Fundamentals and Recent Developments of the GAMS System

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Beijing, China  June 2012
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<th>Agenda</th>
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<tbody>
<tr>
<td>GAMS at a Glance</td>
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<td>A simple Example</td>
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<td>What is new?</td>
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<td>Market Demands and Challenges</td>
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</table>
What's that?

- Formulation mathematical optimization problems
- Notation similar to algebraic notation
- Ready-for-use links to state-of-the-art algorithms

- Simplified model building
- Efficient solution process

Algebraic Modeling System
General Algebraic Modeling System

- Roots: World Bank, 1976
- Went commercial in 1987
- GAMS Development Corporation (Washington, Houston)
- GAMS Software GmbH (Köln, Braunschweig)

- Broad academic & commercial user community and network
Monthly System Downloads

Download GAMS Distribution 23.8.1 - March 17, 2012

Monthly Downloads

Amazon CloudFront Download Usage Report

United States
- $0.120 per GB - first 10 TB / month data transfer out: 197.126 GB
- $0.0100 per 10,000 HTTPS Requests: 3 Requests
- $0.0075 per 10,000 HTTP Requests: 52,154 Requests

Europe
- $0.120 per GB - first 10 TB / month data transfer out: 212,982 GB
- $0.0120 per 10,000 HTTPS Requests: 1 Request
- $0.0090 per 10,000 HTTP Requests: 16,456 Requests

Asia Pacific (Tokyo) Region
- $0.201 per GB - first 10 TB / month data transfer out (includes consumption tax): 23,800 GB
- $0.0120 per 10,000 HTTPS Requests: 4,675 Requests
- $0.0090 per 10,000 HTTP Requests: 4,797 Requests

Transfer out
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- 197.126 GB
- 3 Requests
- 52,154 Requests
- 23.71
- 212,982 GB
- 1 Request
- 16,456 Requests
- 25.58
- 23,800 GB
- 4,675 Requests
- 4,797 Requests

GAMS
Model Structure

1. Regional farmer employment accounting row in man-years:

\[-12LMAN + \sum_i LMAN_i = 0\]

2. Total employment accounting row in man-months:

\[-22LMANt + \sum_d dDLt + \sum_d dFLq + \sum_q dFLt = 0,\]

3. Total monthly employment accounting row in man-months:

\[-22LMANt + \sum_d dDLt + \sum_d dFLq + \sum_q dFLt = 0,\]

4. Regional farmer employment activity:

\[-RFSr + 3 \sum_{q} dFLq + \sum_{q} dFLt = 0,\]

5. Sum over districts and quarters of quarterly farmer employment:

\[\sum_{q} \text{Sum over districts and months of monthly farmer employment} = 0\]

6. Additional notes:

- In irrigated districts, the quarterly contract device is used for farmers, but in non-irrigated districts, farmers are assumed to be available on a monthly basis, so that seasonal migration to irrigated areas may occur.
- The activities for hiring farmers and day laborers are stated in units of man-months or man-hours, and there are 22 working days per month; hence the conversion factor of 2.2 is required in the limit term of this equation.
## Table 3
### Sequence of standard operations for cotton cultivation (days of unskilled labor, machinery services, and draft animal services required per hectare by month)

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INFORMS Lanchester Prize 1973

1973 Frederick W. Lanchester Prize: Winner [-hide]

Citation: Multi-Level Planning: Case Studies in Mexico, edited by Louis M. Goreux and Alan S. Manne.
This book is a bench mark quantitative study of policy oriented issues in a growing economy. In the modern tradition of Professor W. Leontief's input-output analysis, a team of researchers from several institutions employed advanced mathematical programming approaches to study in depth the problems of interdependency among national economic choices. This monograph on multi-level planning is impressive in its dedication to developing and testing large-scale models based on available statistical data. The team's decision a half-decade ago to give special emphasis to the agricultural and energy sectors was prophetic in anticipating many of today's critical world-wide problems. Beyond its substantial contribution to empirical analysis, the book also enhances conceptual understanding of multi-level national planning as well as demonstrates the benefits to strategic policy analysis of continuing technical innovations in operations research.
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Matrix Generator Input

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- REV2
- REV4
- REV5
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- CLA, V.02: 5.03328
- CLA, V.03: 5.03328
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PLANNING PROBLEM AND OBJECTIVES INITIALLY OFTEN

UNSTRUCTURED

ILL-DEFINED

CONFLICTING

UNCERTAIN

CHANGING

EMOTIONAL

MATHEMATICAL MODEL USED TO RECOGNIZE AND FORMULATE PROBLEMS, DEFINE ISSUES AND EXPLORE SOLUTION SPACE
RESULT:  
- Drain of resources (technical, time, money)  
- Essentially no documentation
MAJOR CONSTRAINTS:

- COST
- SKILLS
- TIME
- TOOLS
- DOCUMENTATION
- TRUST
RESULT:
- Limited drain of resources
- Same representation of models for humans and machines
- Model representation is also model documentation
DEVELOPMENT OF GAMS

Phase 1 (1978)

- The system can be used to represent and analyze any algebraic model (be it linear or nonlinear)
- The system can perform algebraic manipulations on all data
- The system can generate and solve linear programs automatically
- The system can generate reports on data and solutions via simple 'display' statements
DEVELOPMENT OF GAMS

Phase 2 (1979)

- The system can generate and solve nonlinear programs
- The system will provide links to special-purpose algorithms for econometric problems, network problems, etc.
- Appropriate extensions to the language will be made as the need arises
DEVELOPMENT OF GAMS

Phase 3 (?)

- Automatic structure recognition

- Internal generation of exact point-derivatives

- Improved data-base design with e.g. unit analysis, and links to existing data bases

- Availability of GAMS on different machines

- World-wide availability of the system so that it can be used as a market for testing models and algorithms
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

• Declarative: Model Algebra

• Procedural: Programming Flow Control Features

  • Loop, For, While, Repeat

  • If, else, else…

  • Macros

  • Access to external programs/libraries

  • …
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
- Windows 64
- Linux 32
- Linux 64
- Mac
- HP
- 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

30+ Integrated Solvers

- XA
- XPRESS
- COIN-OR
- BDMLP
- CPLEX
- BARON
- LINDOGLOBAL
- GUROBI
- GLOMIQO
- JAMS
- SCIP
- CONOPT
- LINDO
- MOSEK
- MINOS
- ALPHAECP
- DICOPT
- BARON
- COIN-OP
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- GLOMIQO
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- CPLEX
- GLOMIQO
- CONOPT
- JAMS
- SCIP
- LINC
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
System Overview

Connectivity Tools
- Uniform Data Exchange:
  - ASCII
  - GDX (ODBC, SQL, XLS, XML)
- GDX Tools
- Component Library with Interfaces to C++, Java, .NET,…
- Ext. programs
  - EXCEL
  - MATLAB
  - GNUPLOT, …
- CONVERT

Productivity Tools
- Integrated Development Environment (IDE)
- Integrated Data Browser and Charting Engine
- Model Libraries
- Benchmarking and Deployment
- Model Debugger and Profiler
- Transparent and reproducible Quality Assurance and Testing System
- Data and Model Encryption
- Grid Computing
- Scenario Reduction
- MPSGE for general equilibrium modeling

User Interfaces

GAMS Language Compiler and Execution System

Interactive

API / Batch

Solvers
LP/MIP-QCP-MIQCP-NLP/DNLP-MINLP-CNS-MCP-MPEC, global, and stochastic

ALPHAEC, BARON, COIN, CONOPT, CPLEX, DECIS, DICOPT, GUROBI, KNITRO, LGO, LINDO, MINOS, MOSEK, OQNLP, PATH, SNOPT, XA, XPRESS, …
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
ReMIND-R is a global energy economy climate model in a multi-regional setting. It 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
IMPACT - Modeling the Effects of Climate Change and Water Availability on Food Security

The International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT) examines alternative futures for global food supply, demand, trade, prices, and food security. IMPACT-WATER integrates the primary IMPACT model with a water simulation module that balances water availability and uses within various economic sectors at the global and regional scale.

- divides the world into 281 food-producing units and covers 40 different agricultural crop commodities
- incorporates a system of supply and demand elasticities into a series of linear and nonlinear equations to approximate the underlying production and demand functions
- examines the impact of water availability on food supply, demand and prices
- generates annual projections for crop area, yield, and production

IMPACT Spatial Resolution
115 Regions X 126 H2O Basins

281 Food Producing Units
HABITAT – a reserve selection tool for European wetland biodiversity conservation

Developed at the University of Hamburg, the HABITAT model was explicitly designed for the special requirements for conservation planning on the European continent with its fragmented habitats and high human population density. It is based on principles of systematic conservation planning and economic theory. This central component of the systematic conservation planning philosophy aims at efficiency of resource use. The objective is to find a set of conservation sites that achieves a conservation target at minimum cost.

- A set-covering problem formulated as a mixed integer program to find the cost-efficient allocation of nature reserves
- Integration of representation and persistence principles in the „conservation target” approach
- Endogenous calculation of reserve sizes
- Explicit integration of land market feedbacks
BALMOREL - A Model for Analyzing the Energy Sector in an International Perspective

- A large partial equilibrium model
- Supports modelling and analysis of the energy sector with emphasis on the electricity, combined heat and power sectors
- Covers international and regional electricity trade with transmission constraints, costs and losses
- Handles policy measures like taxes, quotas, CO2 emission markets, targets for energy efficiency improvement and renewables.
- Applied in projects in Denmark, Norway, Estonia, Latvia, Lithuania, Poland, Germany, Austria, Ghana, Mauritius and Canada
- More information and the full model source is available at: http://www.balmorel.com
AGMEMOD – Agri-food projections for EU member states

- An econometric, dynamic, multi-product partial equilibrium model and additional tools.
- Allows projections and simulations in order to evaluate measures, programmes and policies in agriculture at the European Union (EU) level as well as at the (candidate) member states level.
- Data and all equations of the country models are stored in spreadsheets.
- AgMemod2GAMS checks data as well as the specified equations (distinguishing 17 different types of errors) and automatically generates GAMS code (more than 145,000 lines).
- Data and model experts are working with a consistent and stable instance of the models.
- xxGraph compares scenarios and makes all results available in spreadsheets.

For more information please visit: http://www.tnet.teagasc.ie/agmemod/
Global Public Policy Modeling

PEAT-SIM is the Partial Equilibrium Agricultural Trade Simulation model used to analyze the effects of alternative proposals for agricultural trade liberalization and policy reform on a global scale. It has been developed jointly by the Economics Research Service (ERS) of the U.S. Dept. of Agriculture and the Dept. of Agricultural Economics and Rural Sociology at Penn State University.

- Freely available for public use: current users include government & academic agencies worldwide
- Sustained, collaborative development effort, beginning January 1999
- Multi-region, multi-commodity model drawing data from many sources
- Incorporates a wide range of policy instruments, e.g.: specific and ad-valorem tariffs/subsidies, tariff-rate quotas (TRQ's), producer & consumer subsidies, production quotas
- Discontinuous functions (e.g. TRQ's) modeled using complementarity and solved using PATH
Climate Policy Modeling

Climate Policy Modeling with GAMS

MERGE is a Model for Evaluating Regional and Global Effects of GHG reduction policies originally developed by Alan S. Manne from Stanford University and Richard Richels from the Electric Power Research Institute. MERGE provides a framework for thinking about climate change management proposals. The model is used to explore alternative views on a wide range of issues related to climate policy design, e.g., costs, damages, valuation, and discounting.

- The GAMS source code for MERGE is licensed by EPRI at zero cost and is available for public use. Current users include government & academic agencies worldwide. (See http://www.stanford.edu/group/MERGE/)

- MERGE is a multi-region, multi-commodity model combining both “top-down” and “bottom-up” elements of the global supply and demand for energy.

- A stochastic optimization formulation accommodates an explicit representation of uncertainty, although the model may also be operated in a deterministic mode.

- The model is solved using the CONOPT and MINOS nonlinear optimization solvers.

Facets

FACETS - An evolving Framework for Analysis of Climate-Energy-Technology Solutions

FACETS is a highly regionalized technology-rich US national planning framework under development that:

- Maintains NEMS/IPM/other data regions, relying on advanced techniques for representing and managing trade for integration
- Comprehensively encompasses the entire energy system, with associated climate and local emissions
- Is geographically and sector "scalable", and
- Can be readily linked to economic models

The core model includes tools for assembling data, managing models, and communicating the relevance of results to foster better informed decision-making.

For further information about this application please contact:
Gary Goldstein (DecisionWare.NY@gmail.com), Amit Kanudia (amit@kanors.com),
or visit:  http://www.KanORS.com/DCM/RES2020
ProCom Optimization Suite

ProCom is a leading OR solution provider for the energy and raw material processing industries specializing in integrated planning of power generation and trading.

The ProCom® Optimization Suite is powered by GAMS, enhancing its applicability for a variety of optimization tasks. For example, ProCom developed a decision-support system for operational and strategic planning in surface coal mining with significant attention to detail. Operational considerations, e.g. assignment of tilting and production sides of the excavators and variation in material properties, are included in the optimization of the schedule.

The Optimization Suite enables ProCom to provide the following services:

- Feasibility studies and analyses
- OR consulting and strategic planning
- Development of customized operational planning and control systems
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
Optience Core Application Builder

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
Scheduling and Planning at BASF

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
SCA Technologies offers Cost Analysis and Business Planning solutions to create a framework for better business planning and decision making. This is accomplished with their SCAplanner predictive operations cost modeling software.

Through SCAplanner technology, Finance and Operations come together into one platform! This helps in several ways including:

- **Product Cost Optimization** through understanding of your actual product costs, intermediates and associated activities
- **Budgeting, Forecasting & Planning** driven by ABC constraints. Allows rapid response to ongoing changes such as those in production
- **Operational Decision Support** on concerns like Make/Buy, Restructuring Plants or DC’s, Shutdowns, Outsourcing, etc.

This integrated view of a business allows managers to execute alternative “what-if” scenarios and see their impact on the items mentioned above. This is achieved by bringing together concepts of Activity Based Costing, Operations Modeling and Optimization. Put simply, with SCAplanner software, you see and understand the true P&L impact on operational changes beforehand, and therefore the consequences of these decisions!

SCA Technologies LLC
Intelligent Cost Management Solutions

www.sca-tech.com
DemandTec Leverages GAMS to Drive Innovation in Retail and CPG Industries

DemandTec uses sophisticated econometric and optimization models to help retailers and manufacturers make merchandising and marketing decisions based on a quantified understanding of consumer demand. DemandTec's applications are used to:

- Model price elasticity, cross-price elasticity, and other merchandising causals to predict and influence demand given different merchandising conditions and strategies.

- Optimize prices and promotions to maximize sales, volume, or profit, while operating within the constraints of competitive pricing and other business rules.

- Accurately forecast the impact of merchandising strategies and tactics, taking into account cannibalization, halo effects, seasonality, trend, and other factors.
Agenda

- GAMS at a Glance
- A simple Example
- What is new?
- Market Demands and Challenges
A Simple Example: Transportation Model

Seattle (350)

San Diego (600)

Chicago (300)

New York (325)

Topeka (275)
A Simple Example: Modifications

LP → MIP → MINLP → NLP → LP
A Simple Example: Algebra

Minimize Transportation cost
subject to Demand satisfaction at markets
Supply constraints

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

$$\sum_i \sum_j c_{i,j} \times x_{i,j} \quad \rightarrow \quad \min$$

$$\sum_j x_{i,j} \leq a_i \quad \forall i$$

$$\sum_i x_{i,j} \geq b_j \quad \forall j$$

$$x_{i,j} \geq 0 \quad \forall i, j$$
A Simple Example: 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 \( \text{ship} = 1 \rightarrow x \geq 100: x \geq 100 \times \text{ship} \)
  – If \( \text{ship} = 0 \rightarrow x = 0: x \leq \text{bigM} \times \text{ship} \)
A Simple Example: Economy of Scales

Cost $= Volume^{\beta}$

- **Beta >1**
- **Beta =1**
- **Beta <1**
Agenda

- GAMS at a Glance
- A simple Example
- What is new?
- Market Demands and Challenges
What is new: GAMS System

- Support for user-defined
  - Macros
  - Function libraries
- Asynchronous execution
- Extended Mathematical Programming (EMP)
- Stochastic 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

- **Lindo**: Global and stochastic optimization

- **Gather-Update-Solve-Scatter**
What is new: Interfaces

• **GAMS Modeling Object**

• API’s for various programming languages (C, Fortran, Delphi)

• Component libraries

• Better integration into Python

• .Net Integration ("GAMS.NET")
## Agenda

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<td>What is new?</td>
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<tr>
<td>Market Demands and Challenges</td>
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Market Demands

• **Minimize risks** for (new) clients / management
  • Support rapid prototyping
  • Increase productivity
  • Deliver (expected) results

• Do not lock users into a certain environment

• Protect user investments

• Provide cutting edge technology
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
Challenge 1

- Data transfer between different systems slow, error prone and bulky.

- Application (real time) require the capture of data instances that can be analyzed off-line in other environments.

- Management of name space mappings between different problems and their transformations into other data representations.

- Separate the model from its environment

- Search for a common low level high performance data container
GDX
Gams Data eXchange
Gams Data eXchange

Binary Data Exchange

- Fast
- Compact in memory and/or disk space
- Tailored for large sparse data structures
- Platform independent
- Direct GDX interfaces
- API support for high-level programming languages
- No license required
GDX: GAMS in Control
GDX: GAMS in Control
GDX: GNUPLOT
GDX: Application in Control

Application

GDX API

GDX Container

Creating Input

GAMS (Executable / DLL)

Call GAMS

GDX API

GDX Container

Reading Solution
| c1 | c2 | c3 | c4 | c5 | c6 | c7 | c8 | c9 | c10 | c11 | c12 | c13 | c14 | c15 | c16 | c17 | c18 | c19 | c20 | c21 | c22 | c23 | c24 | c25 |
|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| 12 | 17 | 8  | 18 | 11 | 3  | 7  | 12 | 22 | 3  | 17 | 1  | 13 | 20 | 22 | 11 | 15 | 3  | 18 | 12 | 16 | 14 | 8  | 10 | 16 | 4  | 22 |
| 4  | 2  | 8  | 9  | 3  | 24 | 20 | 9  | 18 | 1  | 15 | 3  | 8  | 12 | 13 | 9  | 25 | 8  | 12 | 4  | 11 | 20 | 12 | 24 | 14 | 7  |
| 21 | 12 | 24 | 23 | 4  | 10 | 5  | 9  | 18 | 1  | 15 | 3  | 8  | 12 | 13 | 9  | 25 | 8  | 12 | 4  | 11 | 20 | 12 | 24 | 14 | 7  |

GDX: Sudoku-Example (Datalib)
GDX: MATLAB

Figure 1: US dollar short rate scenarios

Figure 2: Short vs. long rates
GDX: GDX and the IDE

Using the GDX Viewer

- GDX-Browser
- Data cube
- Drag and drop
- Search engine
- Export to Excel,…
- Charting Engine
Parameter d(i,j) distance in thousands of miles;
$call GDXXRW dist.xlsx par=d rng=A1 rdim=2 cdim=0
$if errorlevel 1 $abort "Problem with file dist.xls!"
$gdxin dist
$load d
GDX: GDXDiff
GDX: CSV Output (gdxdump)

```plaintext
gdxdump results symb=x format csv

<table>
<thead>
<tr>
<th>Dim1</th>
<th>Dim2</th>
<th>Val</th>
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<tr>
<td>seattle</td>
<td>new-york</td>
<td>50</td>
</tr>
<tr>
<td>seattle</td>
<td>chicago</td>
<td>300</td>
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<tr>
<td>seattle</td>
<td>topeka</td>
<td>0</td>
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<tr>
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<td>new-york</td>
<td>275</td>
</tr>
<tr>
<td>san-diego</td>
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<td>0</td>
</tr>
<tr>
<td>san-diego</td>
<td>topeka</td>
<td>275</td>
</tr>
</tbody>
</table>
```
Challenge 2

- Problems may contain
  - Complementarity
  - Hierarchy
  - Interacting agents
  - Risk measures
  - Logic relationships
  - Stochastic parameters

- Cannot be expressed with current modeling languages and have no direct solution method.

→ How to automate the transformations by annotations of existing optimization models that convey model structure to the solver.
EMP
Extended Math. Programming
EMP: Current state: Model-Side

- Traditional problem format

\[
\min_{x} c(x) \quad \text{s.t.} \quad A_1(x) \leq b_1, \ A_2(x) = b_2
\]

- Support for complementarity constraints

- Interactions between models possible
  - Series of models
  - Scenario analysis / parallel model runs (grid)
  - Iterative sequential feedback
  - Decomposition
EMP: Less-traditional concepts

- Global Optimization
  - BARON, LINDOGLOBAL
    - Proven global optimum
    - Require full problem algebra – point derivatives not enough
    - Achieved by model rewriting / syntax translation (CONVERT)

- Solving non-integer models as MCPs
  - PATHNLP
    - Reformulation via KKT conditions (1st and 2nd order deriv.)

- MP with Equilibrium Constraints (MPEC)
  - NLPEC
    - Solves MPECs via reformulation as NLPs
    - NLP problems are written out and processed by GAMS
EMP: New solution concepts

- Embedded Complementarity Systems
- Disjunctive Programs
- Bilevel Programs
- Extended Nonlinear Programs
- Variational Inequalities
- 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
EMP: Some Helpful Facts

- Symbolic model translations and processing are very fast
- Experience with symbolic differentiation and convex hull generators
- Reliable MCP solvers
- Emerging MPEC / SP solvers
- Experience with ‘wrapped’ solvers, i.e. with one solver calling another to solve a reformulation or subproblem
EMP: What now?

Do not:
• overload existing GAMS notation right away!
• attempt to build new solvers right away!

But:
• Use existing language features to specify additional model features
• Express extended model in symbolic form and apply existing matured solution technology
• Automate symbolic reformulations to avoid error-prone and time-consuming manual algebra (re)writing
• Include EMP free of charge in any GAMS system
• Continued development
EMP: GAMS “Solver” JAMS

EMP Information

Original Model

Translation

Reformulated Model

Solving using established Algorithms

Mapping Solution into original space

Viewable

Solution
EMP: Information File + Summary Log

randvar om1 discrete 0.25 1
    0.25 2
    0.25 3
    0.25 4

randvar om2 discrete 0.3333 1
    0.3334 2
    0.3333 3

chance E1 0.6
chance E2 0.6

--- EMP Summary

Logical Constraints = 0
Disjunctions = 7
Adjusted Constraint = 0
Flipped Constraints = 0
Dual Variable Maps = 0
Dual Equation Maps = 0
VI Functions = 0
Equilibrium Agent = 0
Bilevel Followers = 0
EMP: Examples

GAMS EMP-Library

- Distributed with GAMS
- SP:
  - Single-Stage
  - Multi-Stage
  - Chance Cons.

http://www.gams.com/emplib/emplib.htm
Building and maintaining solver specific links in different programming languages became a huge resource sink and made the introduction of new features difficult.

- Simplify the building and maintaining of solver links
- Manage multiple interacting models
- Minimize the solver specific tailoring
- Maintain one source only
- Wrap automatically for different languages

Share libraries between the data management part of a modeling system and the solver. Example: function evaluations, first and second order derivatives, intervals,

Ease linking of experimental (meta-)solvers to GAMS
GMO

Gams Modeling Object
Gams Modeling Object (GMO)

GAMS’ Next-Generation Model API

- Why a new model API?
- What do we need it to do?
- What does it look like? How is it put together?
- How did we do it?
- When are we going to be finished?
GMO: Solver Links – Different Perspectives

GAMS User
- Standardized solver interface allows “hassle free” replacement of solvers: `option nlp=conopt;`
  …nothing will change

Solver & Solver-link Developer
- IO Library provides access to
  - Matrix
  - Function/Gradient/Hessian evaluations
  - Solution file writer
  - Output handling
  - GAMS Options (e.g. resource limit)
  - Problem attributes (SOS, semicont, semiint, priorities, scales)
  - Utility routines
  - problem rewriting, matrix reordering
  …our focus here
GMO: Reuse - what’s that?!?

Solver Links

AlphaECP
Baron
......
Xa
Xpress
(~50 total)

Fortran I/O
Library
Delphi I/O
Library
C I/O
Library
MPEC I/O
SMAG Lib
G2D Lib

CONOPT
MINOS
SNOPT
PATH
MILES
CPLEX
GUROBI
XPRESS
Advantages

- proven over many years
- all platforms supported
- all GAMS-features available
- written by language experts, use all language features
- resulted in high-quality links across solvers and platforms → has been one factor in our success
Disadvantages

• inconvenient & expensive to maintain
• Not always intuitive to use
• Outdated design – I/O, STOP
• feature-poor (e.g. no automatic reformulation of objective func/var)
• linking your solver (without buddy at GAMS) is very difficult
GMO: Checklist

- Powerful & convenient API – a few calls do the job
- In-core or file communication between GAMS and the solver, making potentially large model scratch files unnecessary
- Implement once, run everywhere (multiple platforms & multiple languages)
  - Platform-independent code, isolate the “dirty bits”.
  - API wrapper & multi-language interface
- Support meta-solvers (e.g. DICOPT, SBB, Examiner)
- Separate model from environment
- Comprehensive – one-stop shop for all linking needs
- Support shared-library implementation of solver links
GMO: Summary

Solver Links

AlphaECP
Baron
......
Xa
Xpress
(~50 total)

Your solver!

Gams
Modeling
Object
GMO: Implement Once, Run Everywhere

- All GMO coding done in a single language and style
  - Allows code sharing with other components
  - Allows for shared development

- All GMO coding is platform-independent
  - Makes writing code faster, more reliable
  - Maintenance is simplified

- Platform-dependent code isolated in utility libraries
  - Makes adding a new platform easier
  - Maintenance is simplified
  - Unit testing is easy and effective
Distributed GAMS APIs

- Component Libraries
  - GAMS
  - GDX
  - Option

- Supported languages
  - C, C++, C#
  - Delphi
  - Fortran
  - Java
  - VBA, VB.Net
  - Python

- Examples/Documentation
Challenge 4

GAMS integrates more than 30 Solvers and is available on more 10 platforms:

- Do we meet our quality standards?
- Is our new distribution backward compatible?
- What is the impact of new implementation of parts of the GAMS system?
- How can we automate this process?
QA
Quality Assurance
Key components of SQA

• **Software configuration management (SCM)**
  – All activities related to version control and change control
  → Version control via remote SVN server
  → Bug tracking via remote TRAC server

• **Quality control and testing**
  – Focus on the quality of product *within each phase* of the software development lifecycle
  – Objective: identify and remove defects throughout the lifecycle, as *early as possible*

→ Public Test Libraries
→ Performance comparison tools
→ Solution verification tools
→ Proactive Software Development Lifecycle
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>Wednesday</td>
<td>Inx</td>
<td>Download</td>
<td>23.9.0</td>
<td>32515 Test started 12Apr2012 01:32:39</td>
<td>798 runs 3 failures (q=3, s=0)</td>
<td>Report results pending</td>
<td></td>
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<tr>
<td>Wednesday</td>
<td>vs8</td>
<td>Download</td>
<td>23.9.0</td>
<td>32517 Test done 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>
<td>Report</td>
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<tr>
<td>Wednesday</td>
<td>weib</td>
<td>Download</td>
<td>23.9.0</td>
<td>32522 Test done 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>
<td>Report</td>
</tr>
</tbody>
</table>

GAMS System Builds and Test Results Archive

| Total: | 9112 runs | 20 failures |
| Quality: | 1838 runs | 19 failures |
| Slowest: | 7576 runs | 1 failures |
| EMP: | 126 runs | 0 failures |
| Data: | 36 runs | 0 failures |

**** QUALITY TEST FAILURES (failures_qa.gms)

```python
GAMS quality DEMOSIZE=1 lo=2 --prefix=vs8 --fail=failures_qa.tmp run time=BADPT2 --ftrace=1
GAMS quality DEMOSIZE=1 lo=2 --prefix=vs8 --fail=failures_qa.tmp run time=BADPT3 --ftrace=1
GAMS quality DEMOSIZE=1 lo=2 --prefix=vs8 --fail=failures_qa.tmp run time=BADPT4 --ftrace=1
GAMS quality DEMOSIZE=1 lo=2 --prefix=vs8 --fail=failures_qa.tmp run time=BADPT5 --ftrace=1
GAMS quality DEMOSIZE=1 lo=2 --prefix=vs8 --fail=failures_qa.tmp run time=BADPT6 --ftrace=1
GAMS quality DEMOSIZE=1 lo=2 --prefix=vs8 --fail=failures_qa.tmp run time=BADPT7 --ftrace=1
GAMS quality DEMOSIZE=1 lo=2 --prefix=vs8 --fail=failures_qa.tmp run time=BADPT8 --ftrace=1
GAMS quality DEMOSIZE=1 lo=2 --prefix=vs8 --fail=failures_qa.tmp run time=BADPT9 --ftrace=1
GAMS quality DEMOSIZE=1 lo=2 --prefix=vs8 --fail=failures_qa.tmp run time=BADPT10 --ftrace=1
GAMS quality DEMOSIZE=1 lo=2 --prefix=vs8 --fail=failures_qa.tmp run time=BADPT11 --ftrace=1
GAMS quality DEMOSIZE=1 lo=2 --prefix=vs8 --fail=failures_qa.tmp run time=BADPT12 --ftrace=1
```
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)
Summary

What is GAMS

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

Market Demands:

• Minimize Risks
• Provide cutting edge technology
• Protect user investments

Challenges and Solutions

• GDX
• GMO
• EMP
• Quality Assurance
Thank You!

<table>
<thead>
<tr>
<th>USA</th>
<th>Europe</th>
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</thead>
<tbody>
<tr>
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