Agenda

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

GAMS Development / GAMS Software

- Roots: **Research project** World Bank 1976
- Pioneer in **Algebraic Modeling Systems** used for economic modeling
- Went **commercial** in 1987
- **Offices** in Washington, D.C and Cologne

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

Typical Application Areas *

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

* Illustrative examples in the GAMS Model Library

GAMS Solutions Specialists Network

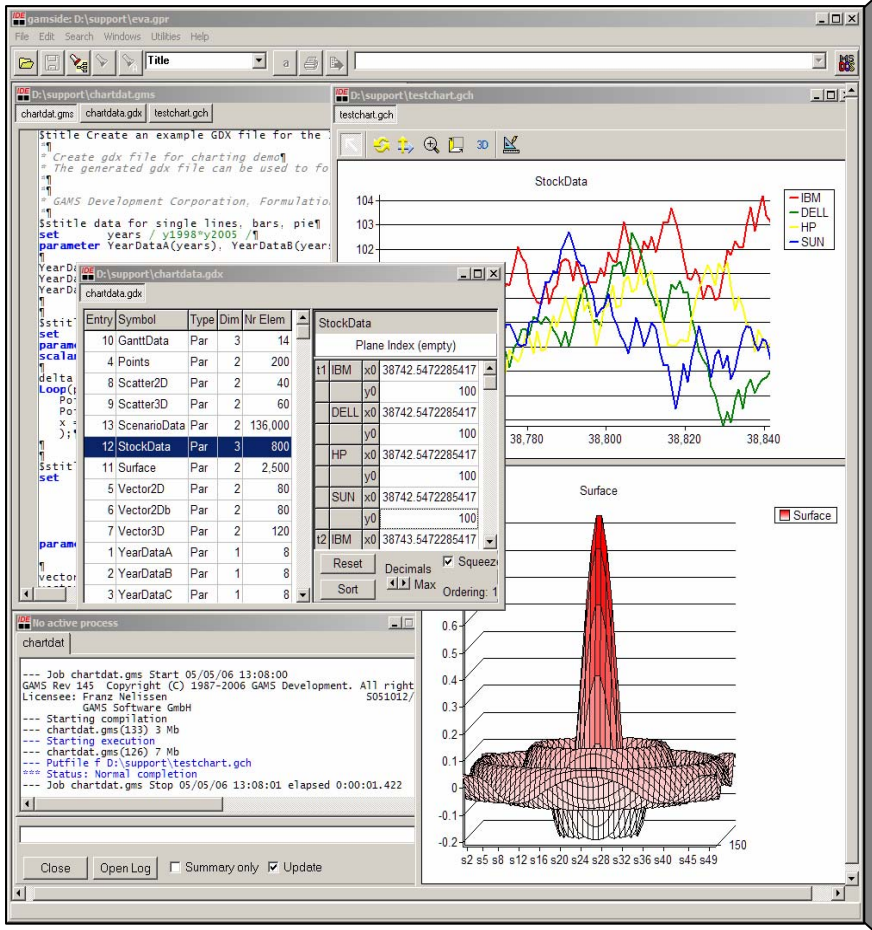
Companies with wide experience in GAMS modeling

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

Agenda

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

GAMS at a Glance

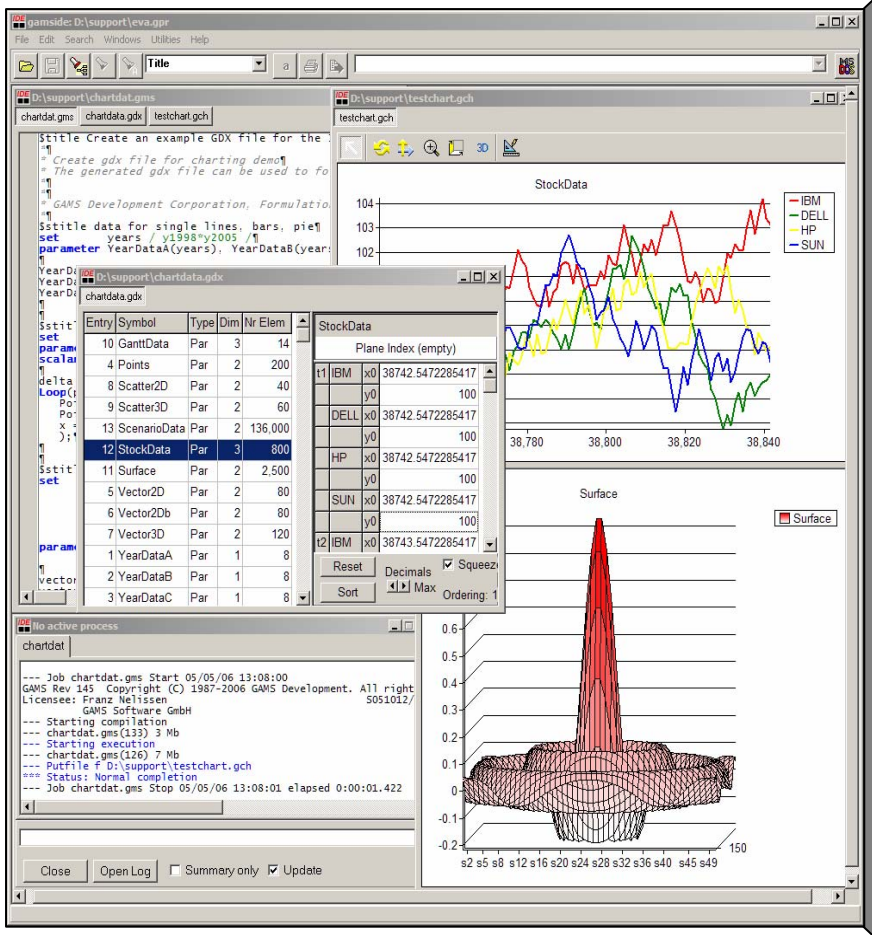


General **A**lgebraic **M**odeling **S**ystem:
Algebraic Modeling Language, Integrated Solver, Model Libraries, Connectivity- & Productivity Tools

Design Principles:

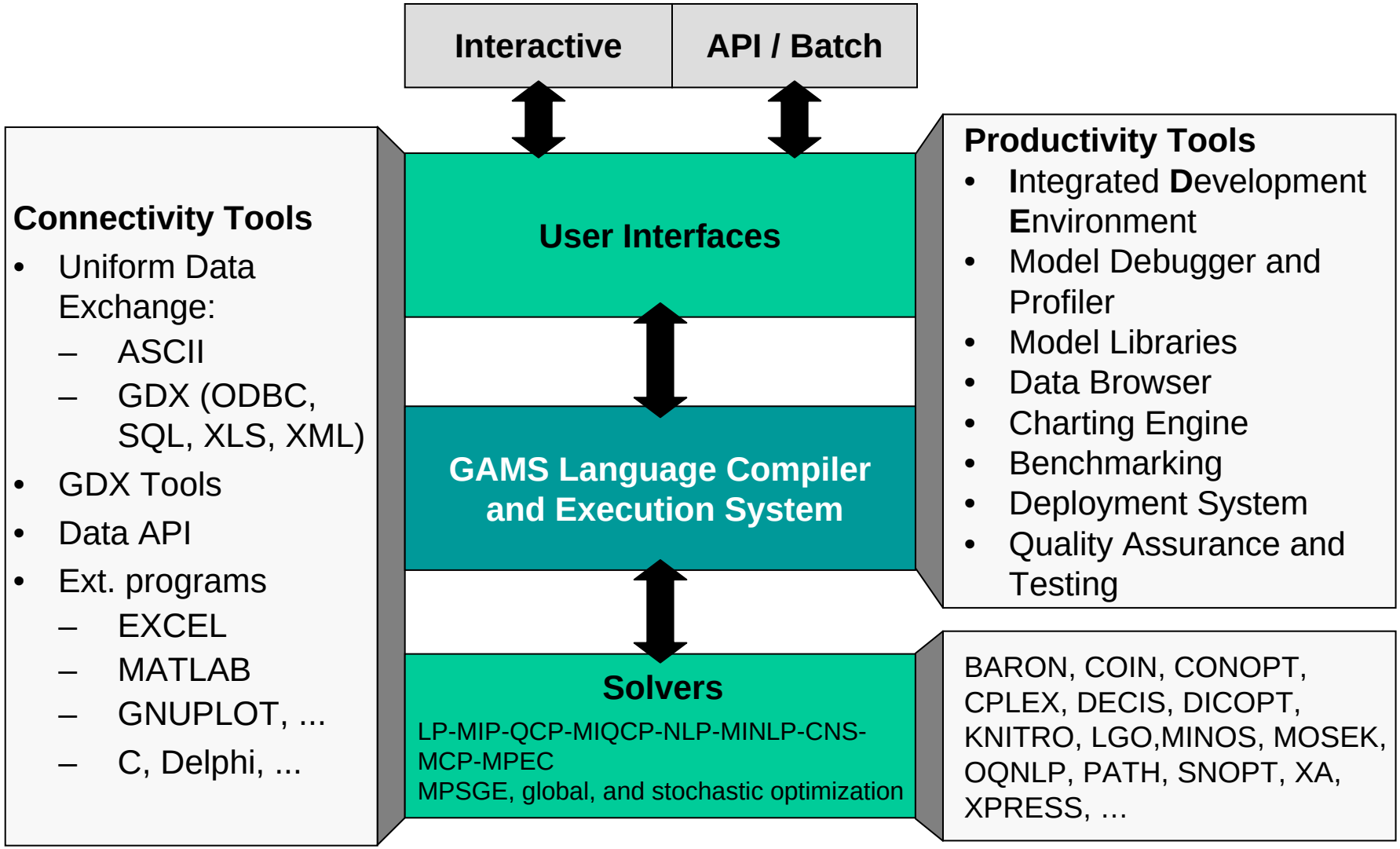
- Balanced mix of declarative and procedural elements
- Open architecture and interfaces to other systems
- Different layers with separation of:
  - model and data
  - model and solution methods
  - model and operating system
  - model and interface

More GAMS Features



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

System Overview



Multiple Solvers & Platforms

Solver/Platform availability - 22.2 April 21, 2006	x86 MS Windows	x86_64 MS Windows	x86 Linux	x86_64 Linux	Sun Sparc SOLARIS	HP 9000 HP-UX 11	DEC Alpha Digital Unix 4.0	IBM RS-6000 AIX 4.3	SGI IRIX	Mac PowerPC Darwin
BARON 7.5	✔	32bit	✔	32bit				✔		
BDMLP	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
COIN	✔	✔	✔	✔						✔
CONOPT 3	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
CPLEX 10.0	✔	✔	✔	✔	✔	✔	8.1	✔	9.1	
DECIS	✔	✔	✔	✔	✔	✔	✔	✔	✔	
DICOPT	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
KNITRO 4.0	✔	32bit	✔	✔						
LGO	✔	✔	✔	✔	✔	✔	✔		✔	✔
MILES	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
MINOS	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
MOSEK 3.2	✔	✔	✔	✔	✔	✔				✔
MPSGE	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
MSNLP	✔	✔	✔	✔	✔	✔			✔	✔
NLPEC	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
OQNLP	✔	32bit	✔	32bit						
OSL V3	✔	32bit	✔	32bit	✔	V2		✔	V2	
OSLSE	✔	32bit	✔	32bit	✔			✔		
PATH	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
SBB	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
SNOPT	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
XA	✔	32bit	✔	✔	✔	✔	✔	✔		
XPRESS 16.10	✔	32bit	✔	32bit	✔	✔		✔		

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

Integrated Development Environment

Interfacing with different Applications

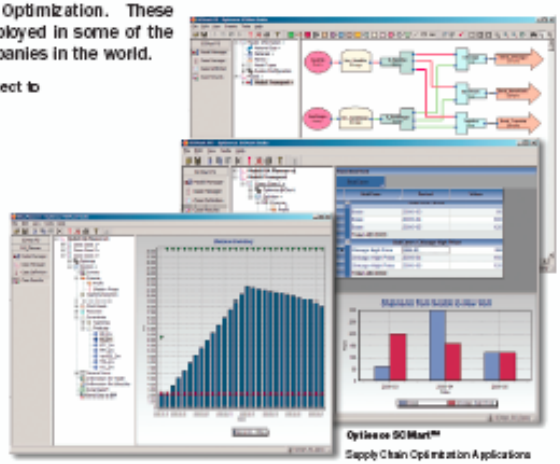
Deploy Your GAMS Model in Optience Core Application Builder

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.

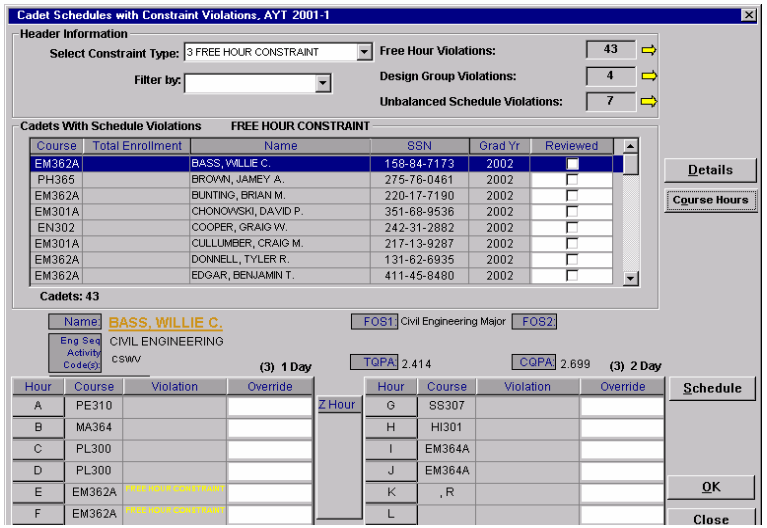
- Database centric, can connect to multiple databases
- Rich grid & graph features
- Design user interface to fit your workflow
- Execute GAMS model in the same environment

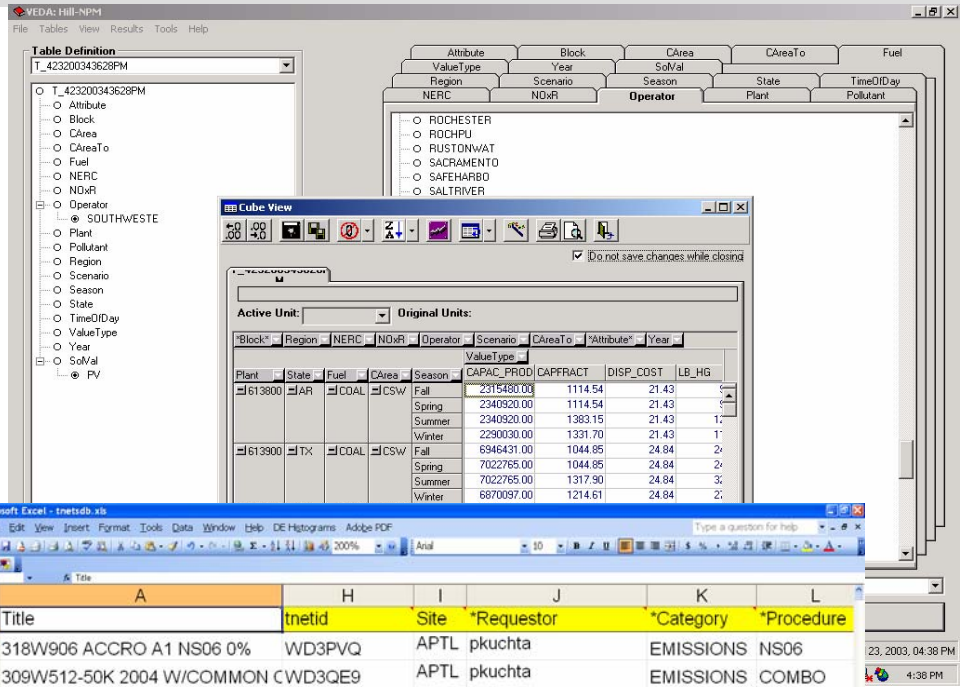
OPTIENCE
Strategic Solutions through Optimization Science

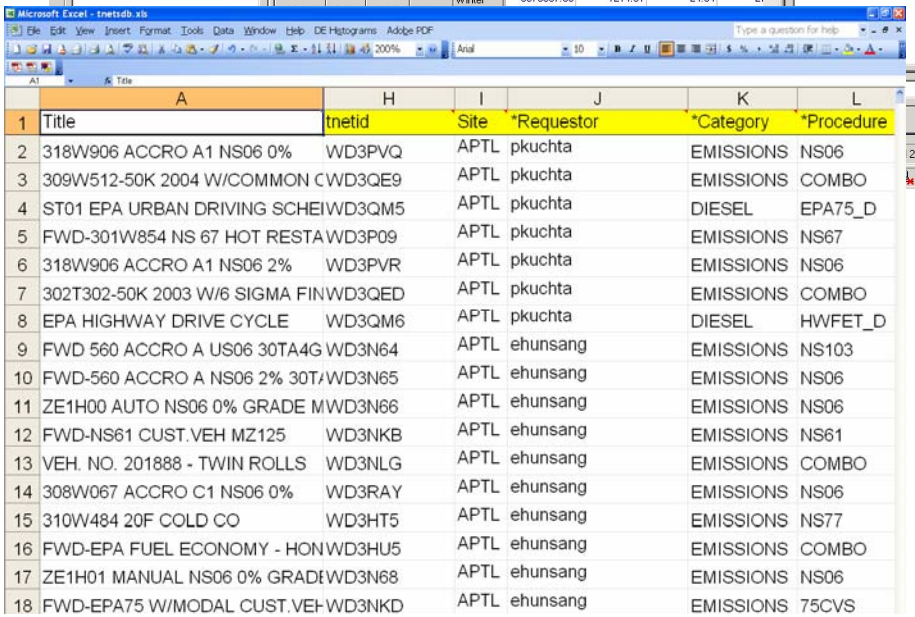
http://www.optience.com



Optience SCMart™
Supply Chain Optimization Applications

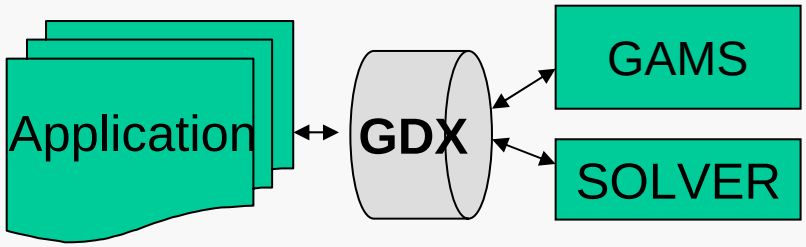






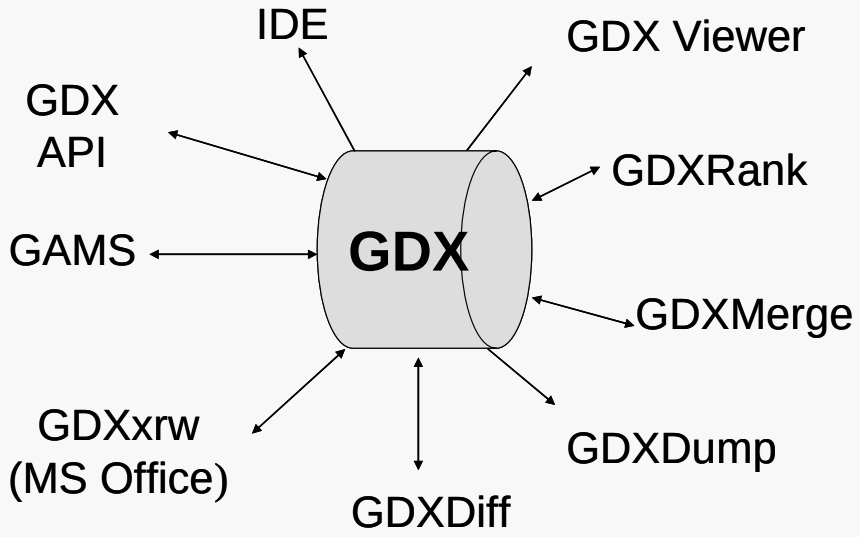
Gams Data eXchange

Binary Data Exchange

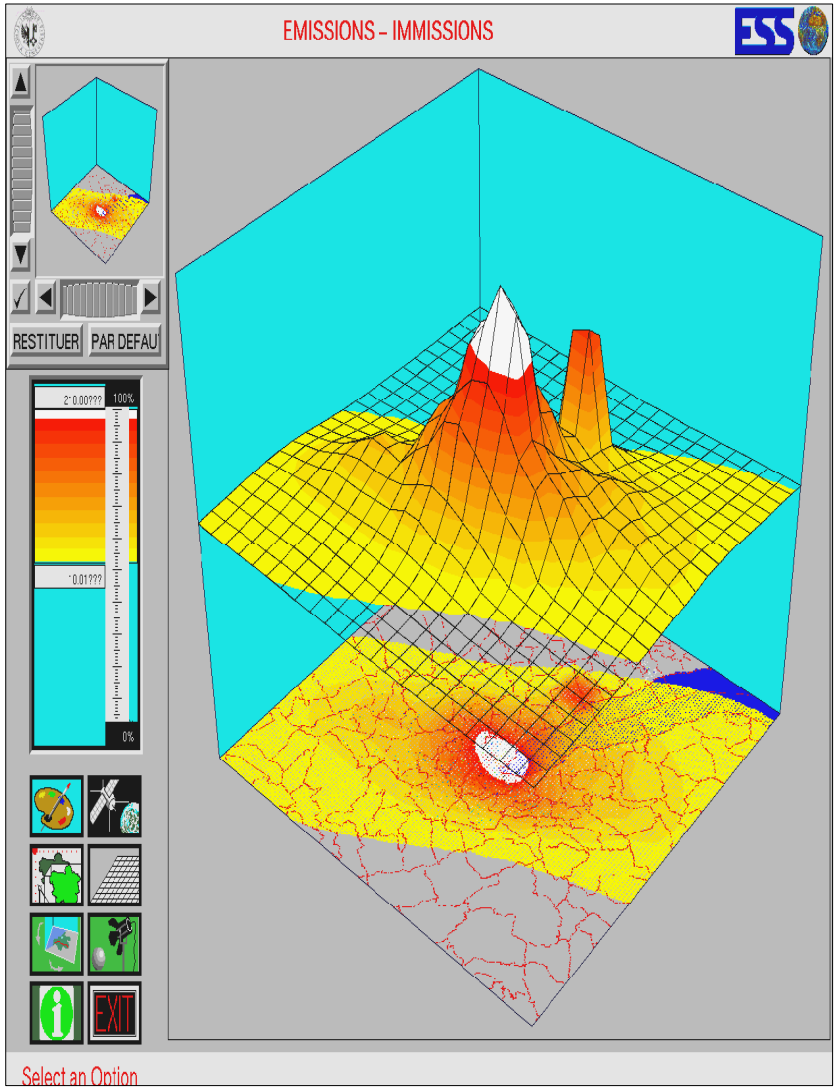


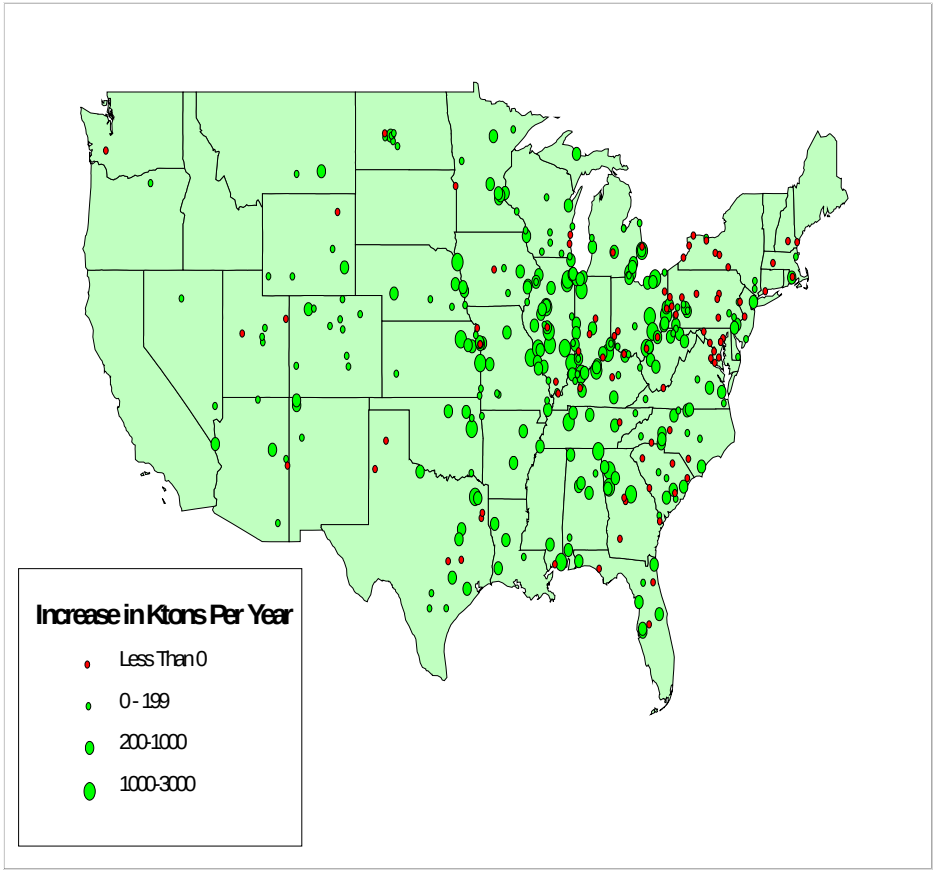
- complements ASCII data exchange
- Data exchange at any stage
  - Supports ODBC and XML
  - Direct Excel connectivity
  - General API
  - Visual Data Inspector
  - Scenario Management Support
  - Full Support of Batch Runs

GDX Tools



Interfacing with GIS Applications





Interfacing with MATLAB

Figure 1: US dollar short rate scenarios

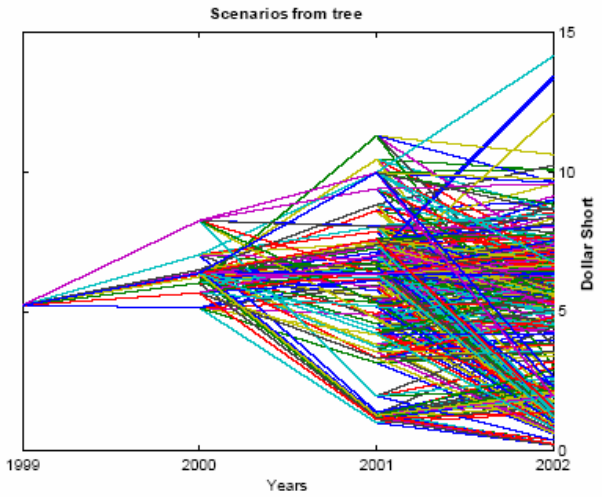
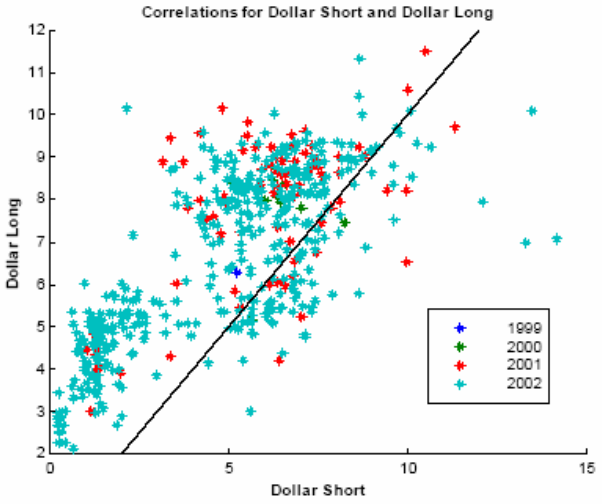
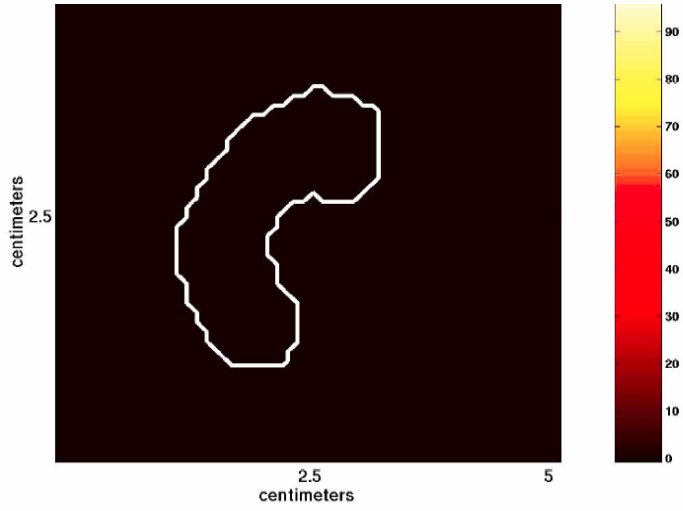
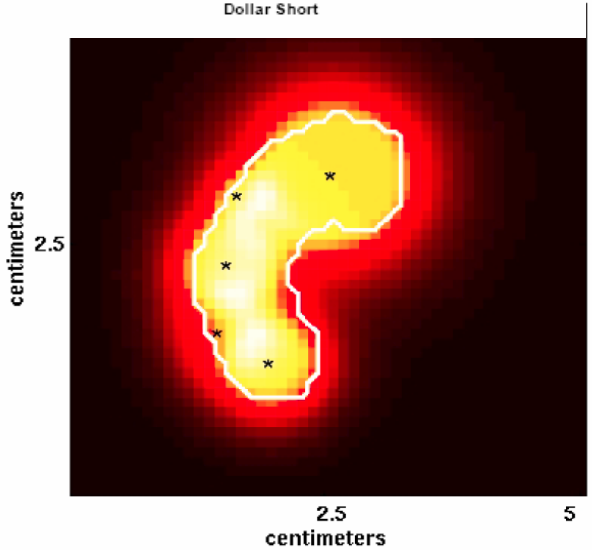


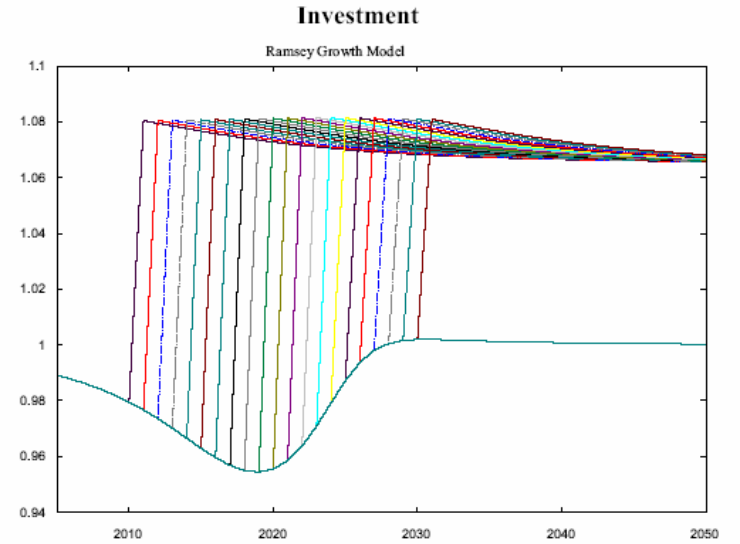
Figure 2: Short vs. long rates

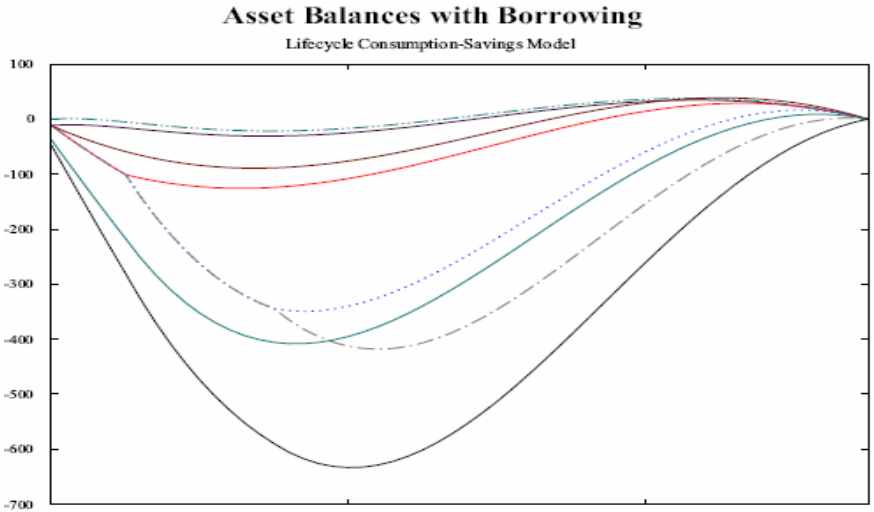


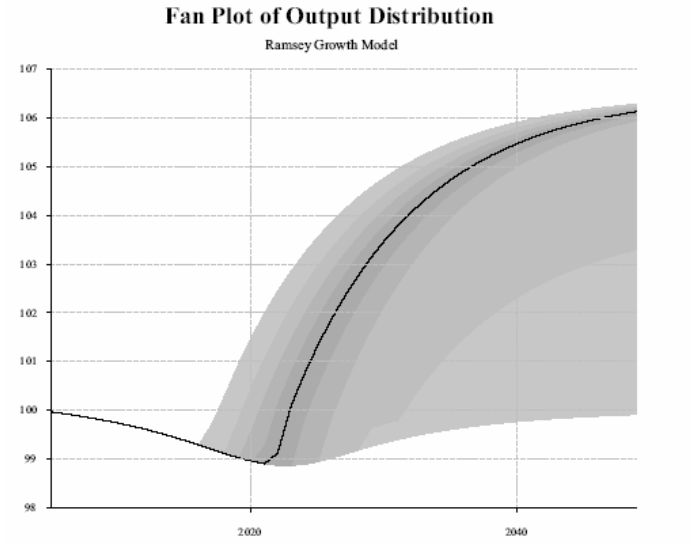


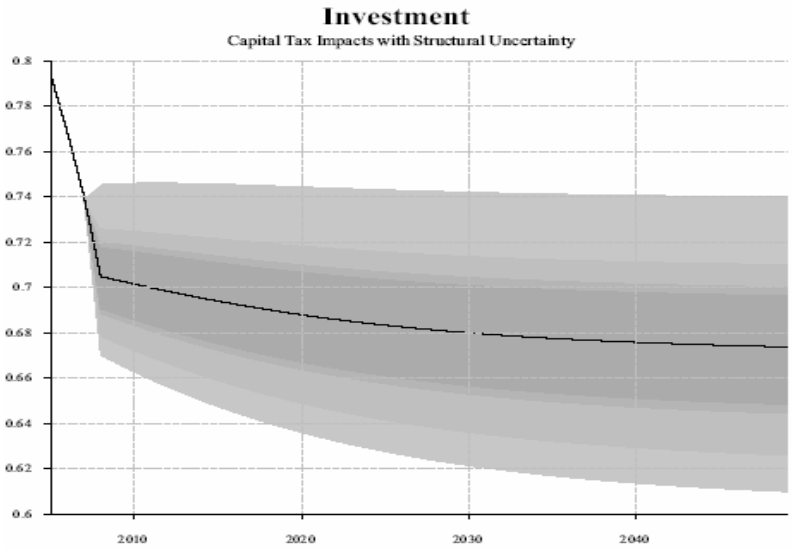


Interfacing with GNUPLOT









GAMS Model Library

GAMS Model Library Version 24.0

Search

SeqNr	Name	Application Area	Type	Contributor	Description
316	DPLYTEST	GAMS Language Features	GAMS	GAMS Develop	A Deployment Test Model
315	TRNSGRID	Management Science and OR	LP	Ferris, M C	Grid Transportation Problem
314	FEASOPT1	Management Science and OR	LP	Dantzig, G B	An Infeasible Transportation Problem analyzed with Cplex option FeasOpt
313	CHARTDAT	GAMS Language Features	GAMS	GAMS Develop	Create an example GDX file for the IDE Charting facility
312	LRS	Management Science and OR	MIP	GAMS Develop	Linear Recursive Sequence Optimization Model
311	GSOLVER	GAMS Language Features	GAMS	GAMS Develop	Compare the actual system with the original solver database
310	CTA	Management Science and OR	MIP	Cox, L H	Controlled Tabular Adjustments
309	OPENPIT	Management Science and OR	MIP	GAMS Develop	Dynamic open pit mining extraction
308	DEPLOY	GAMS Language Features	GAMS	GAMS Develop	GAMS Deployment Model
307	LICEMEMO	GAMS Language Features	GAMS	GAMS Develop	License Memorandum
306	CSP	Management Science and OR	MIP	Meneses, C N	Closest String Problem
305	HERVES	Engineering	DNLP	Meeraus, W H	Herves (Transposable Element) Activity Calculations
304	DECOMPHH	Applied General Equilibrium	MPSGE	Rutherford,	A Successive Recalibration Algorithm for GE Models with Many Households
303	MLGAMMA	Statistics	NLP	Cox, D R	Maximum Likelihood estimation of parameters of the gamma distribution
302	MLBETA	Statistics	NLP	Kotz, J	Fitting of beta distribution through maximum likelihood
301	PROCMEAN	Statistics	NLP	Chen, C H	Optimal Process Mean
300	QUANTUM	Statistics	DNLP	Ogura, A	An application from quantum mechanics
299	MINGAMMA	Statistics	DNLP	Sloane, N J	Minimal y of GAMMA(x)
298	AWKTSP	GAMS Tools	MIP	Juenger, M	Traveling Salesman Problem Instance prepared with AWK
297	SEDERS	GAMS Tools	GAMS	Somwaru, A	ERS Data Manipulations with SED
296	AWKQAP	GAMS Tools	MIQCP	Burkard, R E	Input file generation with AWK for the Quadratic Assignment Problem

```
Dynamic open pit mining extraction (OPENPIT,SEQ=309)

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

Reference:
GAMS Development Corporation, Formulation and Language Example.
```

… currently more than 316 models from various areas

Benchmarking

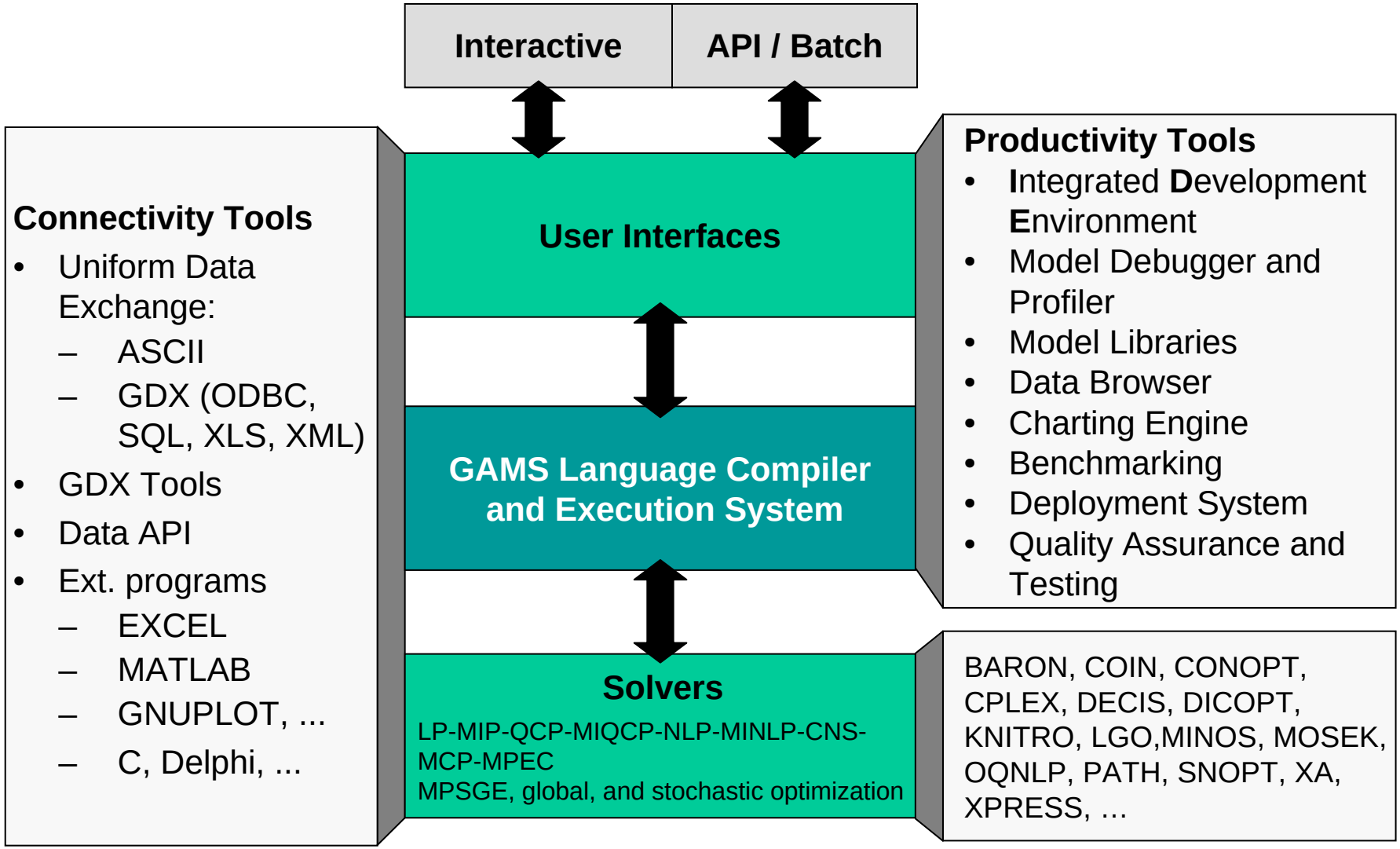
- **BENCH -"solver":**

D:\support\trnsport.log

bench.opt | indus89.gms | indus89.lst | trnsport.gms | trnsport.log | trnsport.lst

```
Dual constraints satisfied (tol = 1e-006)
Primal CS is zero (tol = 1e-007)
Dual CS is zero (tol = 1e-007)

EXAMINER ALL DONE.



--- BENCH SUMMARY:

  Solver     Modstat Solstat       Objective       ResUsd  Examiner
  ---------------------------------------------------------------------
  BDMLP            1       1        153.6750        0.000       P/P
  COINCBC          1       1        153.6750        0.000       P/P
  COINGLPK         1       1        153.6750        0.000       P/P
  CONOPT           1       1        153.6750        0.047       P/P
  CPLEX            1       1        153.6750        0.015       P/P
  MINOS            1       1        153.6750        0.016       P/P
  MOSEK            1       1        153.6750        0.141       P/P
  PATHNLP          1       1        153.6750        0.093       P/P
  SNOPT            1       1        153.6750        0.000       P/P
  XA               1       1        153.6750        0.015       P/P
  XPRESS           1       1        153.6750        0.031       P/P

--- Restarting execution
--- trnsport.gms(65) 0 Mb
--- Reading solution for model transport
--- Executing after solve
--- trnsport.gms(67) 3 Mb
*** Status: Normal completion
--- Job trnsport.gms Stop 05/26/06 11:00:25 elapsed 0:00:02.110
```

System Overview



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- **An illustrative Example: The Mean Variance Model**
- Grid Computing

The Mean-Variance Model

Markowitz (1952), Nobel prize 1990

Given

Some investments x_i with historical data

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

Goal

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

Minimize variance *v* of portfolio for a given target return *r*

MV Model Algebra

Talk: Wednesday, 18:00, Geb. 11.40, R. 202

Variance of Portfolio	$Min \sum_{i=1}^{I}\sum_{j=1}^{J} x_i \, Q_{i,j} \, x_j$
Target return	$s.t. \quad \sum_{i=1}^{I} \mu_i x_i \geq r$
Budget constraint	$\sum_{i=1}^{I} x_i = 1$
No short sales	$x_i \geq 0$

Declarative Model and some Data

gamside: D:\projects\gor-basf\qmeanvarx.gpr

File Edit Search Windows Utilities Help

a=c

D:\projects\gor-basf\core.gms

core.gms | core.lst | mod.gms | mod.lst | qmeanvar.gdx | qmeanvar.gms | qmeanvar.lst

```
Set         i  investments;
alias (i,j);
Parameter   mu(i)     expected return of i,
            q(i,j)    covariance matrix;
Variables
    var       variance of portfolio,
    ret       return of portfolio,
    x(i)      current holdings of i;
Positive variables x;

Equations   vardef     variance definition,
            retdef     return definition,
            budget     budget constraint;
vardef..   var =e= sum((i,j), x(i)*q(i,j)*x(j));
retdef..   sum(i, mu(i)*x(i))=g= ret;
budget..   sum(i, x(i))      =e=  1 ;
```

16: 30 | Insert

GAMS Model Type: QCP

No active process

core

```
--- Job core.gms Start 05/17/06 16:34:47
GAMS Rev 145  Copyright (C) 1987-2006 GAMS Deve
Licensee: Franz Nelissen
          GAMS Software GmbH
--- Starting compilation
--- core.gms(16) 2 Mb
*** Status: Normal completion
--- Job core.gms Stop 05/17/06 16:34:47 elapsed
```

gamside: D:\work\qmeanvarx.gpr - [D:\work\qmeanvar.gdx]

File Edit Search Windows Utilities Help

qmeanvar.gdx | qmeanvar.gms | qmeanvar.lst

Entry	Symbol	Type	Dim	Nr Elem
8	bdata	Par	2	31
22	binsum	Equ	1	7
16	budget	Equ	0	1
1	i	Set	1	7
2	j	Set	1	7
20	maxdec	Equ	1	7
18	maxinc	Equ	1	7
21	mindec	Equ	1	7
19	mininc	Equ	1	7
3	mu	Par	1	7
26	p	Set	1	8
7	pd	Set	1	5
27	pp	Set	1	4

qorg: covariance matrix

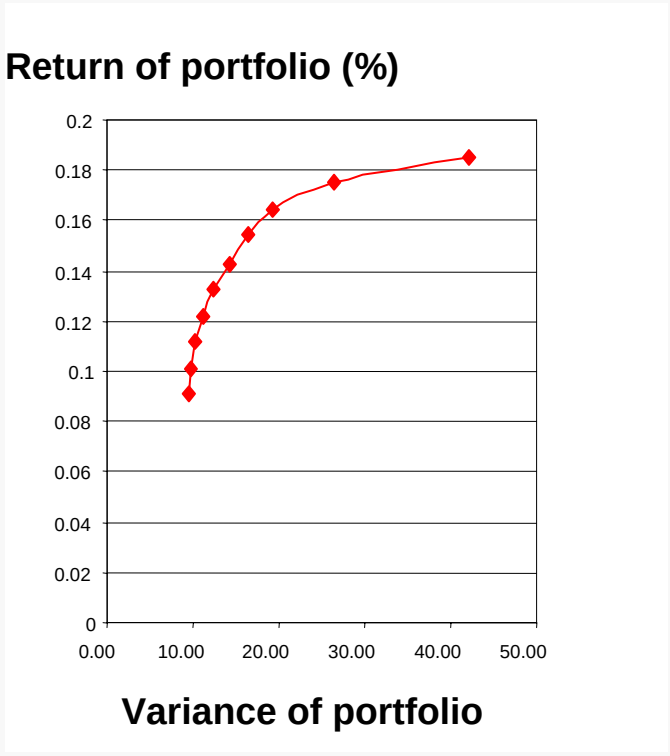
Plane Index (empty)

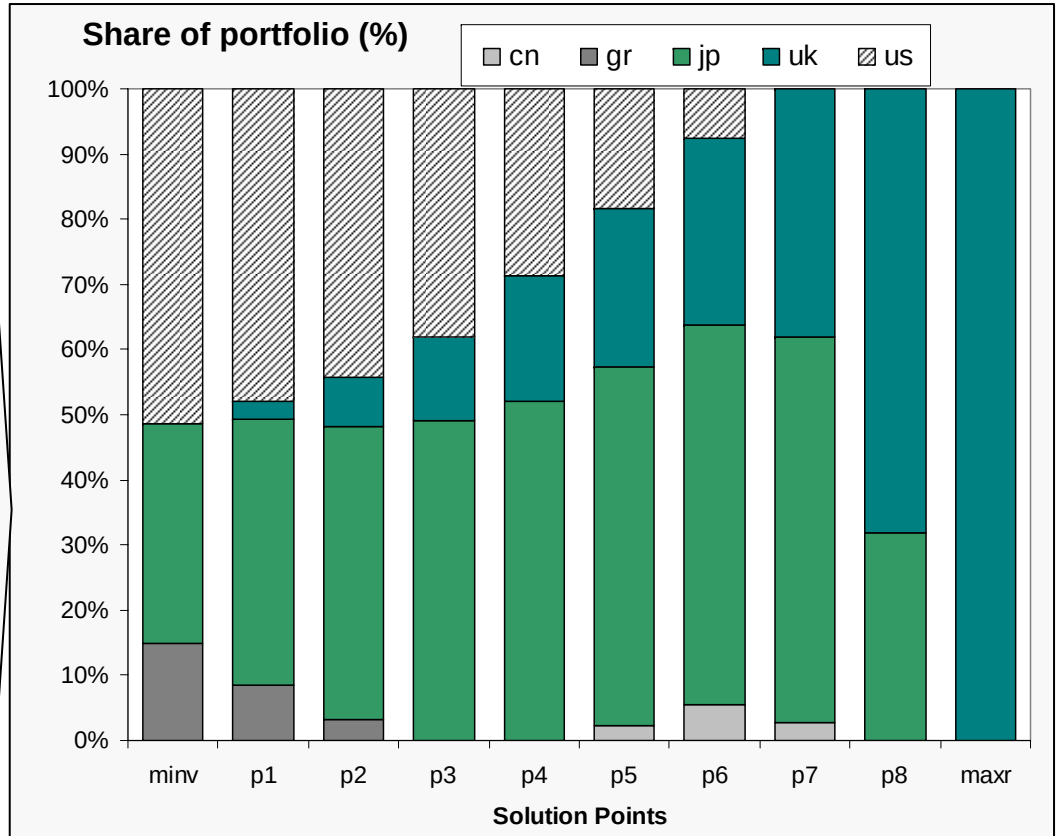
	cn	fr	gr	jp	sw	uk	us
cn	42,180						
fr	20,180	70,890					
gr	10,880	21,580	25,510				
jp	5,300	15,410	9,600	22,330			
sw	12,320	23,240	22,630	10,320	30,010		
uk	23,840	23,800	13,220	10,460	16,360	42,230	
us	17,410	12,620	4,700	1,000	7,200	9,900	16,420

Procedural Elements

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

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

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

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

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

Efficient Frontier and Portfolios





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- An illustrative Example: The Mean Variance Model
- **Grid Computing**

Grid Computing

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

Imagine…

.. you have to solve 1.000's of independent scenarios..

.. and you can do this very rapidly for little additional money…

.. without having to do lots of cumbersome programming work..

Grid Computing

What is Grid Computing?

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

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

Advantages of Grid Computing

- Solve a certain number of scenarios faster, e.g:
  - sequential: 50 hours
  - parallel (200 CPUs): ~15 minutes

    → Cost is $100 (2$ CPU/h)
- Get better results by running more scenarios*:

#SIM	VaR error	CVaR error
1000	5.42%	6.74%
20,000	1.21%	1.49%

*** http://www.tc.cornell.edu/NR/shared/Presentations/24Feb04.Garp.pdf**

Economics of Grid Computing

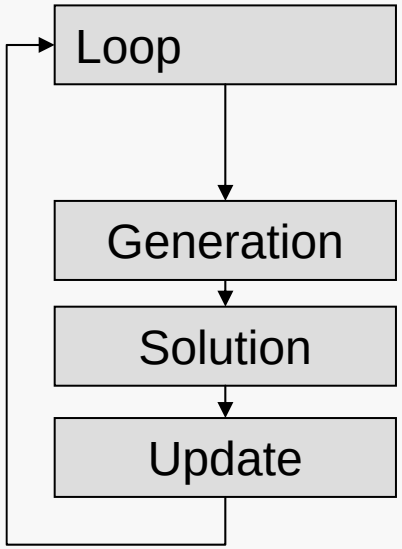
- Yearly cost, 2-CPU workstation: $5200
  - Hardware: $1200
  - Software: $4000
- Hourly cost on the grid: $2/cpu
  - $1/hour for CPU time (to grid operator)
  - $1/hour for software (GAMS, model owner)
- 1 workstation:
  - ~ 2600 hrs grid time or
  - ~ 50 hrs/week grid time
- Up-front vs. deferred,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

GAMS & Grid Computing

- **Scalable**:
  - support of massive grids, **but also**
  - multi-cpu / multiple cores desktop machines
  - “1 CPU - Grid”
- Platform **independent**
- Only **minor changes** to model required
- **Separation** of model and solution method
  → Model stays **maintainable**

Simple Serial Solve Loop

```
Loop(p(pp),
   ret.fx = rmin +(rmax-rmin)
     /(card(pp)+1)*ord(pp) ;
   Solve minvar min var using miqcp;
   xres(i,p)          = x.l(i);
   report(p,i,'inc') = xi.l(i);
   report(p,i,'dec') = xd.l(i)
  );
```

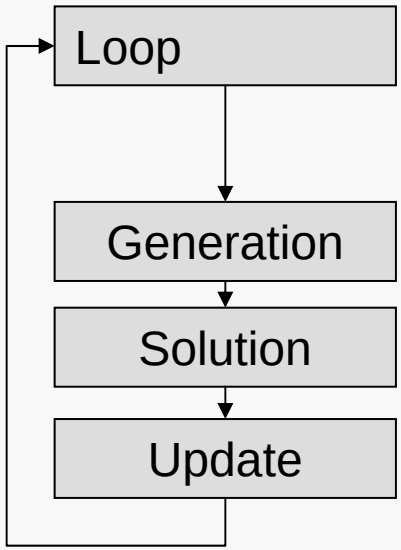


How do we get to parallel and distributed computing?

Simple Serial Solve Loop

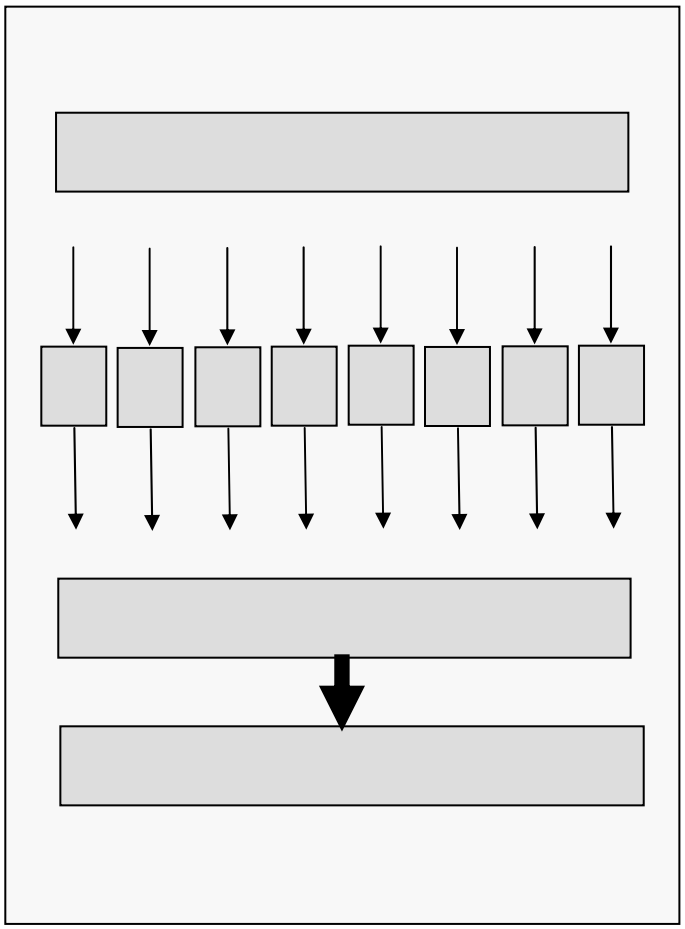
```
Loop(p(pp),
   ret.fx = rmin +(rmax-rmin)
     /(card(pp)+1)*ord(pp) ;
   Solve minvar min var using miqcp;
   xres(i,p)          = x.l(i);
   report(p,i,'inc') = xi.l(i);
   report(p,i,'dec') = xd.l(i)
  );
```

How do we get to parallel and distributed computing?



GRID Specific Enhancements

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



Job Submission Loop

```
Parameter h(p) store the instance handle;
minvar.solvelink = 3;        # turn on grid option
Loop(p(pp),
   ret.fx = rmin + (rmax-rmin)
   /(card(pp)+1)*ord(pp) ;
   Solve minvar min var using miqcp ;
   h(pp) = minvar.handle ); # save instance handle
```

LOG:

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

“Grid”- Middleware (PC)

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

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

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

Solution Collection Loop

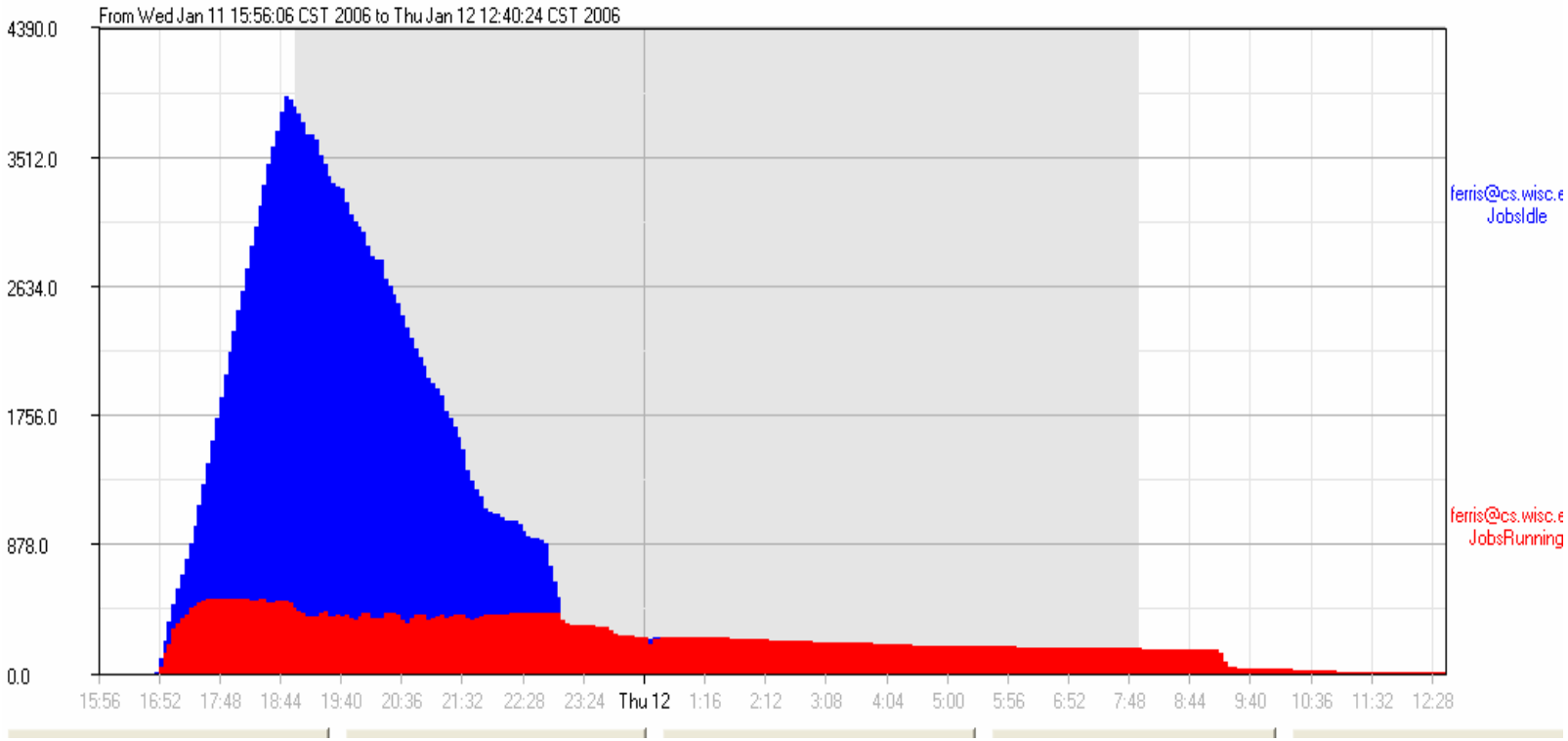
```
Repeat
  loop(p(pp)$h(p),
    if(handlestatus(h(p))=2,
      minvar.handle = h(p); execute_loadhandle minvar;
      xres(i,p)=x.l(i); report(p,i,'inc')=xi.l(i);
      report(p,i,'dec')= xd.l(i)
      display$handledelete(h(p))'Could not remove handle';
      h(p) = 0)
   );                      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

LOG: …

```
--- GDXin=c:\work\mod\225b\grid137000002\gmsgrid.gdx
--- grid_qmeanvar.gms(154) 3 Mb
--- Removing handle grid137000002
--- GDXin=c:\work\mod\225b\grid137000003\gmsgrid.gdx
--- Removing handle grid137000003
--- GDXin=c:\work\mod\225b\grid137000007\gmsgrid.gdx
…
```

Results for 4096 MIPS on Condor Grid

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



More Developments

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

Release Notes

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

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

Distribution 22.2 Apr 21, 2006

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

Acknowledgements

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

GAMS System

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

Solvers

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

Distribution 22.1 Mar 15, 2006

GAMS System

- *Relaxation of discrete variables (.prior=Inf)*:

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