMS.htm
  – Wietse Dol: Gtree, GAMS-R link: http://www3.lei.wur.nl/gamstools/

• Details and more sources: http://interfaces.gams.com
# Agenda

<table>
<thead>
<tr>
<th>What is GAMS?</th>
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<tbody>
<tr>
<td>GAMS at a Glance</td>
</tr>
<tr>
<td><strong>A simple Example</strong></td>
</tr>
<tr>
<td>Applications</td>
</tr>
</tbody>
</table>
A Simple Example: Transportation Model

Minimize transportation cost
subject to supply & demand constraints
A Simple Example: Algebra

Objective
Observe supply limit at plant $i$:
Satisfy demand at market $j$:

\[
\sum_i \sum_j c_{i,j} \times x_{i,j} \rightarrow \min
\]
\[
\sum_j x_{i,j} \leq a_i \quad \forall i
\]
\[
\sum_i x_{i,j} \geq b_j \quad \forall j
\]
\[
x_{i,j} \geq 0 \quad \forall i, j
\]
A Simple Example: Declarative Model

Sets
  i   canning plants
  j   markets;

Parameters
  a(i) capacity of plant i in cases
  b(j) demand at market j in cases
  d(i,j) distance in thousands of miles
  f freight in dollars per case per thousand miles
  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)) =l= a(i) ;
    demand(j) .. sum(i, x(i,j)) =g= b(j) ;

Model transport /all/ ;
A Simple Example: Model Data

sets i / seattle, san-diego /,
    j / new-york, chicago, topeka / ;

Parameters
    a(i) / seattle    350,
                  san-diego   600 /,
    b(j) / 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/ ;
A Simple Example: Complete Model

Sets
i    canning plants
j    markets;

Parameters
a(i) capacity of plant i in cases
b(j) demand at market j in cases
d(i,j) distance in thousands of miles
f   freight in dollars per case per thousand miles
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)) =l= a(i) ;
demand(j).. sum(i, x(i,j)) =g= b(j) ;

Model transport /all/ ;
$include data.inc

c(i,j) = f * d(i,j) / 1000 ;
Solve transport using lp minimizing z ;
Display x.l, x.m ;
A Simple Example: Results

**** REPORT SUMMARY : 0 NONOPT
0 INFEASIBLE
0 UNBOUNDED

GAMS Rev 238 WEX-Wei 23.3.1 x86_64/MS Windows 03/29/12 13:25:06 Page 6

A Transportation Problem (TRANSPORT,SEQ=1)

--- 68 VARIABLE x.L = 153.675  total transportation costs in thousands of dollars

--- 68 VARIABLE x.L shipment quantities in cases

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<thead>
<tr>
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<th>new-york</th>
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<td>z</td>
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x: shipment quantities in cases

<table>
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<tr>
<th></th>
<th>new-york</th>
<th>chicago</th>
<th>topeka</th>
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</table>
A Simple Example: Modifications

- LP
- MIP
- NLP
- MINLP
A Simple Example: Minimum Shipment

• Extension: Minimum Shipment
  – Ship at least 100 units or don’t ship

• Continuous variable $x(i,j)$
• Binary variable $ship(i,j)$

• Coupling constraints:
  – if $ship = 1 \rightarrow x \geq 100: x \geq 100 \times ship$
  – If $ship = 0 \rightarrow x = 0: x \leq bigM \times ship$
A Simple Example: Min/Max Shipments

Parameter rep1(i,j,*) Shipments between plants and markets
    rep2(*) Objective value;
rep1(i,j,'lp') = x.l(i,j);
rep2('lp') = z.l;

scalars xmin / 100 /
    xmax / 325 /;
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 min shipments / all /;
solve m2 using mip minimizing z;
rep1(i,j,'mip') = x.l(i,j);
rep2('mip') = z.l;

option mip=coincbc
solve m2 using mip minimizing z;
rep1(i,j,'mip-coincbc') = x.l(i,j);
rep2('mip-coincbc') = z.l;
display rep1,rep2;
A Simple Example: Economy of Scales

Cost = Volume^{\beta}

- Beta > 1
- Beta = 1
- Beta < 1
A Simple Example: Nonlinear Costs (NLP)

* nonlinear cost
equation nlcost nonlinear cost function;
scalar beta;

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

model m3 / transport -cost +nlcost /;

beta = 1.5;
solve m3 using nlp minimizing z;
rep1(i,j,'nlp-convex') = x.l(i,j);
rep2('nlp-convex') = z.l;

beta = 0.6;
solve m3 using nlp minimizing z;
rep1(i,j,'nlp-concave') = x.l(i,j);
rep2('nlp-concave') = z.l;

option nlp=baron;
solve m3 using nlp minimizing z;
rep1(i,j,'nlp-baron') = x.l(i,j);
rep2('nlp-baron') = z.l;

display rep1,rep2;
A Simple Example: MIP and Nonlinear

* min/max and nonlinear objective

model m4 / m3 +minship +maxship/;

option minlp=baron;
solve m4 using minlp minimizing z;
rep1(i,j,'minlp-bar') = x.l(i,j);
rep2('minlp-bar') = z.l;

option minlp=lindoglobal;
solve m4 using minlp minimizing z;
rep1(i,j,'minlp-lin') = x.l(i,j);
rep2('minlp-lin') = z.l;

display rep1,rep2;

<table>
<thead>
<tr>
<th></th>
<th>142 PARAMETER rep1 Shipments between plants and markets</th>
<th></th>
<th>142 PARAMETER rep2 Objective value</th>
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<td>mip-ccinc-</td>
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<td>What is GAMS?</td>
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<td>A simple Example</td>
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<tr>
<td>Applications</td>
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## Typical Application Areas

<table>
<thead>
<tr>
<th>Agricultural Economics</th>
<th>Applied General Equilibrium</th>
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<tbody>
<tr>
<td>Chemical Engineering</td>
<td>Economic Development</td>
</tr>
<tr>
<td>Econometrics</td>
<td>Energy</td>
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<tr>
<td>Environmental Economics</td>
<td>Engineering</td>
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<tr>
<td>Finance</td>
<td>Forestry</td>
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<tr>
<td>International Trade</td>
<td>Logistics</td>
</tr>
<tr>
<td>Macro Economics</td>
<td>Military</td>
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<tr>
<td>Management Science/OR</td>
<td>Mathematics</td>
</tr>
<tr>
<td>Micro Economics</td>
<td>Physics</td>
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Illustrative examples in the GAMS Model Library
Agriculture

The CAPRI (Common Agricultural Policy Regional Impact) Modelling System

CAPRI is a global agricultural sector model powered by GAMS with focus on 27 countries of the European Union and Norway

- Global multi-commodity model for agricultural products in 18 trade blocks
- About 250 regions or even up to six farm types for each region
- Evaluates regional and aggregate impacts of trade policies on production, income, markets, trade and environment
- Used by research institutions and EU Commission services

More information and an online exploitation tool at:
http://www.ilr1.uni-bonn.de/agpo/rsrch/capri/capri_e.htm

http://www.gams.com/presentations/index.htm#Ads
Agriculture

The ERS/USDA China Agricultural Regional Model
The ERS/USDA China Agricultural Regional Model is a dynamic, multi-regional, partial equilibrium agricultural model with graphical tools. The highly non-linear model is used to generate 10 year projections of supply, demand, trade, and prices for 24 commodities, 6 major producing regions in China as well as aggregate national level.

- First developments spreadsheet based, now model moved to GAMS formulation
- Major parts of the GAMS code are generated automatically
- Automated exchange of data between GAMS and several spreadsheets for scenario analysis and reporting
- For more information about this model please contact: carm@gams.com

http://www.gams.com/presentations/index.htm#Ads
Optimal transmission switching

Researchers and policy makers are looking for ways to make the bulk electricity transmission system more efficient, dynamic and responsive. One way this could be done is by opening and closing transmission lines in response to grid conditions to optimize how generators meet demand for electricity. A team of researchers at the Johns Hopkins University, the University of Wisconsin, the University of California at Berkeley and the Federal Energy Regulatory Commission are exploring the extent of savings possible in real systems.

- Bulk transmission network models contain hundreds of generators and thousands of transmission lines.
- Transmission line status modeled as binary variable in a mixed integer program formulated in GAMS.
- Model is solved with GAMS/CPLEX, using indicator constraints and multithread options.
- For more information please visit [http://www.cs.wisc.edu/~ferris/TransSwitch.html](http://www.cs.wisc.edu/~ferris/TransSwitch.html)

![Graph showing savings realized per hour for a model of the New England electricity system.](image-url)
Cutting Stock Optimization at GSE

GSE-TRIM is a fully integrated module of the ERP-System GSE-PPS for Cutting Stock Optimization. Close cooperation of our in-house specialists with scientists in the area of discrete optimization has led to a number of successfully deployed applications used by the paper industry. Exact and hybrid optimization techniques coded in GAMS and Fortran have been implemented in our software package GSE-TRIM.

Our clients in various Mid-European paper industry companies benefit from:
- Exact waste minimization in roll production
- Non-standard objective functions
- Considering detailed operational restrictions
- Multi-stage format production

Based on a daily basis GSE-TRIM improves our clients key indicators and has been proven very stable over 7 years.

For more information please contact: www.gse-software.de

http://www.gams.com/presentations/index.htm#Ads
Biology

**Integer Optimization for Identification of Drug Effects**

Understanding the mechanisms of cell function is a major challenge for the scientific community and a cornerstone for drug development. An interdisciplinary team at the National Technical University Athens and the Massachusetts Institute of Technology developed a methodology integrating high-throughput experiments with state-of-the-art combinatorial optimization, building on existing boolean models of signaling pathways.

- Phosphoproteomic experiments are performed in normal and cancer liver cells with and without the influence of drugs.
- The signaling pathways in each case are identified by an integer linear programming formulation.
- The computational time is orders of magnitude faster than previous approaches allowing for larger pathways and data sets.
- Known and unknown drug effects (shown in red) are identified by comparing the two networks.

For more information about this application please contact Alexander Mitsos

---

http://www.gams.com/presentations/index.htm#Ads
Climate Change

ReMIND-R - A global energy economy climate model in a multi-regional setting

ReMIND-R provides a model framework developed for the implementation of energy-economic models in a multi-regional setting. The framework allows for the representation of energy carriers and conversion technologies with various techno-economic characteristics. The energy system part is coupled with a macroeconomic part represented by a nested CES production function with flexible structure. The regional models are implemented as optimal growth models linked by trade in energy carriers, tradeable permits and generic goods.

- 11 world regions and 7 types of traded products (incl. emission rights)
- Climate policy analysis: Business as usual and different climate policies
- Combines complex optimization and simulation models
- Developed by group of experts from different fields
- Model documentation - see http://www.pik-potsdam.de/research/research-domains/sustainable-solutions/models

REMIND-R has been developed and is being maintained by the ReMind Team at the Potsdam Institute for Climate Impact Research (PIK); for more information about this application please visit http://www.pik-potsdam.de/research/research-domains/sustainable-solutions/models/remind
Process Industry

Deploy Your GAMS Model in Optience Core Application Builder

Optience has developed world class applications for solving real world problems in the process industry utilizing the Optience Core Builder Platform, from Product Development Optimization to Business Supply Chain Optimization. These applications have been deployed in some of the largest petrochemical companies in the world.

- Database centric, can connect to multiple databases
- Rich grid & graph features
- Design user interface to fit your workflow
- Execute GAMS model in the same environment

Optience
Strategic Solutions through Optimization Science

http://www.optience.com

http://www.gams.com/presentations/index.htm#Ads
Grid Computing

Cyberinfrastructure: GAMS, Condor and the Grid

Researchers at the University of Wisconsin in Madison, partially supported by NSF Cyberinfrastructure-OR funding, have used the GAMS Grid Computing language extensions in conjunction with the Condor Resource Manager to process long running mixed integer programming models.

In the case depicted in the figure, over 4000 MIP subproblems were solved on a collection of over 1000 workstations managed by the Condor system.

At times over 500 workstations were running multiple instances of the CPLEX and XPRESS solvers delivering more than 5000 CPU hours in a little over 20 hours wall clock time. Communication of cutoff values and incumbent solutions between models running asynchronously over the grid was handled automatically using recently added solver features.

http://www.gams.com/presentations/index.htm#Ads
Scheduling

Scheduling and Planning at BASF

Close cooperation between logistics, information services and the scientific computing group of BASF, Prof. Dr. C. A. Floudas (Princeton University), Dr. A. V. Eremeev and Dr. P. A. Borisovski (Omsk Branch of Sobolev Institute of Mathematics SB RAS), SAP AG, and Mathesis GmbH led to a number of successfully deployed applications based on exact and hybrid optimization techniques. One of the results is a novel modeling approach of batch and continuous plants:

- State-task network formulation resulting in mixed-integer linear program
- Unit-specific, event-specific continuous-time formulations
- Hybrid methods and decomposition schemes to handle large instances
- Tight lower bounds derived from auxiliary models
- Implementation in GAMS with parallel GAMS/CPLEX
- New interfacing technology and integration approaches to connect to SAP-APO
- Used on a daily basis to improve planning and scheduling

http://www.gams.com/presentations/index.htm#Ads
Agenda

• What is GAMS?
• What is special?
• What is new?
<table>
<thead>
<tr>
<th>Agenda</th>
</tr>
</thead>
<tbody>
<tr>
<td>What is special?</td>
</tr>
<tr>
<td>Then and Now</td>
</tr>
<tr>
<td>Quality Assurance at GAMS</td>
</tr>
</tbody>
</table>
Then ...

In Table 17.1 we list sizes and attributes of representative models that are “large" in the sense that they are near the limit of what is practical on a personal computer, along with the model generation time (GAMS) and solution time (solver), both in minutes. These examples were run on an 8 MHz AT with an 80287 coprocessor and 640K of RAM. The times shown are to give you a rough idea of what is possible; these are not precisely controlled benchmarks, and we have a host of performance improvements in mind for the near future.

Table 17.1: Problem Characteristics

<table>
<thead>
<tr>
<th>Name</th>
<th>Number of Rows</th>
<th>Number of Columns</th>
<th>Number of Nonzeros</th>
<th>Generation Time*</th>
<th>Solution Time*</th>
<th>Iterations</th>
<th>Solver</th>
</tr>
</thead>
<tbody>
<tr>
<td>DINAMICO</td>
<td>318</td>
<td>425</td>
<td>4156</td>
<td>3.0</td>
<td>30.1</td>
<td>628</td>
<td>MINOS</td>
</tr>
<tr>
<td>SARF</td>
<td>532</td>
<td>542</td>
<td>3949</td>
<td>37.7</td>
<td>115.8</td>
<td>2775</td>
<td>MINOS</td>
</tr>
<tr>
<td>FERTU</td>
<td>458</td>
<td>2968</td>
<td>7252</td>
<td>11.4</td>
<td>28.3</td>
<td>1368</td>
<td>ZOOM</td>
</tr>
<tr>
<td>CAMCGE</td>
<td>243</td>
<td>280</td>
<td>1356</td>
<td>0.8</td>
<td>7.0</td>
<td>189</td>
<td>MINOS</td>
</tr>
<tr>
<td>GANGES</td>
<td>274</td>
<td>357</td>
<td>1405</td>
<td>1.8</td>
<td>7.3</td>
<td>187</td>
<td>MINOS</td>
</tr>
<tr>
<td>VENCEM</td>
<td>168</td>
<td>258</td>
<td>953</td>
<td>0.9</td>
<td>7.6</td>
<td>600</td>
<td>ZOOM</td>
</tr>
<tr>
<td>EGYPT</td>
<td>281</td>
<td>618</td>
<td>3168</td>
<td>4.0</td>
<td>25.3</td>
<td>1551</td>
<td>ZOOM</td>
</tr>
</tbody>
</table>

*Measured in minutes.

The problem is too big for MINOS, ZOOM was used instead.

* A nonlinear problem. 63% of the non-zeros are nonlinear.

* A nonlinear problem. 58% of the non-zeros are nonlinear.

* A mixed binary problem, with 55 binary variables (solved with a relative termination criterion of 10%).

* A linear problem, solved using XMP which is contained within ZOOM.
... and now

<table>
<thead>
<tr>
<th>Type</th>
<th>s in 1988</th>
<th>s in 2008</th>
<th>Improvement Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>camcge</td>
<td>NLP</td>
<td>468</td>
<td>0.031</td>
</tr>
<tr>
<td>dinamico</td>
<td>LP</td>
<td>1986</td>
<td>0.125</td>
</tr>
<tr>
<td>egypt*</td>
<td>MIP</td>
<td>1758</td>
<td>0.015</td>
</tr>
<tr>
<td>fertd*</td>
<td>MIP</td>
<td>2382</td>
<td>0.062</td>
</tr>
<tr>
<td>ganges</td>
<td>NLP</td>
<td>546</td>
<td>0.109</td>
</tr>
<tr>
<td>sarf</td>
<td>LP</td>
<td>9210</td>
<td>0.139</td>
</tr>
<tr>
<td>yemcem*</td>
<td>MIP</td>
<td>510</td>
<td>0.140</td>
</tr>
</tbody>
</table>

* MIP 1988 solver ZOOM, 2008 solver CPLEX
Change in Focus

- **Computation**
  - Past: Users left out
  - Now: Users involved

- **Model**
  - Future: Users hardly aware of model
Market Demands

• **Minimize risks** for (new) clients / management

• Provide cutting edge technology

• Protect user investments
Minimize Risks

• Support rapid prototyping

• Increase productivity

• Deliver (expected) results

• Do not lock users into a certain environment
Provide cutting edge technology

- **Industry**: Reliable, high performance system for developing and deploying optimization applications

- **Academia (research tool)**:
  - New modeling paradigms (e.g. SDP, bilevel, SP, …)
  - Emerging solution technology (e.g. MPEC)
  - New computing environments
Bridging the Gap

GAMS serves both worlds (synergy):

- Large user base in industry and academia
- Dissemination of research ideas
- Challenging/relevant problems from industry

30% of revenue invested in research and product development
Life time of a model: 15+ years:
- New maintainer, platform, solver, user interface
- Protection of investment in a model

Blessing for the user (mostly) – curse for developers
- Old concepts in new situations
  - Example: GAMS listing file
- Language additions have to be supported in the future
  - GAMS is conservative when it comes to syntax additions

Danger of becoming a barrier for innovation
Striving for Innovation and Compatibility

The “GAMS” – approach:

- Do not overload existing GAMS notation: Use existing language features to specify additional model features, structure, and semantics
- Express extended model in symbolic (source) form and apply existing modeling/solution technology
- Integrate new solver technology right away
- Package new tools with the production system
- Quality Assurance: Reproducible and automated tests, which are included in any distribution
<table>
<thead>
<tr>
<th>Agenda</th>
</tr>
</thead>
<tbody>
<tr>
<td>What is special?</td>
</tr>
<tr>
<td>Then and Now</td>
</tr>
<tr>
<td>Quality Assurance at GAMS</td>
</tr>
</tbody>
</table>
Quality Assurance at GAMS

Quality Test Models Library

• Include tests to verify proper behavior of the system

• More than 550 quality test models (included in the distribution), each containing numerous pass/fail tests

• Continuous quality improvement using automated and reproducible tests (> 20,000 solves for each platform)

• Automatic generated test summaries with different levels of information
Quality Assurance at GAMS

Latest GAMS System Builds and Test Results

<table>
<thead>
<tr>
<th>nightly</th>
<th>System</th>
<th>Libraries</th>
<th>Build</th>
<th>Rev</th>
<th>Status and Time (UTC)</th>
<th>Initial Tests</th>
<th>Full Tests</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Wednesday Inx</strong></td>
<td>Download</td>
<td>23.9.0</td>
<td>32515</td>
<td>Test started</td>
<td>12Apr2012 01:32:39</td>
<td>798 runs 3 failures (q=3,s=0)</td>
<td>Report results pending</td>
</tr>
<tr>
<td><strong>Wednesday vs8</strong></td>
<td>Download</td>
<td>23.9.0</td>
<td>32517</td>
<td>Test done</td>
<td>12Apr2012 10:11:52</td>
<td>710 runs 3 failures (q=3,s=0)</td>
<td>Report 9112 runs 20 failures (q=19,s=1)</td>
</tr>
<tr>
<td><strong>Wednesday wei</strong></td>
<td>Download</td>
<td>23.9.0</td>
<td>32522</td>
<td>Test done</td>
<td>12Apr2012 09:29:15</td>
<td>688 runs 3 failures (q=3,s=0)</td>
<td>Report 6581 runs 19 failures (q=19,s=0)</td>
</tr>
</tbody>
</table>

GAMS System Builds and Test Results Archive

| Total: | 9112 runs | 20 failures |
| Quality: | 1538 runs | 19 failures |
| Solves: | 7978 runs | 1 failures |
| EMP: | 126 runs | 0 failures |
| Data: | 36 runs | 0 failures |
| API: | 14 runs | 0 failures |

**QUALITY TEST FAILURES**

```
scalename = gams quality --DEMOFILE=1 lo=2 --prefix=vs8 --fail=failures_qa.txt --test=BADFT2 --ftrace=1
scalename = gams quality --DEMOFILE=1 lo=2 --prefix=vs8 --fail=failures_qa.txt --test=BADFT3 --ftrace=1
scalename = gams quality --DEMOFILE=1 lo=2 --prefix=vs8 --fail=failures_qa.txt --test=DFNAPFT1 --ftrace=1
scalename = gams quality --DEMOFILE=1 lo=2 --prefix=vs8 --fail=failures_qa.txt --test=DFNAPFT3 --ftrace=1
scalename = gams quality --DEMOFILE=1 lo=2 --prefix=vs8 --fail=failures_qa.txt --test=DFNAPFT5 --ftrace=1
scalename = gams quality --DEMOFILE=1 lo=2 --prefix=vs8 --fail=failures_qa.txt --test=DFNAPFT7 --ftrace=1
scalename = gams quality --DEMOFILE=1 lo=2 --prefix=vs8 --fail=failures_qa.txt --test=DFNAPFT9 --ftrace=1
scalename = gams quality --DEMOFILE=1 lo=2 --prefix=vs8 --fail=failures_qa.txt --test=DFNAPFT11 --ftrace=1
scalename = gams quality --DEMOFILE=1 lo=2 --prefix=vs8 --fail=failures_qa.txt --test=DFNAPFT13 --ftrace=1
scalename = gams quality --DEMOFILE=1 lo=2 --prefix=vs8 --fail=failures_qa.txt --test=DFNAPFT15 --ftrace=1
```
Client Model Testing

”After upgrading to the latest distribution, runs take about twice or three times as much time as before (3 to 4 hours instead of 1 or 1 and half). We decided to downgrade and investigate the problem later.”

“… solver ***** has slowed down about 90% in last 4 years on this problem …”
Client Model Testing

- Requires changes to the model of the clients to allow automated pass/failure tests

- Includes:
  - Ability to solve (= no bugs)
  - Returns the same solution back
  - Similar or better performance

- Gives clients assurance that their application will also work with new GAMS releases

- Improves communication between development team and clients (specific wishes)
Agenda

- What is GAMS?
- What is special?
- What is new?
Agenda

What is new?

- GAMS System
- Platforms
- Solvers
- Interfaces
- Stochastic Programming
What is new: GAMS System

• Support for user-defined:
  – Macros
  – Function libraries
  – External equations

• Asynchronous execution

• Extended Mathematical Programming (EMP)

• More and further details: http://www.gams.com/docs/release/release.htm
What is new: Platforms

• Support for MAC OS X

• Cross-platform licenses

• Wine (Linux, Mac)
What is new: Solvers

• **GLoMIQO**: Branch-and-bound global optimization for mixed-integer quadratic models

• **Gather-Update-Solve-Scatter**

• **(Stochastic) EMP**

• **Lindo**: Global and stochastic optimization
What is new: Interfaces

- API’s for various programming languages (C, Fortran, Delphi)
- Component libraries
- Better integration into Python
- .Net Integration (“GAMS.NET” – Alpha)
## Agenda

<table>
<thead>
<tr>
<th>What is new?</th>
</tr>
</thead>
<tbody>
<tr>
<td>GAMS System</td>
</tr>
<tr>
<td>Platforms</td>
</tr>
<tr>
<td>Solvers</td>
</tr>
<tr>
<td>Interfaces</td>
</tr>
<tr>
<td>Stochastic Programming</td>
</tr>
</tbody>
</table>
Extended Mathematical Programming

- Disjunctive Programs
- Bilevel Programs
- Extended Nonlinear Programs
- Stochastic Programming
- ...

- Breakouts of traditional MP classes
- No conventional syntax
- Limited support with common model representation
- Incomplete/experimental solution approaches
- Lack of reliable/any software
SP with EMP

- EMP Information (stoch. Ext.)
- Original Model (det.)

Translation

Reformulated Model

Viewable

Solving using Established algorithms

Solution

Mapping Solution into original space
Newsboy Problem (NP) - deterministic

Equations Row1, Row2, Profit;

* demand = UnitsSold (S) + LostSales (L)
Row1.. d =e= S + L;

* Inventory = UnitsBought (X) - UnitsSold (S)
Row2.. I =e= X - S;

* Profit, to be maximized;
Profit.. Z =e= v*S # Revenue per sold unit
   - c*X # Purchase per unit
   - h*I # Holding cost per unit leftover
   - p*L; # Penalty shortage cost
      # per unit unsatisfied demand

Model nb / all /;
file emp / '%emp.info%' /; put emp '* problem
%gams.i%'/;
$onput
randvar d discrete 0.7 45 0.2 40 0.1 50
stage 2 I L S d
stage 2 Row1 Row2
$offput
putclose emp;
- **Randvar**: both discrete and parametric random variables
- **Stage**: Random variables (rv), equations (equ) and variables (var) are assigned to non-default stages

- **Correlation**: correlation between a pair of random variables

- **Jrandvar**: discrete random variables and their joint distribution

- **Chance**: individual or joint chance constraints
Set scen  Scenarios / s1*s6 /;

Parameter
  s_d(scen)   Demand realization by scenario
  s_x(scen)   Units bought by scenario
  s_s(scen)   Units sold by scenario
  srep(scen,*) Scenario probability / #scen.prob 0/;

Set dict / scen .scenario.''
  d   .randvar .s_d
  s   .level   .s_s
  x   .level   .s_x
  '' .opt   .srep /;

solve nb max z use emp scenario dict;
Display s_d, s_x, s_s, srep;
--- 62 PARAMETER s_d Demand realization by scenario
s1 45.000, s2 40.000, s3 50.000

--- 62 PARAMETER s_x Units bought by scenario
s1 45.000, s2 45.000, s3 45.000

--- 62 PARAMETER s_s Units sold by scenario
s1 45.000, s2 40.000, s3 45.000

--- 58 PARAMETER srep Scenario probability
prob
s1 0.700
s2 0.200
s3 0.100
## NP - Parametric Distributions

<table>
<thead>
<tr>
<th>Distribution</th>
<th>Par 1</th>
<th>Par 2</th>
<th>Par 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beta</td>
<td>shape 1</td>
<td>shape 2</td>
<td></td>
</tr>
<tr>
<td>Cauchy</td>
<td>location</td>
<td></td>
<td>scale</td>
</tr>
<tr>
<td>Chi_Square</td>
<td>deg. of freedom</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Exponential</td>
<td>lambda</td>
<td></td>
<td></td>
</tr>
<tr>
<td>F</td>
<td>deg. of freedom 1</td>
<td>deg. of freedom 2</td>
<td></td>
</tr>
<tr>
<td>Gamma</td>
<td>shape</td>
<td></td>
<td>scale</td>
</tr>
<tr>
<td>Gumbel</td>
<td>location</td>
<td></td>
<td>scale</td>
</tr>
<tr>
<td>Laplace</td>
<td>mean</td>
<td></td>
<td>scale</td>
</tr>
<tr>
<td>Logistic</td>
<td>location</td>
<td></td>
<td>scale</td>
</tr>
<tr>
<td>LogNormal</td>
<td>mean</td>
<td></td>
<td>std dev</td>
</tr>
<tr>
<td>Normal</td>
<td>mean</td>
<td></td>
<td>std dev</td>
</tr>
<tr>
<td>Pareto</td>
<td>scale</td>
<td></td>
<td></td>
</tr>
<tr>
<td>StudentT</td>
<td>deg. of freedom</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Triangular</td>
<td>low</td>
<td></td>
<td>mid</td>
</tr>
<tr>
<td>Uniform</td>
<td>low</td>
<td></td>
<td>high</td>
</tr>
<tr>
<td>Weibull</td>
<td>shape</td>
<td></td>
<td>scale</td>
</tr>
<tr>
<td>Binomial</td>
<td>n</td>
<td></td>
<td>p</td>
</tr>
<tr>
<td>Geometric</td>
<td>p</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hyper_Geometric</td>
<td>total</td>
<td></td>
<td>good</td>
</tr>
<tr>
<td>Logarithmic</td>
<td>p-factor</td>
<td></td>
<td>trials</td>
</tr>
<tr>
<td>Negative_Binomial</td>
<td>failures</td>
<td></td>
<td>p</td>
</tr>
<tr>
<td>Poisson</td>
<td>lambda</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 1.1: Parametric distributions
### Table 1.2: Solver Capabilities

<table>
<thead>
<tr>
<th></th>
<th>DE</th>
<th>DECIS</th>
<th>LINDO</th>
</tr>
</thead>
<tbody>
<tr>
<td>chance</td>
<td>✔</td>
<td></td>
<td>✔</td>
</tr>
<tr>
<td>correlation</td>
<td></td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td>jrandvar</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td>randvar (discrete)</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td>randvar (parametric)</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
</tr>
</tbody>
</table>
file emp / '%emp.info%' /; put emp '* problem %gams.i%'/;
$onput
randvar d normal 45 10
stage 2 I L S d
stage 2 Row1 Row2
$offput
putclose emp;
NP – stochastic (Results)

----  62 PARAMETER s_d  Demand realization by scenario
s1 63.975,  s2 47.774,  s3 43.505,  s4 53.372,
s5 37.035,  s6 35.139

----  62 PARAMETER s_x  Units bought by scenario
s1 43.505,  s2 43.505,  s3 43.505,  s4 43.505,
s5 43.505,  s6 43.505

----  62 PARAMETER s_s  Units sold by scenario
s1 43.505,  s2 43.505,  s3 43.505,  s4 43.505,
s5 37.035,  s6 35.139

----  58 PARAMETER srep  Scenario probability
prob
s1 0.167,  s2 0.167,  s3 0.167,  s4 0.167,
s5 0.167,  s6 0.167
More Examples

GAMS EMP-Library

- Various Applications
- Single-Stage
- Multi-Stage
- Chance Constraints

http://www.gams.com/emplib/emplib.htm
Summary

What is GAMS

- Balanced mix of declarative and procedural elements
- Platform and solver independence
- Open architecture and independent layers

Focus: Computation → Model → Application (Integration)

Challenges

- Minimize Risks
- Provide cutting edge technology
- Protect user investments
Thank You!

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