General Algebraic Modeling System

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GAMS Development Corporation

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Annandale, NJ, August 2002
Introduction

Background and Motivation

GAMS Examples

MCPs and MPECS

www.gamsworld.org

Future
## Change in Focus

<table>
<thead>
<tr>
<th>Computation</th>
<th>Model</th>
<th>Application</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Past</strong></td>
<td><strong>Present</strong></td>
<td><strong>Future</strong></td>
</tr>
<tr>
<td>- Algorithm limits applications</td>
<td>- Modeling skill limits applications</td>
<td>- Domain expertise limits application</td>
</tr>
<tr>
<td>- Problem representation is low priority</td>
<td>- Algebraic model representation</td>
<td>- Off-the-shelf graphical user interfaces</td>
</tr>
<tr>
<td>- Large costly projects</td>
<td>- Smaller projects</td>
<td>- Links to other types of models</td>
</tr>
<tr>
<td>- Long development times</td>
<td>- Rapid development</td>
<td>- Models embedded in business applications</td>
</tr>
<tr>
<td>- Centralized expert groups</td>
<td>- Decentralized modeling teams</td>
<td>- New computing environments</td>
</tr>
<tr>
<td>- High computational cost, mainframes</td>
<td>- Low computational cost, workstations</td>
<td>- Internet/web</td>
</tr>
<tr>
<td>- Users left out</td>
<td>- Machine independence</td>
<td>- Users hardly aware of model</td>
</tr>
</tbody>
</table>
GAMS Overview

- Started as a Research Project at the World Bank 1976
- GAMS went commercial in 1987
- Opened European Office in Cologne, Germany 1996
- 10,000s of customers in over 100 countries
Basic Principles

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

- LP Linear Programming
- MIP Mixed Integer Programming
- NLP Nonlinear Programming
- MCP Mixed Complementarity Programming
- MINLP Mixed Integer Nonlinear Programming
- MPEC NLP with Complementarity Constraints
- MPSGE General Equilibrium Models
- Stochastic Optimization
## Supported Solvers

<table>
<thead>
<tr>
<th>Solver</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>BDMLP</td>
<td>LP solver that comes with any GAMS system</td>
</tr>
<tr>
<td>CONOPT</td>
<td>Large scale NLP solver from ARKI Consulting and Development</td>
</tr>
<tr>
<td>CPLEX</td>
<td>High-performance LP/MIP solver from Ilog</td>
</tr>
<tr>
<td>DECIS</td>
<td>Large scale stochastic programming solver from Stanford University</td>
</tr>
<tr>
<td>DICOPT</td>
<td>Framework for solving MINLP models. Needs both an NLP solver and a MIP solver. From Carnegie M</td>
</tr>
<tr>
<td>MILES</td>
<td>MCP solver from University of Colorado at Boulder that comes with any GAMS system</td>
</tr>
<tr>
<td>MINOS</td>
<td>NLP solver from Stanford University</td>
</tr>
<tr>
<td>MPSGE</td>
<td>Modeling Environment for CGE models from University of Colorado at Boulder</td>
</tr>
<tr>
<td>OSL</td>
<td>High performance LP/MIP solver from IBM</td>
</tr>
<tr>
<td>OSLSE</td>
<td>OSL Stochastic Extension for solving stochastic models</td>
</tr>
<tr>
<td>PATH</td>
<td>Large scale MCP solver from University of Wisconsin at Madison</td>
</tr>
<tr>
<td>SBB</td>
<td>Branch-and-Bound algorithm from ARKI Consulting and Development for solving MINLP models, requi</td>
</tr>
<tr>
<td>SNOPT</td>
<td>Large scale SQP based NLP solver from Stanford University</td>
</tr>
<tr>
<td>XA</td>
<td>Large scale LP/MIP system from Sunset Software</td>
</tr>
<tr>
<td>XPRESS</td>
<td>High performance LP/MIP solver from Dash</td>
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</table>
# Beta Solvers

<table>
<thead>
<tr>
<th>Solver</th>
<th>Description</th>
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<tbody>
<tr>
<td>BARON</td>
<td>Branch-And-Reduce Optimization Navigator for proven global solutions from The Optimization Firm</td>
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<tr>
<td>CONVERT</td>
<td>Framework for translating models into scalar models of other languages</td>
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<tr>
<td>LGO</td>
<td>Lipschitz global optimizer from Pinter Consulting Services</td>
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<tr>
<td>MOSEK</td>
<td>Large scale LP/MIP plus conic and convex non-linear programming system from EKA Consulting</td>
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<td>NLPEC</td>
<td>MPEC to NLP translator that uses other GAMS NLP solvers</td>
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<tr>
<td>OQMS</td>
<td>Multi-start method for global optimization from Optimal Methods Inc.</td>
</tr>
<tr>
<td>PATHNLP</td>
<td>Large scale NLP solver for convex problems from University of Wisconsin at Madison</td>
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</tbody>
</table>

## Contributed Plug & Play Solvers

<table>
<thead>
<tr>
<th>Solver</th>
<th>Description</th>
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<tbody>
<tr>
<td>AMPLwrap</td>
<td>Framework for using AMPL solver for GAMS models</td>
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<tr>
<td>DEA</td>
<td>Large scale Data Envelop Analysis Solver from University of Wisconsin at Madison</td>
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<td>Kestrel</td>
<td>Framework for using remote NEOS solvers with a local GAMS system</td>
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<tr>
<td>QPwrap</td>
<td>Quadratic programming in GAMS</td>
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## Supported Platforms

**Solver/Platform availability - 20.7**

<table>
<thead>
<tr>
<th></th>
<th>Intel Windows 95/98/Me/NT/2000/XP</th>
<th>Intel Linux</th>
<th>Sun Sparc Solaris</th>
<th>HP 9000 HP-UX 10</th>
<th>DEC Alpha Digital Unix 4.0</th>
<th>IBM RS-6000 AIX 4.3</th>
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*June 14, 2002*
Minimize Transportation cost subject to Demand satisfaction at markets, Supply constraints.
GAMS Implementation

• Using the GAMS IDE to build a model
• Data Entry
• Max/Min Shipments
• Nonlinear Cost
• MCP Formulation
• Flexible Demand
• call GAMS IDE
GAMS IDE

```gams
*--- data entry

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     2.8       1.7        1.9
    san-diego   2.5       1.2        1.4 ;

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

Parameter rate(i,j); rate(i,j) = f * d(i,j) / 1000 ;
```
sets  i    canning plants
        j    markets

parameters a(i)       capacity of plant i in cases
                    c(i,j)    transport cost in thousands of dollars per case
                    b(j)      demand at market j in cases

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;

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

            supply(i)  .  a(i)  =g=  sum(j, x(i,j));

            demand(j)  .  sum(i, x(i,j))  =g=  b(j);

Model  m1 /all/ ;
Model m1.gms (cont.)

model m1 /all/ ;

$call gams dat1 gdx=dat1
$gdxin dat1
$load i j a b c=rate

*--- solve LP and store results

Solve m1 us lp min z ;

parameter rep(i,j,*) Summary Report;

rep(i,j,'lp') = x.l(i,j);
* min and max shipments
option limcol=0,limrow=0;

scalars xmin / 100 /
    xmax / 275 /;

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

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

minship(i,j).. x(i,j) =g= xmin*ship(i,j);
maxship(i,j).. x(i,j) =l= xmax*ship(i,j);

model m2 min shipments / cost, supply, demand, minship, maxship /;
solve m2 using mip minimizing z;

rep(i,j,'mip') = x.l(i,j); display rep;
Nonlinear Cost

* nonlinear cost

equation nlcost nonlinear cost function; scalar beta;

\[ z = \sum_{i,j} c(i,j) \cdot x(i,j)^{\beta} \]

model m3 / nlcost, supply, demand /;

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

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

option nlp=baron; solve m3 using nlp minimizing z;
rep(i,j,'nlp-baron') = x.l(i,j); display rep;
Min/Max and NL objective

* min/max and nl obj

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

option minlp=baron; solve m4 using minlp minimizing z;
option nlp =snopt; option optcr=0;
option minlp=sbb; solve m4 using minlp minimizing z;

rep(i,j,'minlp') = x.l(i,j); display rep;
* lp as mcp

positive variables \( w(i) \) shadow price at supply node

\( p(j) \) shadow price at demand node;

equations profit\( (i,j) \) zero profit condition;

\[
\text{profit}(i,j) .. w(i) + c(i,j) =g= p(j);
\]

model m5 / profit.x, supply.w, demand.p /;

solve m5 using mcp;

\[
\text{rep}(i,j,'mcp') = x.l(i,j); \text{ display rep};
\]
* flexible demand

parameter pbar(j) reference price

  esub(j) price elasticity

  / new-york 1.5, chicago 1.2, topeka 2.0 /;

equation flexdemand(j) price responsive demand;

flexdemand(j).. sum(i, x(i,j)) =g= b(j)*(pbar(j)/p(j))**esub(j);

model m6 / profit.x, supply.w, flexdemand.p /;

pbar(j) = p.l(j); solve m6 using mcp; rep(i,j,'mcp-flex') = x.l(i,j);
* counter factual

\[ c('seattle', j) = 2.0 \times c('seattle', j); \]

solve m5 using mcp; rep(i, j, 'cf-fix') = x.l(i, j);
solve m6 using mcp; rep(i, j, 'cf-flex') = x.l(i, j);
display rep;

$libinclude xldump rep rep
## Summary Result

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
<th>I</th>
<th>J</th>
<th>K</th>
<th>L</th>
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<tbody>
<tr>
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<td>lp</td>
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</table>
New Technologies

- Second order derivatives:
  - CONOPT3 multi-method NLP solver
  - PATHNLP solves NLP as an MCP
- GAMS Data Exchange (GDX) provides platform independent data transfer and mapping facilities.
- MCP and MPEC model types
CONOPT3 Performance

Performance Profile: CONOPT3 default, w/o QP, w/o QP and w/o LP

Models solved (%)

1 10

10 100

CONOPT3

CONOPT3 NOSQP

CONOPT3-NOSQP
Find $y$ such that
\[ h(y) \perp y \in B = \{ y \mid a \leq y \leq b \} \]

The variable $y$ “complements” the function $h$

Exactly one of
\begin{align*}
(a) \ & a_i < y_i < b_i \quad \text{and} \quad h_i(y) = 0 \\
(b) \ & y_i = a_i \quad \text{and} \quad h_i(y) \geq 0 \\
(c) \ & y_i = b_i \quad \text{and} \quad h_i(y) \leq 0
\end{align*}
Special Cases

Nonlinear equations:

\[ a_i = -\infty, \quad b_i = +\infty \Rightarrow h_i(y) = 0 \]

Nonlinear complementarity:

\[ a_i = 0, \quad b_i = +\infty \Rightarrow 0 \leq y_i, \quad h_i(y) \geq 0 \]
\[ y_i h_i(y) = 0 \]

Key: either \( y_i = 0 \) or \( h_i(y) = 0 \)
* data specified i,j,A,b,c,g

positive variables p(i), z(j);

equations S(i), L(j);

S(i).. b(i) + sum(j, A(i,j)*z(j))
    - c(i)*sum(k, g(k)*p(k)) / p(i) =g= 0;

L(j).. - sum(i, p(i)*A(i,j)) =g= 0;

model walras /S.p, L.z/;

solve walras using mcp;
minimize \( f(x, y) \)
such that \( g(x, y) \leq 0 \)

Add complementarity to definition of \( h \); parameter \( x \)

\[ h(x, y) \perp y \in B \]

Theory hard; no constraint qualification
Definition: $\phi(r, t) = 0 \iff 0 \leq r \perp t \geq 0$

Example: $\phi_{\text{min}}(r, t) = \min\{r, t\}$

Example: $\phi_F(r, t) = \sqrt{r^2 + t^2} - r - t$

Componentwise definition: $\Phi_i(x, y) = \phi(h_i(x, y), y_i) = 0$

$\Phi(x, y) = 0 \iff 0 \leq h(x, y) \perp y \geq 0$
• Implicit: $\min f(x, y(x))$

• Auxiliary variables: $s = h(x, y)$

• NCP functions: $\Phi(s, y) = 0$

• Smoothing: $\Phi_\mu(s, y) = 0$

• Penalization: $\min f(x, y) + \mu \{s'y\}$

• Relaxation: $s'y \leq \mu$

• Different problem classes require different solution techniques
Parametric algorithm

NLPEC

- Equreform = 1
- Initmu = 0.01
- Numsolves = 5
- Updatefac = 0.1
- Finalmu = 0
- Initslo = 0

Reformulate problem and set up sequence of solves

\[
\text{NLP} (\mu) : \min f(x, y) \\
g(x, y) \leq 0 \\
0 \leq s, \ y \geq 0 \\
s_i y_i = \mu
\]
• Create the GAMS model as an MPEC
• Setup nlpec.opt
  • `gams modelfile mpec=nlpec optfile=1`
• Reformulated automatically
• Results returned directly to GAMS
Benefits/Drawbacks

• Easy to adapt existing models
• Large-scale potential
• Customizable solution to problem
• Available within GAMS right now
• Models hard to solve
• Local solutions found
• Scarcity of MPEC models
• Find all or multiple equilibria
  – Use nlp=baron parametrically

• Structural identification
  – Inverse problems

• Optimal tariff calculations
  – Large-scale datasets

• Stackelberg (leader/follower) games
Thin or Zero client modeling

- Model and modeling system reside on application server
- Prototype user and data interfaces with Excel style data exchange
- Model submission via e-mail or web
- Model results delivered via the web and e-mail with Excel style attachments
### Excel Data

#### Table 1: Test Object Information

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<th>Site</th>
<th>*Requestor</th>
<th>*Category</th>
<th>Procedure</th>
<th>Test Object</th>
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#### Table 2: Objective Weights

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<th>C</th>
<th>D</th>
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#### Table 3: Fixed Week-1 Tests

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Data Interface inside GAMS

```
* Data reading module

$onecho > xlsin.txt
par=tnet  dim=9  rng=tnet!h1:r65536
par=capf  dim=2  rng=cap!a2:e8
par=dp    rdim=1  rng=cap!b13:c26
par=objw  rdim=1  rng=cap!a29:b32
par=sd    cdim=0  rng=cap!b10:b10
sset=fix  rdim=1  rng=cap!a35:a65536
$offecho

$if not set xlsname $set xlsname tnetnew.xls

$call =gdxxrw %xlsname%    @xlsin.txt log=con
$if errorlevel 1 $abort 'Reading TNet input sheet'
```
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<th>D</th>
<th>E</th>
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</table>

Ready
Data Interface inside Excel

```
* Get data from the Excel file
$call gdxrw $xlsfile% o=ictin.gdx index=ictpars
$gdxin ictin.gdx

$load I J K KL BR BRI BRJ
$load Cdata CPar Ddata Globrate Hr Mdata Mprice
$load Newportc Odata Pdata Pdatmin Prodmin Qfmaxdat Qfmindat Qmaxdat Qmindat Rate Tdata
```
This email will submit an ICT model to the email submission tool.
Web Submission

Hillmodels Web Submission Tool

Model type: ict

Email Address: gene@gams.com
Subject Line: Web submission tool test
Submit model:

Submit Model
Job Info Via e-mail

Please click on:

http://31517:depre04@www.hillmodels.com/

If you are asked for login and password, type:

user name: 31517
password: depre04
Result Presentation

Increase in Ktons Per Year

- Less Than 0
- 0 - 199
- 200-1000
- 1000-3000
Welcome to the GAMS World

This is the home page of the GAMS World, a web site aiming to bridge the gap between academia and industry by providing highly focused forums and dissemination services in specialized areas of mathematical programming.

Substantial progress was made in the 1980s and 1990s with the development of algebra based modeling systems, algorithms, and computer codes to solve large and complex mathematical programs. The application of these tools, however, was less than expected. The abstraction, expression, and translation of real world problems into reliable and effective operational systems requires highly specialized and domain specific knowledge. The process of acquisition and dissemination of this knowledge is complex and poorly understood and the number of “good modelers” is much less than we all hoped for. Similarly, the process of transforming a new algorithm into a reliable and effective solution system is a slow and expensive process and there are few “good implementers”. This web site hopes to address some of these problems by helping with the collection and dissemination of domain specific information and knowledge that is outside the established channels because of its content or form.

For example, model structures and results get published in commercial and academic papers but it is virtually impossible to reproduce any of those results or lift model components and data from one study to be used in some other study. Algorithm implementers face a similar dilemma when trying to get their hands on real world data models and data to test and refine their systems. This web site offers a few, well focused and maintained services to help with the dissemination of problems and solutions.

GAMS World is featured by GAMS Development Corp. and GAMS Software GmbH
…a web site aiming to bridge the gap between academia and industry by providing highly focused forums and dissemination services in specialized areas of mathematical programming.

Substantial progress in the 1980s and 1990s …. application of these tools less than expected …. abstraction, expression, and translation of real world requires highly specialized and domains specific knowledge … process of acquisition and dissemination of this knowledge is complex and poorly understood…process of transforming a new algorithm into a reliable and effective solution system is a slow and expensive…helping with the collection and dissemination of domain specific information and knowledge that is outside the established channels because of its content or form.
Welcome to the MINLP World!

MINLP World is a forum for discussion and dissemination of information about all aspects of Mixed Integer Nonlinear Programming (MINLP).

MINLP models are models that combine combinatorial aspects with nonlinearities. MINLP models are much more difficult than both Mixed Integer Linear Programming (MIP) and Nonlinear Programming (NLP) models.

MINLP is still a new field, and we cannot yet solve all the problems that naturally fall within this area. It is the purpose of this site to bring people that work with MINLP together. We are interested in practical software (MINLP Solvers), testing, comparison, and quality of solvers (MINLPLib), research in both solution methods and in good model formulations, and in improving the communication between people interested in these topics (Related Links and MINLP list).
Welcome to the MPEC World!

MPEC World is a forum for discussion and dissemination of information about all aspects of Mathematical Programs with Equilibrium Constraints (MPEC).

MPEC is a relatively new field (not nearly so mature as LP or NLP), and we cannot yet solve many of the problems that naturally fall within this area. It is the purpose of this site to bring people that work with MPEC together. We are interested in practical software (MPEC Solvers), testing, comparison, and quality of solvers (MPEC Lib), research in both solution methods and in good model formulations, and in improving the communication between people interested in these topics (Related Links and MPEC list).
Welcome to the Performance World!

Performance World is a forum for discussion and dissemination of information and tools about all aspects of performance testing of mathematical programming problems. This world has been established in response to user demands for independent and reproducible performance results.

Overall performance highly depends on problem formulation, solver, and tuning parameters. Our performance tools are designed to serve the different needs of our user community. One user may be interested in finding the most reliable way to solve a proprietary or classified model. On the other hand, an academic researcher may be interested in testing a new algorithm against a set of existing test problems and competing approaches. The main features are:

- Uniform access to a comprehensive set of established and new test problems
- Automation tools for collecting performance measurements
- Tools for analyzing and visualizing test results

What’s New:

- Try our online PAVER Server for automated performance analysis and batch file creation
- New tools for analyzing non-convex or discrete models
- MINLP type models from the MINLP World have been added to the PerformanceLib. A tutorial (August, 2002)
Translation Services

Instructions

In order to use the GMS2XX translation service which is based on the "solver" GAMS/CONVERT you have to attach your model to an email and send it to our translation server at gms2xx@gamsworld.org. You specify the language in the subject line, for example:

Subject: GAMS

At the moment we support the following languages:

- AMPL
- BARON
- CplexLP
- CplexMPS
- GAMS
- LGO
- LINGO
- MINOPT
- ALL (this creates scalar versions of all supported languages, listed above)
Welcome to GLOBAL World!

The Global World is a forum for discussion and dissemination of all aspects of computational methods to find global optimal solutions to nonconvex nonlinear optimization problems.

Recently, general purpose global solution algorithms have been implemented and have matured into reliable solution systems that can be connected to modeling systems. These new developments make the application of nonlinear global optimization methods available to users outside the narrow global research community.

General purpose global nonlinear optimization is a new field and much work needs to be done to test the capabilities and robustness on real world models. We are interested in practical software (see GLOBAL Solvers) and an ever growing, well maintained library of academic and practical client test problems in the GLOBAL Library. Communication is supported by maintaining the GLOBAL list server and related links.

For other specialized topics in the area of mathematical programming consult the GAMS World.

GLOBAL World is featured by GAMS World.
The solvers differ in the methods they use, in whether they find globally optimal solution with proven optimality, and in the size of models they can handle, and in the format of models they accept.

BARON. Branch-and-Reduce algorithm from N. Sahinidis, University of Illinois Urbana-Champaign

LGO. Lipschitz Global Optimization from Pinter Consulting Services, Canada

OQMS. OptQuest/NLP algorithms by OptTek Systems and Optimal Methods
BARON is a computational system for solving non convex optimization problems to global optimality. Purely continuous, purely integer, and mixed-integer nonlinear problems can be solved with the software. The Branch And Reduce Optimization Navigator derives its name from its combining interval analysis and duality in its reduce arsenal with enhanced branch and bound concepts as it winds its way through the hills and valleys of complex optimization problems in search of global solutions.
LGO combines rigorous statistical methods with traditional mathematical programming methods to find solutions within well defined bounds. Tailored versions of LGO have been applied successfully in number of large scale special purpose applications.
OQMS. This system combines existing the robust nonlinear optimization technologies with OptTek's state-of-the-art metaheuristic search procedures, including Tabu Search, Neural Networks, and Scatter Search, into a single composite method.
Future Directions

• Value Added Applications
• Solution Service Providers
• Distributed System Architectures
• New Solution Approaches
• Continued Changes in the Modeling ‘Industry’
GAMS can be contacted at this address:

GAMS Development Corporation  
1217 Potomac Street, NW  
Washington, DC 20007  
USA  
Phone: (202) 342-0180  
Fax: (202) 342-0181

If you prefer e-mail, here are some important addresses:

General Information and Sales: sales@gams.com  
Customer Support: support@gams.com  
Webmaster: webmaster@gams.com

In Europe you can contact us at this address:

GAMS Software GmbH  
Eupener Str. 135-137  
50933 Cologne  
Germany  
Phone: (+49) 221 949-9170  
Fax: (+49) 221 949-9171

The central e-mail address for our European office is: info@gams.de