INFORMS CONFERENCE ON BUSINESS ANALYTICS & OPERATIONS RESEARCH

Applying Science to the Art of Business

Fundamentals and Recent Developments of the GAMS System

Franz Nelissen FNelissen@gams.com

GAMS Development Corp.

GAMS Software GmbH

www.gams.com

Huntington Beach, CA April 2012

GAMS

Agenda

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

Agenda

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

Algebraic Modeling Languages

What's that?

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

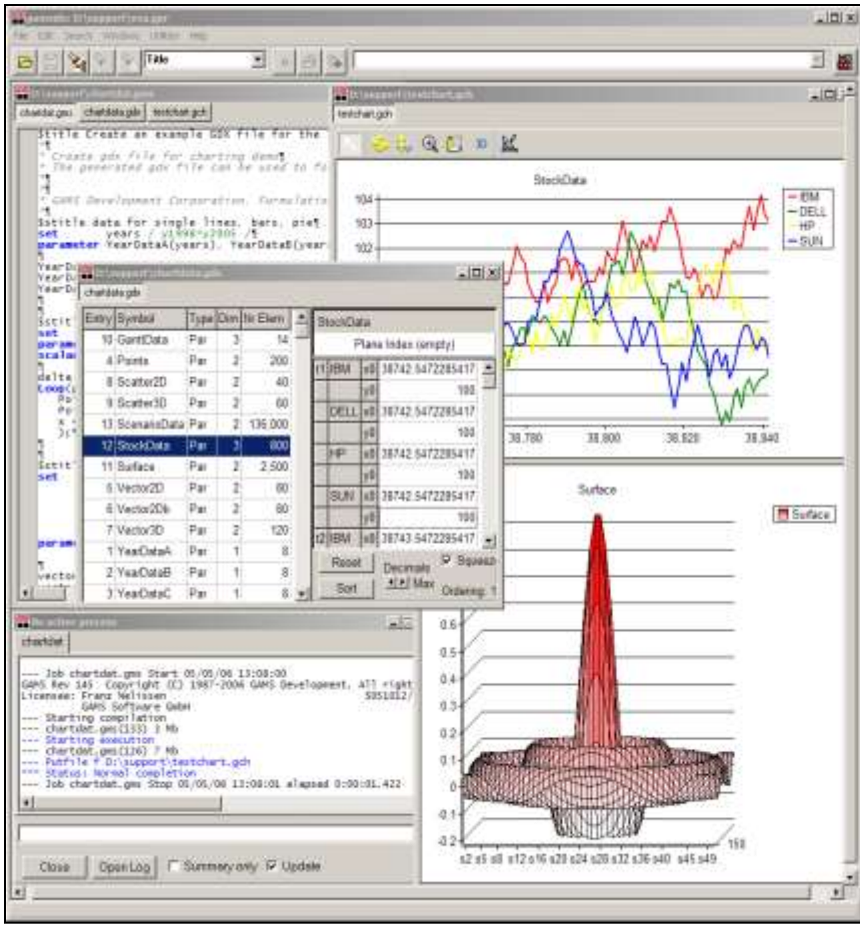
- High-level **computer programming languages** for the formulation of **complex mathematical optimization problems**
- **Notation similar to algebraic notation**: Concise and readable definition of problems in the domain of optimization
- **Do not solve problems directly**, but ready-for-use links to 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

Downloads (March 2012)

Amazon CloudFront
Download Usage Report »

Amazon CloudFront Download Usage Report »			**$67.04**
United States			
	$0.120 per GB - first 10 TB / month data transfer out	197.126 GB	23.66
	$0.0100 per 10,000 HTTPS Requests	3 Requests	0.01
	$0.0075 per 10,000 HTTP Requests	52,154 Requests	0.04
			23.71
Europe			
	$0.120 per GB - first 10 TB / month data transfer out	212.982 GB	25.56
	$0.0120 per 10,000 HTTPS Requests	1 Request	0.01
	$0.0090 per 10,000 HTTP Requests	16,456 Requests	0.01
			25.58
Asia Pacific (Tokyo) Region			
	$0.201 per GB - first 10 TB / month data transfer out (includes consumption tax).	23.800 GB	4.78
	$0.0095 per 10,000 HTTP Requests (includes consumption tax).	4,676 Requests	0.01
			4.79
Asia Pacific (Singapore) Region			
	$0.190 per GB - first 10 TB / month data transfer out	39.512 GB	7.51
	$0.012 per 10,000 HTTPS Requests	1 Request	0.01
	$0.0090 per 10,000 HTTP Requests	18,087 Requests	0.02
			7.54
South America			
	$0.250 per GB - first 10 TB / month data transfer out	21.656 GB	5.41
	$0.0160 per 10,000 HTTP Requests	1,535 Requests	0.01
			5.42

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

Declarative elements

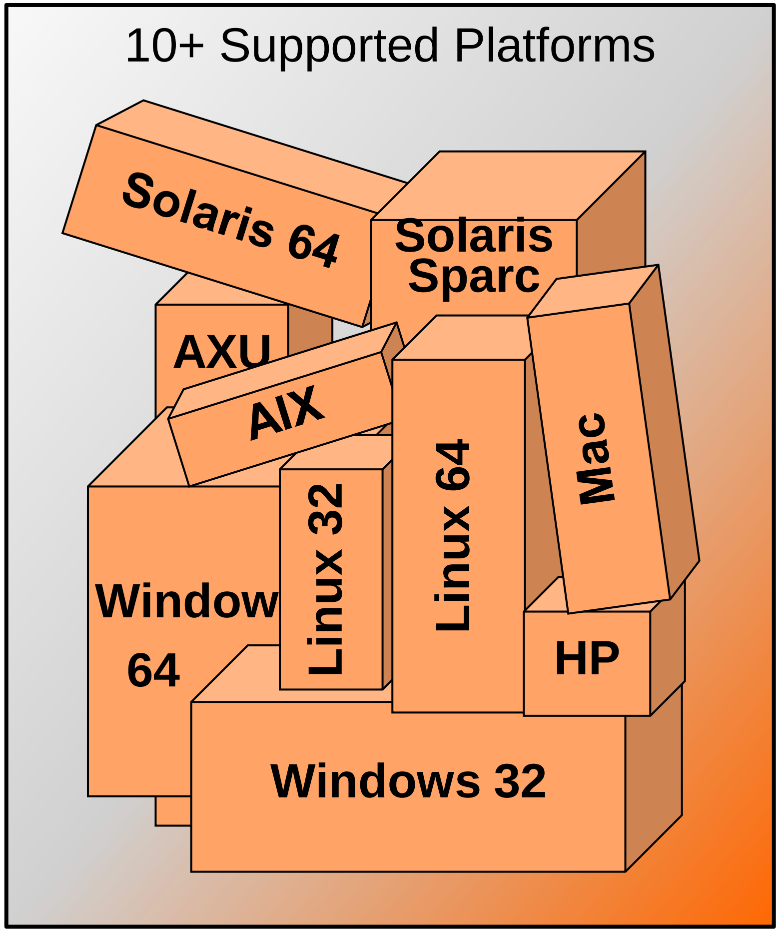
- Parameters
- Variables
- Equations
- Models
- …

combined with procedural elements

- Loops
- If-then-else
- Macros
- User defined functions
- …

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
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- **Hassle-free switch of solution methods**
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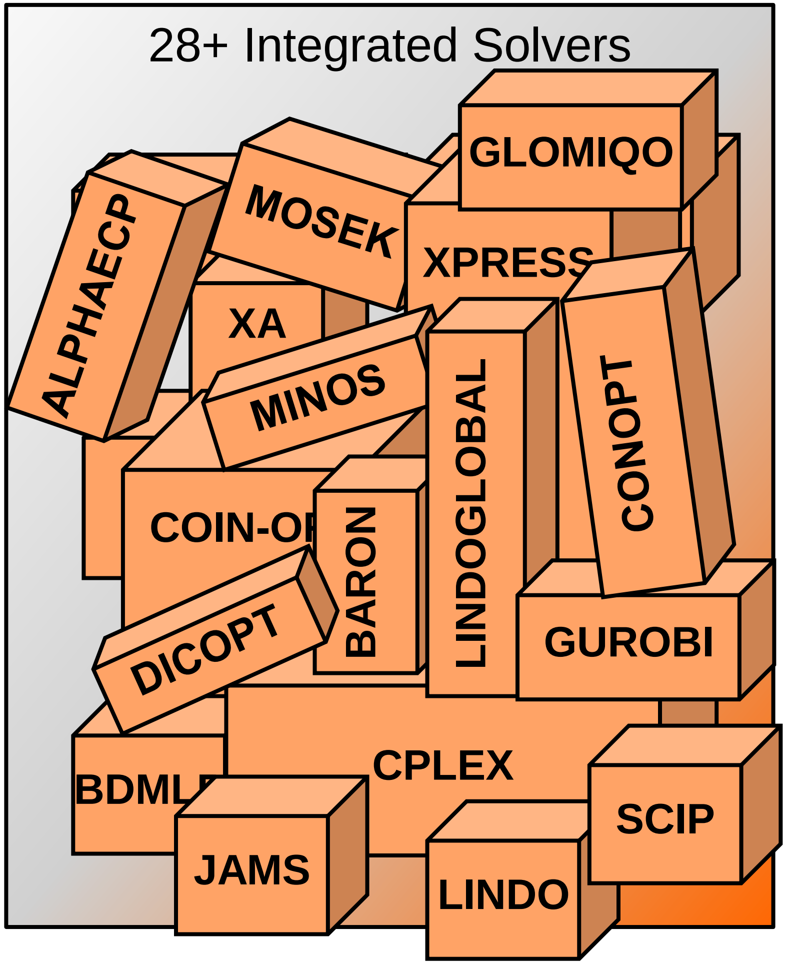


GAMS at a Glance

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

- ASCII
- **G**ams **D**ata e**X**change (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

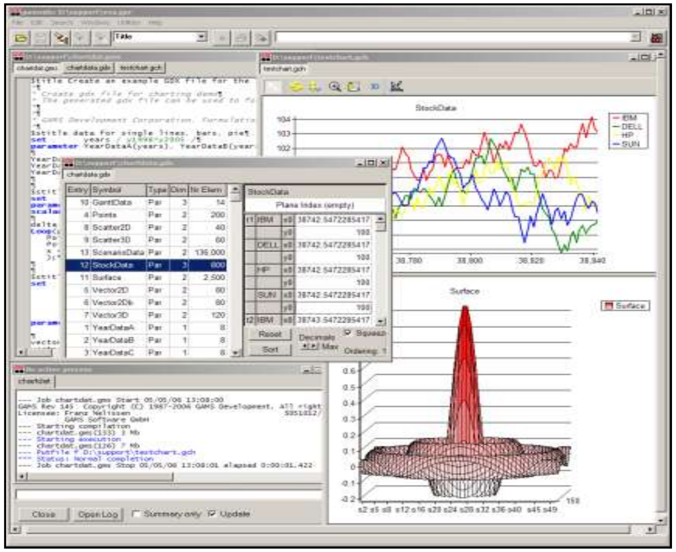
→Models benefit from

- Advancing hardware
- Enhanced / new solver technology
- Improved / upcoming interfaces to other systems

GAMS at a Glance: Development Environm.

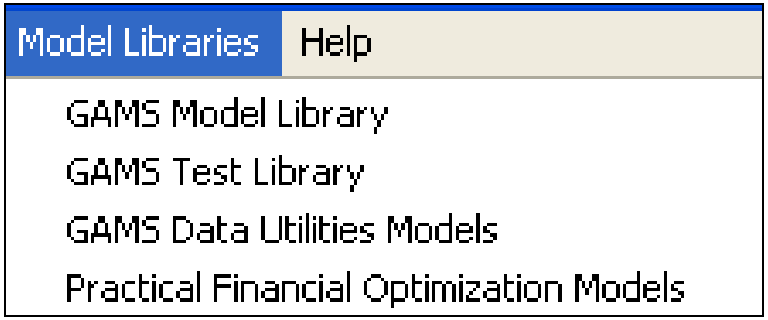
GAMS IDE

- 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



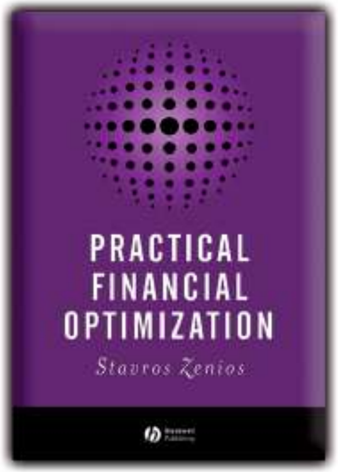
GAMS at a Glance: Model Libraries

- **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:
  - Tom Rutherford: Some GAMS Programming Utilities (productivity tools, advanced data exchange with Excel and Gnuplot: http://mpsge.org/inclib/tools.htm
  - Bruce Mc Carl: GAMSCHK, data exchange tools http://agecon2.tamu.edu/people/faculty/mccarl-bruce/GAMS.htm
  - Erwin Kalvelagen: Statistics, GAMS/LS (a linear regression solver) http://amsterdamoptimization.com/statistics.html
  - Wietse Dol: Gtree, GAMS-R link: http://www3.lei.wur.nl/gamstools/

- Details and more sources: http://interfaces.gams.com

Agenda

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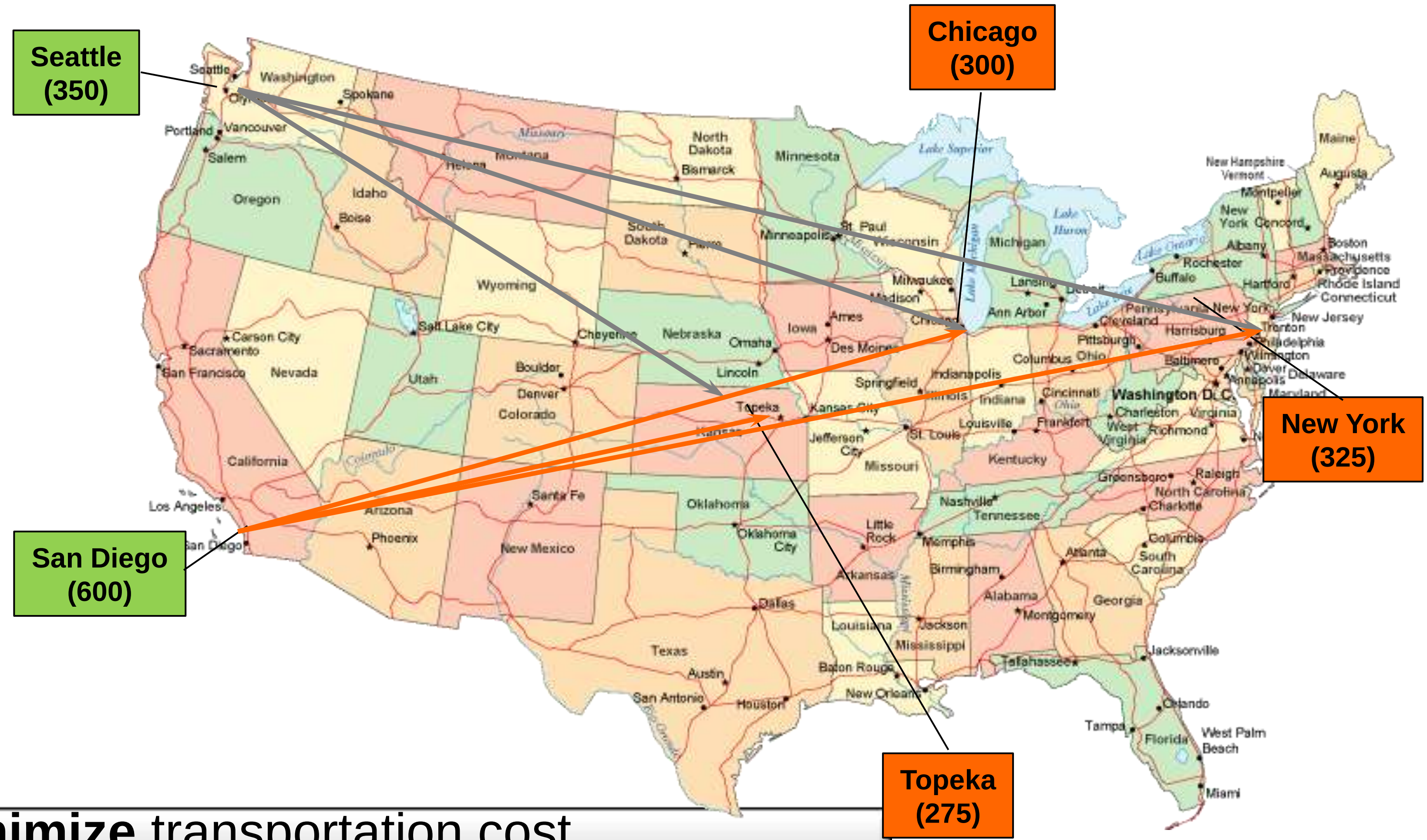
  - A simple Example
  - Applications

A Simple Example: Transportation Model



Minimize transportation cost
subject to supply & demand constraints

A Simple Example: Algebra

$$
\begin{array}{llll}
\text{Objective} & \sum_i \sum_j c_{i,j} \times x_{i,j} & \longrightarrow \min & \\
\text{Observe supply limit at plant } i\text{:} & \sum_j x_{i,j} & \leq a_i & \forall i \\
\text{Satisfy demand at market } j\text{:} & \sum_i x_{i,j} & \geq b_j & \forall j \\
 & x_{i,j} & \geq 0 & \forall i,j
\end{array}
$$

A Simple Example: Declarative Model

C:\Users\Franz\Documents\gamsdir\projdir\trnsport.gms

data.inc | trnsport.gms | trnsport.lst

```
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/ ;
```

1: 3 Modified | Insert

A Simple Example: Model Data

C:\Users\Franz\Documents\gamsdir\projdir\data.inc

data.inc | trnsport.gms | trnsport.lst

```
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/ ;
```

11: 44 | Insert

GAMS

A Simple Example: Complete Model

C:\Users\Franz\Documents\gamsdir\projdir\trnsport.gms

data.inc | trnsport.gms | trnsport.lst

```
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

- Compilation
- Equation Listing — SOLVE transport Usin
- Equation
- Column Listing — SOLVE transport Usir
- Column
- Model Statistics — SOLVE transport Usin
- Solution Report — SOLVE transport Usin
- SolEQU
- SolVAR
- Execution
- Display

```
**** REPORT SUMMARY :        0     NONOPT
                             0 INFEASIBLE
                             0  UNBOUNDED
GAMS Rev 238  WEX-WEI 23.8.1 x86_64/MS Windows          03/29/12 13:28:06 Page 6
A Transportation Problem (TRNSPORT,SEQ=1)
E x e c u t i o n


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

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

             new-york     chicago      topeka

seattle        50.000     300.000
san-diego     275.000                 275.000
```

C:\work\gdxxrw\results.gdx

farmsp.gms | farmsp.lst | nbsimple.gms | nbsimple.lst | results.gdx | trnsport.gms | trnsport.lst

Entr	Symbo	Type	Dim	Nr Elem
3	a	Par	1	2
4	b	Par	1	3
7	c	Par	2	6
10	cost	Equ	0	1
5	d	Par	2	6
12	deman	Equ	1	3
6	f	Par	0	1
1	i	Set	1	2
2	j	Set	1	3
11	supply	Equ	1	2
8	x	Var	2	6
9	z	Var	0	1

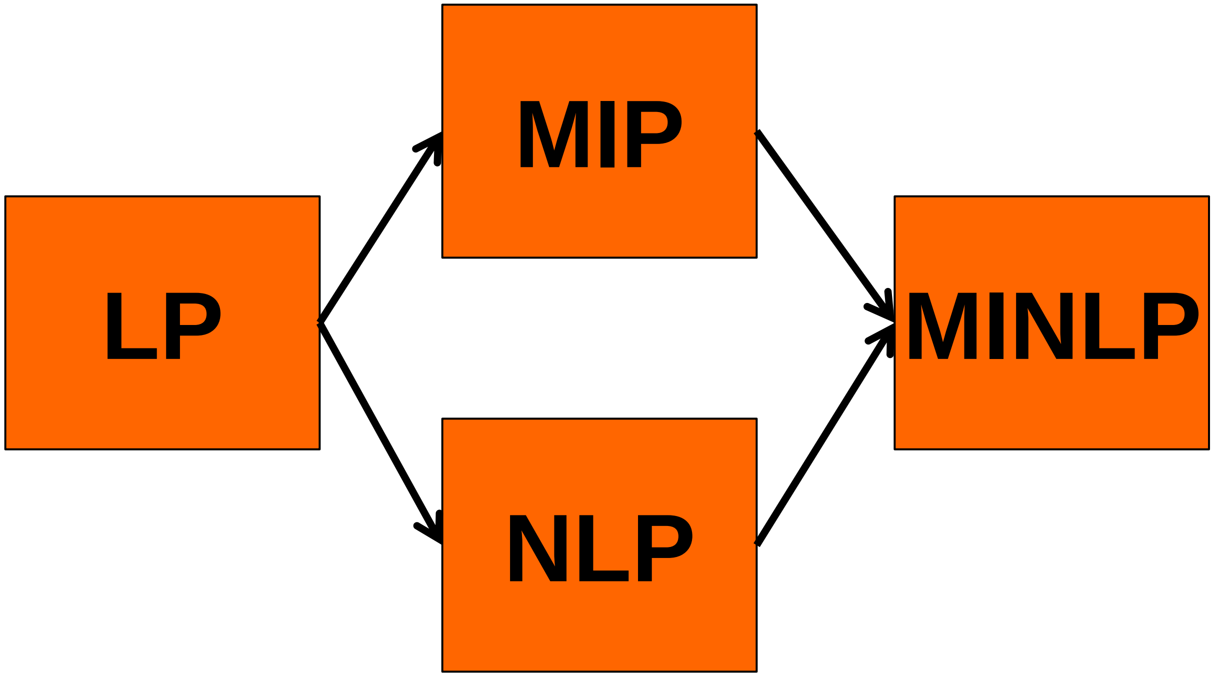
x: shipment quantities in cases

Level

Marginal

	new-york	chicago	topeka
seattle	50	300	
san-diego	275		275

A Simple Example: Modifications



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 → $x \geq 100$: $x \geq 100 * ship$
  - *If ship* = 0 → $x = 0$: $x \leq \text{bigM} * ship$

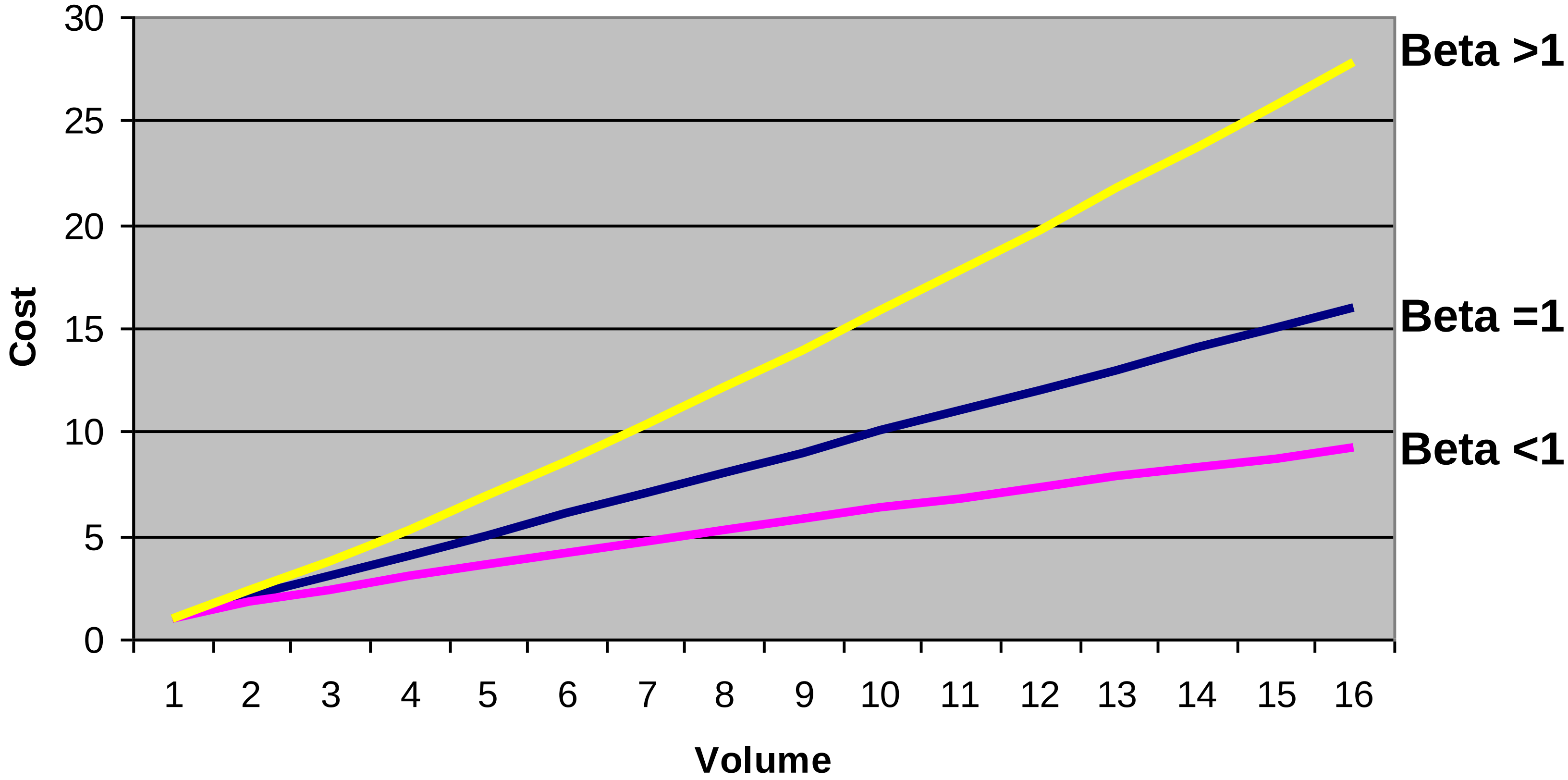
A Simple Example: Min/Max Shipments

```
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;
```

```
----    100 PARAMETER rep1  Shipments between plants and markets

                          lp         mip  mip-coinc~

seattle  .new-york      50.000
seattle  .chicago      300.000     300.000     300.000
san-diego.new-york     275.000     325.000     325.000
san-diego.topeka       275.000     275.000     275.000


----    100 PARAMETER rep2  Objective value

lp        153.675,    mip         153.675,    mip-coincbc 153.675
```

A Simple Example: Economy of Scales

Cost = Volume^{beta}



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;
```

```
----    127 PARAMETER rep1  Shipments between plants and markets

                             lp  nlp-convex  nlp-conca~   nlp-baron

seattle  .new-york       50.000     142.384
seattle  .chicago       300.000     130.930     300.000     300.000
seattle  .topeka                     76.686
san-diego.new-york      275.000     182.616     325.000     325.000
san-diego.chicago                   169.070
san-diego.topeka        275.000     198.314     275.000     275.000


----    127 PARAMETER rep2  Objective value

lp           153.675,    nlp-convex  1983.555,    nlp-concave   15.585
nlp-baron     15.585
```

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;
```

```
----    142 PARAMETER rep1  Shipments between plants and markets

                        lp         mip  mip-coinc~  nlp-convex  nlp-conca~

seattle  .new-york  50.000                           142.384
seattle  .chicago  300.000     300.000     300.000   130.930     300.000
seattle  .topeka                                      76.686
san-diego.new-york 275.000     325.000     325.000   182.616     325.000
san-diego.chicago                                    169.070
san-diego.topeka   275.000     275.000     275.000   198.314     275.000

               +  nlp-baron   minlp-bar   minlp-lin

seattle  .chicago     300.000     300.000     300.000
san-diego.new-york    325.000     325.000     325.000
san-diego.topeka      275.000     275.000     275.000


----    142 PARAMETER rep2  Objective value

lp          153.675,    mip          153.675,    mip-coincbc  153.675
nlp-convex 1983.555,    nlp-concave   15.585,    nlp-baron     15.585
minlp-bar    15.585,    minlp-lin     15.585
```

GAMS

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- What is GAMS?
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  - A simple Example
  - **Applications**

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

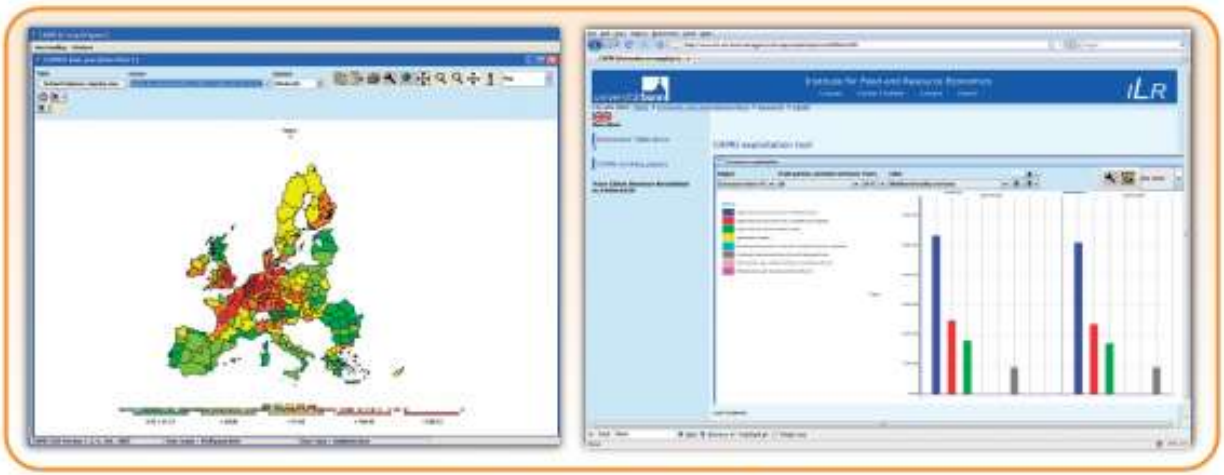
Agriculture

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



Screen shots from the CAPRI exploitation tool

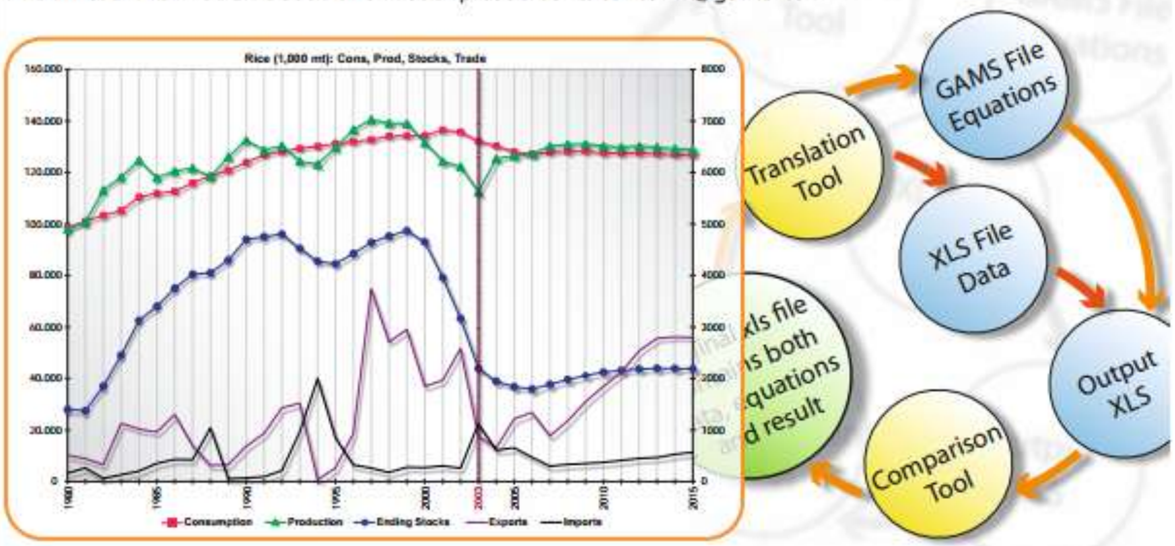
http://www.gams.com/presentations/index.htm#Ads

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 spread sheet 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



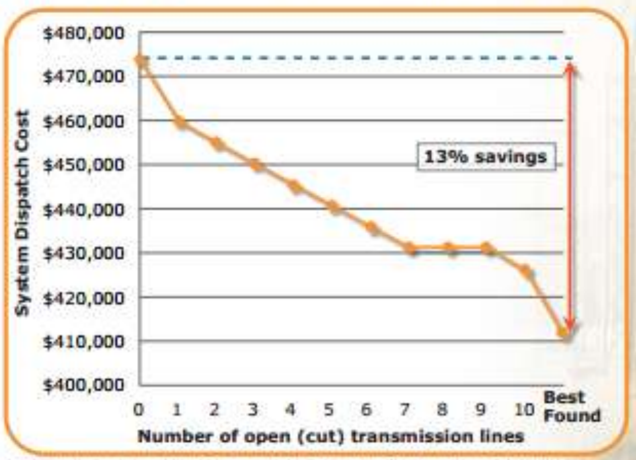
http://www.gams.com/presentations/index.htm#Ads

Energy

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**



Savings realized per hour for a model of the New England electricity system.

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

Cutting Stock Optimization

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.

GSE Software Solutions

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

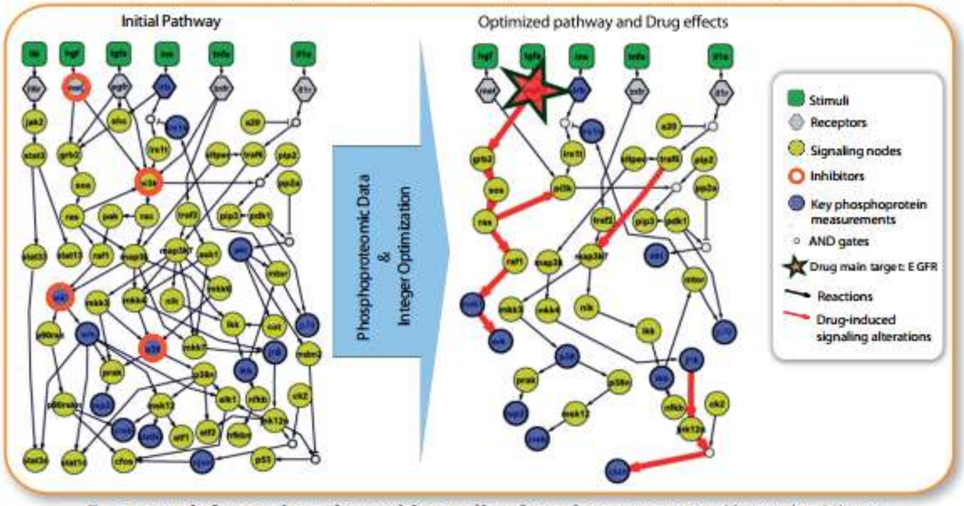
http://www.gams.com/presentations/index.htm#Ads

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 programing 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 <mitsos@mit.edu> or visit: http://www.bio-itworld.com/2010/issues/jul-aug/RND.html

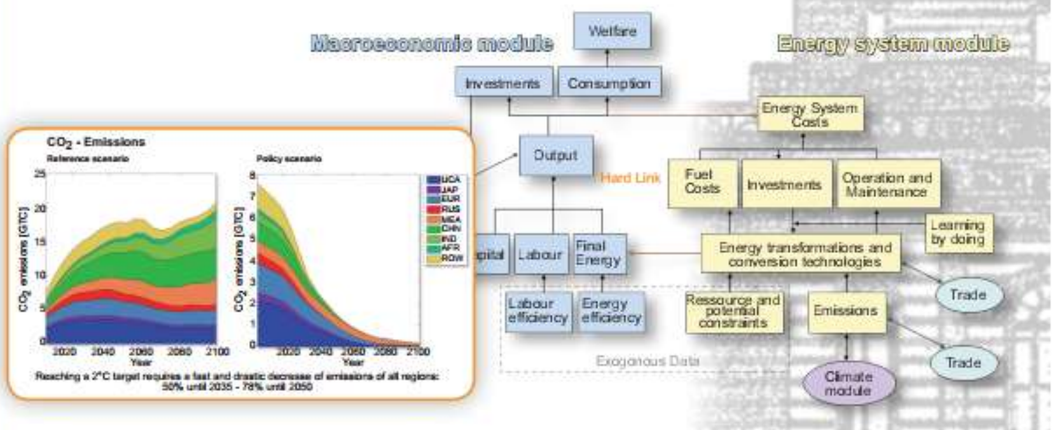
http://www.gams.com/presentations/index.htm#Ads

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

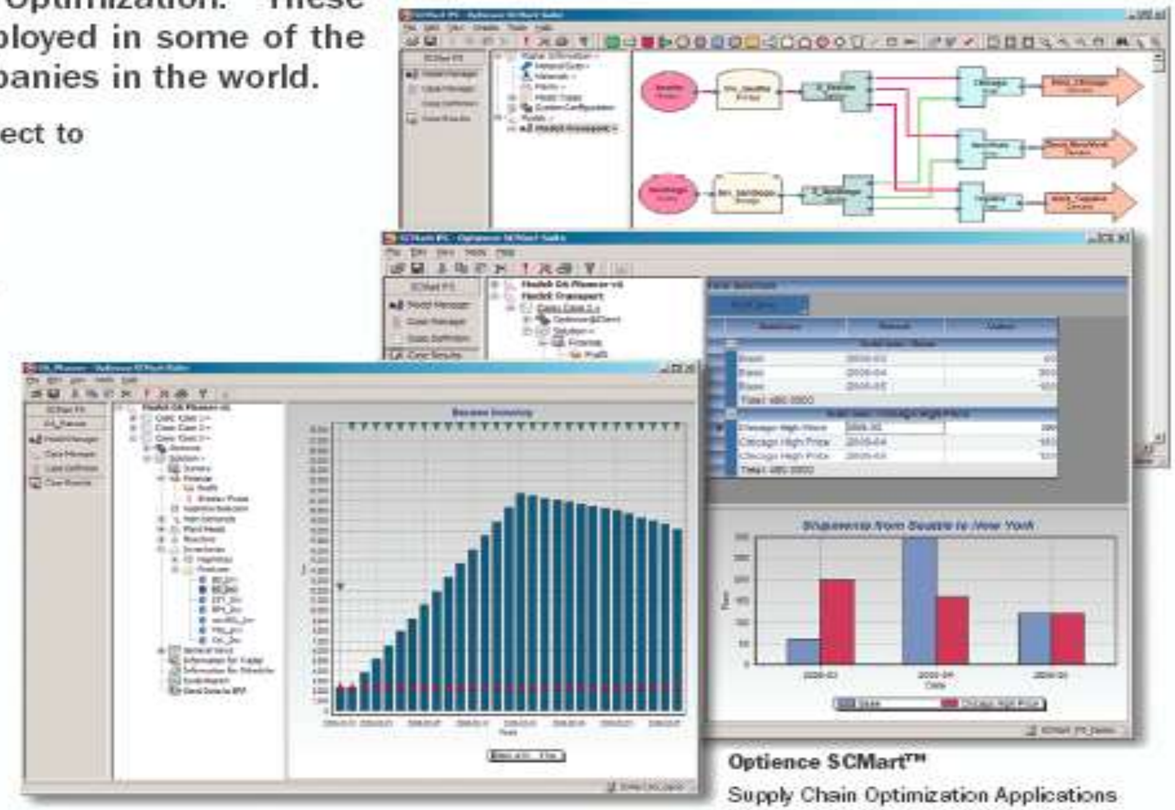
http://www.gams.com/presentations/index.htm#Ads

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 SCMart™
Supply Chain Optimization Applications

OPTIENCE
Strategic Solutions through Optimization Science

http://www.optience.com

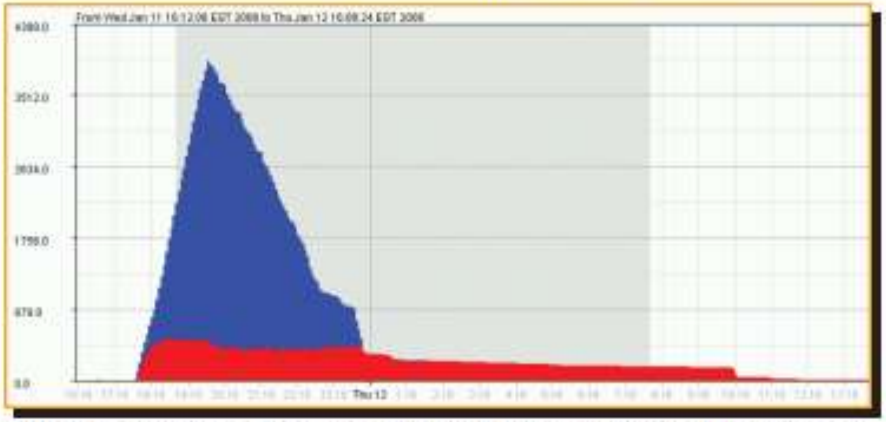
http://www.gams.com/presentations/index.htm#Ads

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.



UW-Madison Condor Pool User Statistics showing running jobs (red) and idle jobs (blue).

Condor
High Throughput Computing

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.

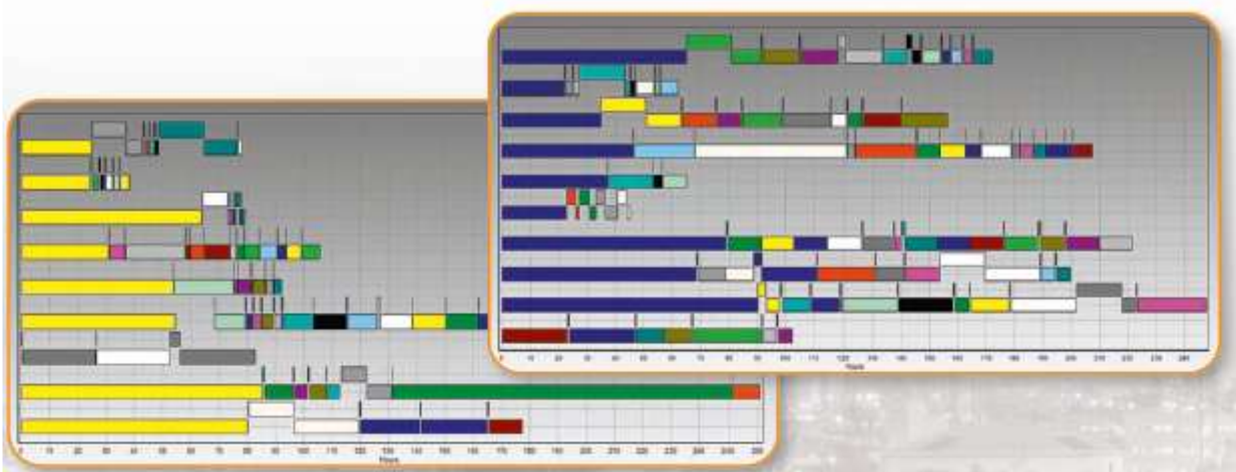
http://www.gams.com/presentations/index.htm#Ads

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



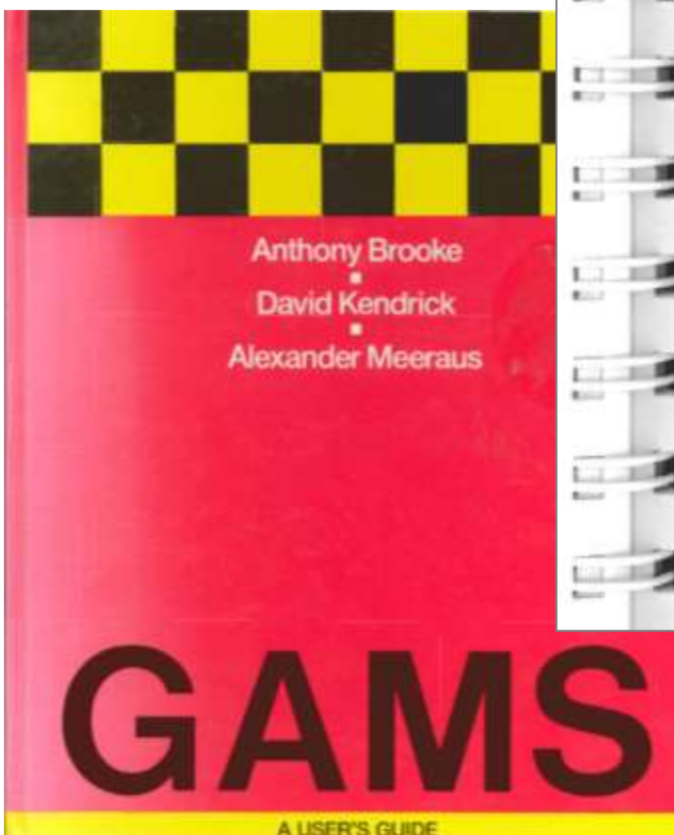
http://www.gams.com/presentations/index.htm#Ads

Agenda

- What is GAMS?
- **What is special?**
- What is new?

Agenda

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

Name	*Number of Rows*	*Number of Columns*	*Number of Nonzeroes*	*Generation Time*[a]	*Solution Time*[a]	*Iterations*	*Solver*
DINAMICO	318	425	4156	3.0	30.1	628	MINOS
SARF	532	542	3949	37.7	115.8	2775	MINOS
FERTD[b]	458	2968	7252	11.4	28.3	1368	ZOOM
CAMCGE[c]	243	280	1356	0.8	7.0	189	MINOS
GANGES[d]	274	357	1405	1.8	7.3	187	MINOS
YEMCEM[e]	168	258	953	0.9	7.6	600	ZOOM
EGYPT[f]	281	618	3168	4.0	25.3	1551	ZOOM

[a] Measured in minutes.
[b] The problem is too big for MINOS. ZOOM was used instead.
[c] A nonlinear problem. 63% of the non-zeroes are nonlinear.
[d] A nonlinear problem. 58% of the non-zeroes are nonlinear.
[e] A mixed binary problem, with 55 binary variables (solved with a relative termination criterion of 10%).
[f] A linear problem, solved using XMP which is contained within ZOOM.

GAMS Users Guide (1988)

… and now

	Type	s in 1988	s in 2008	Improvement Factor
camcge	NLP	468	0.031	15097
dinamico	LP	1986	0.125	15888
egypt*	MIP	1758	0.015	117200
fertd*	MIP	2382	0.062	38419
ganges	NLP	546	0.109	5009
sarf	LP	9210	0.139	66259
yemcem*	MIP	510	0.140	3643

* MIP 1988 solver ZOOM, 2008 solver CPLEX

Change in Focus

Computation	*Model*	*Application*
Past	**Now**	**Future**
→ Users left out	→ Users involved	→Users hardly aware of model

GAMS

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

GAMS

Protect User Investments

- 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

Agenda

- What is special?
  - Then and Now
  - Quality Assurance at GAMS

Quality Assurance at GAMS

Quality Test Models Library

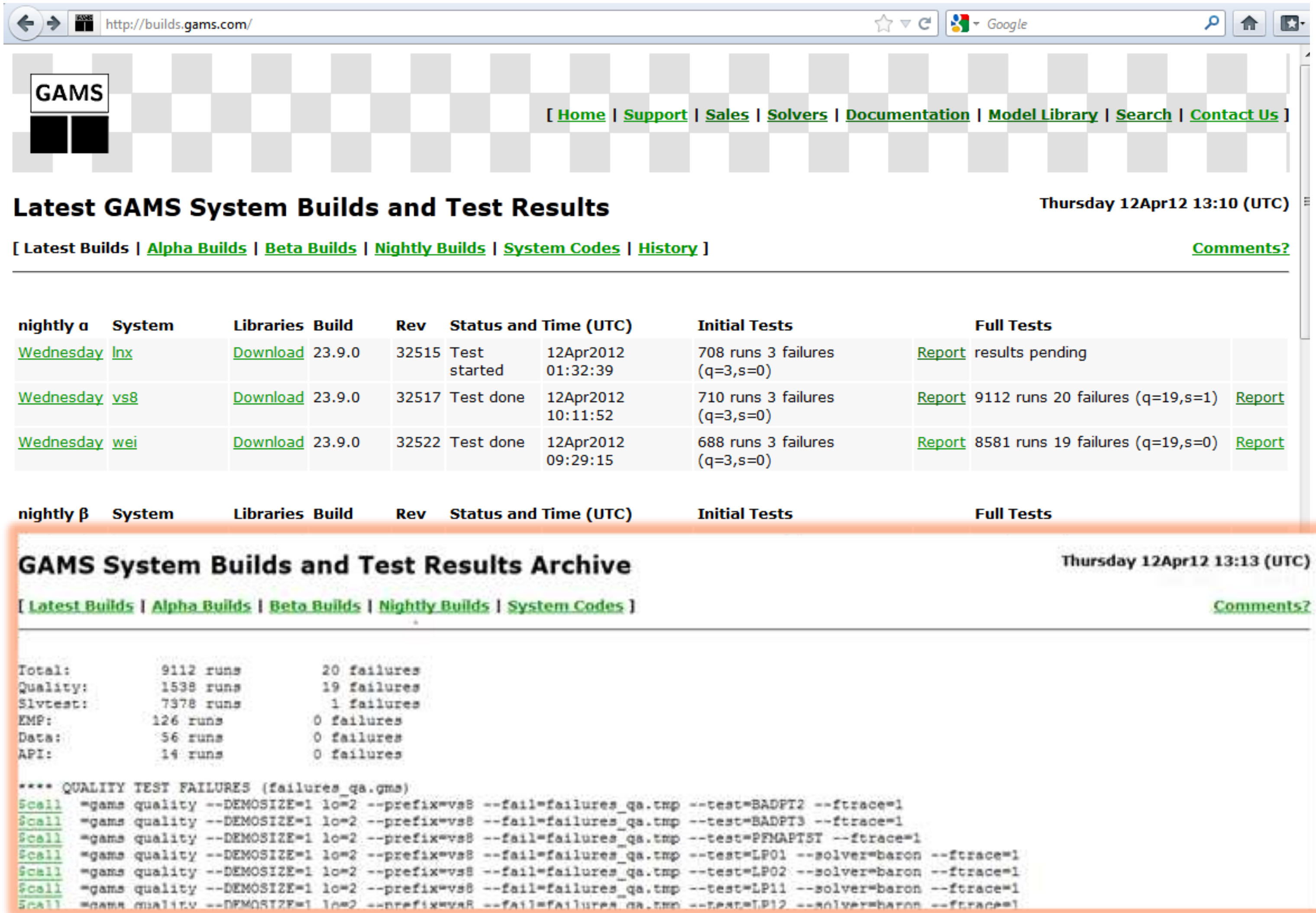
- Include tests to verify proper behavior of the system

- 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



http://builds.gams.com/

GAMS

[Home | Support | Sales | Solvers | Documentation | Model Library | Search | Contact Us]

Latest GAMS System Builds and Test Results

Thursday 12Apr12 13:10 (UTC)

[Latest Builds | Alpha Builds | Beta Builds | Nightly Builds | System Codes | History]

Comments?

nightly α	System	Libraries	Build	Rev	Status and Time (UTC)		Initial Tests		Full Tests	
Wednesday	lnx	Download	23.9.0	32515	Test started	12Apr2012 01:32:39	708 runs 3 failures (q=3,s=0)	Report	results pending	
Wednesday	vs8	Download	23.9.0	32517	Test done	12Apr2012 10:11:52	710 runs 3 failures (q=3,s=0)	Report	9112 runs 20 failures (q=19,s=1)	Report
Wednesday	wei	Download	23.9.0	32522	Test done	12Apr2012 09:29:15	688 runs 3 failures (q=3,s=0)	Report	8581 runs 19 failures (q=19,s=0)	Report

nightly β	System	Libraries	Build	Rev	Status and Time (UTC)	Initial Tests	Full Tests

GAMS System Builds and Test Results Archive

Thursday 12Apr12 13:13 (UTC)

[Latest Builds | Alpha Builds | Beta Builds | Nightly Builds | System Codes]

Comments?

```
Total:          9112 runs          20 failures
Quality:        1538 runs          19 failures
Slvtest:        7378 runs           1 failures
EMP:             126 runs           0 failures
Data:             56 runs           0 failures
API:              14 runs           0 failures

**** QUALITY TEST FAILURES (failures_qa.gms)
$call  =gams quality --DEMOSIZE=1 lo=2 --prefix=vs8 --fail=failures_qa.tmp --test=BADPT2 --ftrace=1
$call  =gams quality --DEMOSIZE=1 lo=2 --prefix=vs8 --fail=failures_qa.tmp --test=BADPT3 --ftrace=1
$call  =gams quality --DEMOSIZE=1 lo=2 --prefix=vs8 --fail=failures_qa.tmp --test=PFMAPTST --ftrace=1
$call  =gams quality --DEMOSIZE=1 lo=2 --prefix=vs8 --fail=failures_qa.tmp --test=LP01 --solver=baron --ftrace=1
$call  =gams quality --DEMOSIZE=1 lo=2 --prefix=vs8 --fail=failures_qa.tmp --test=LP02 --solver=baron --ftrace=1
$call  =gams quality --DEMOSIZE=1 lo=2 --prefix=vs8 --fail=failures_qa.tmp --test=LP11 --solver=baron --ftrace=1
$call  =gams quality --DEMOSIZE=1 lo=2 --prefix=vs8 --fail=failures_qa.tmp --test=LP12 --solver=baron --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)

GAMS

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
- **G**ather**-U**pdate**-S**olve**-S**catter
- ***(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

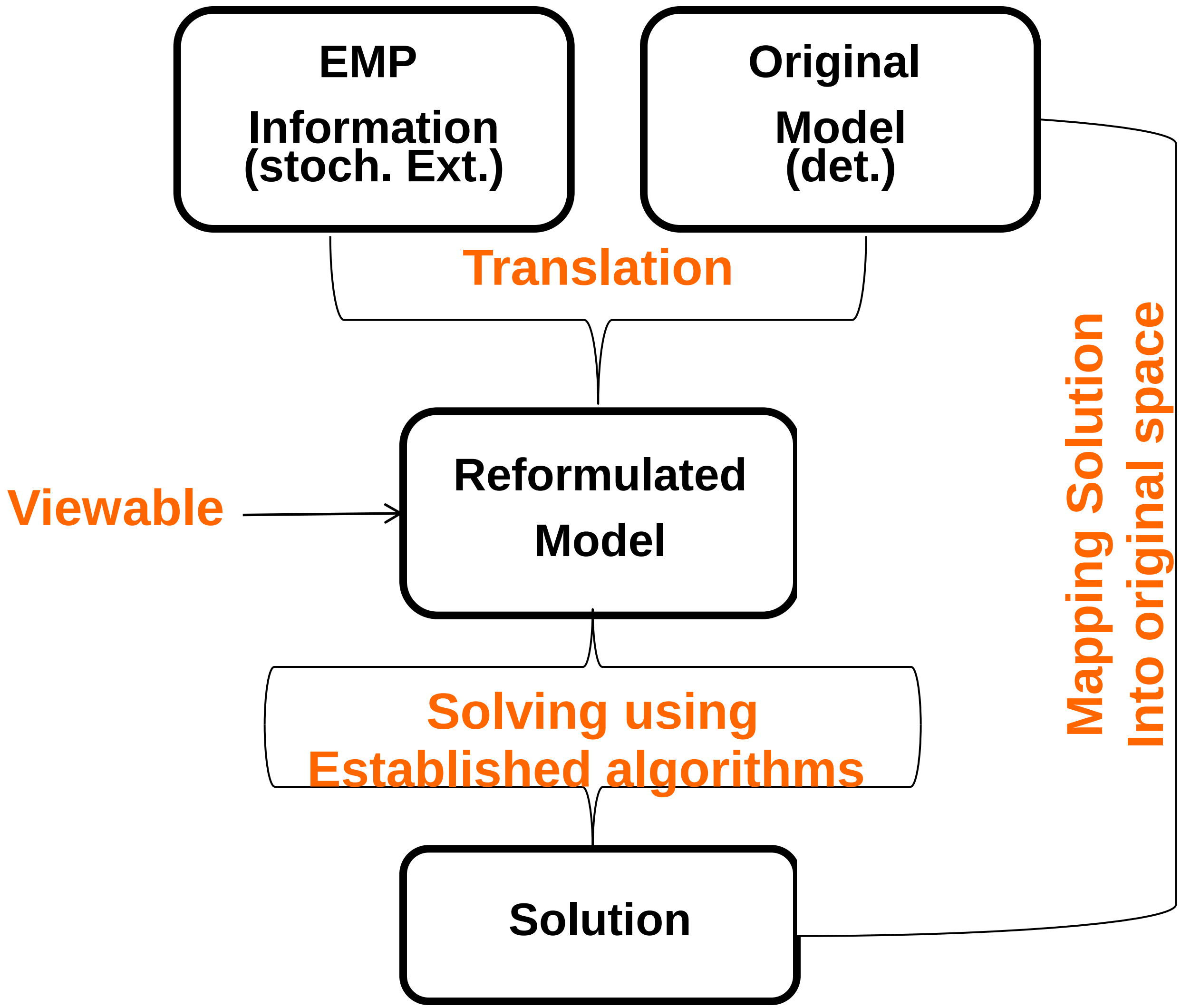
- What is new?
  - GAMS System
  - Platforms
  - Solvers
  - Interfaces
  - Stochastic Programming

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

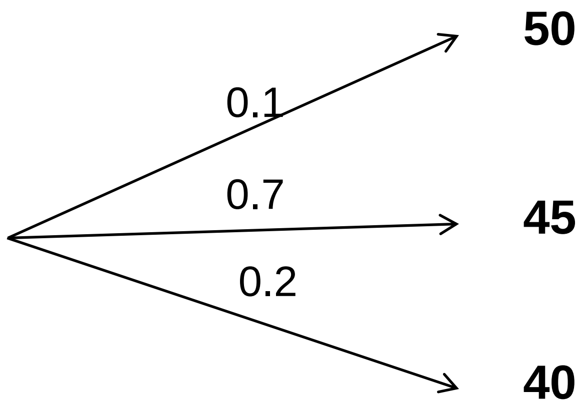

EMP
Information
(stoch. Ext.)
Original
Model
(det.)
Translation
Viewable
Reformulated
Model
Solving using
Established algorithms
Solution
Mapping Solution
Into original space

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 /;
```

NP – Stochastic (discrete Distribution)

```
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;
```



NP - Keywords to describe uncertainty

- **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

NP – Output extraction

```
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;
```

NP – stochastic (Results)

```
----       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

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

Table 1.1: Parametric distributions

NP – Stochastic Solver Capabilities

	DE	DECIS	LINDO
chance	√		√
correlation			√
jrandvar	√	√	√
randvar (discrete)	√	√	√
randvar (parametric)			√

Table 1.2: Solver Capabilities

NP – Stochastic (Normal Distribution)

```
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

GAMS EMP Library

Search

SeqNr	Name	Type	Description
92	SKU1SP	SP	Multi-product assemble model with discrete and Poisson demand distribution
91	GEN2S	SP	Two stage stochastic program in the generic form
90	CARGONET	SP	Cargo network scheduling with stochastic transportation demand
89	BATCHSP	SP	Design of batch chemical plants with stcohastic demand and price
88	CIRCLESP	SP	Circle Enclosing Points - Stochastic Example
87	STOCFOR3	SP	Long Range Forest Planning
86	AIRLIFT	SP	Airlift operations schedule
85	NBSIMPLE	SP	Simple newsboy problem, discrete
84	TR20	SP	Extended transport model with stochastic demand and costs
83	SP3X2	SP	Simple stochatic model
82	SIMPLECHANCE	SP	Simple chance constraint model
81	PRODSP3	SP	Stochastic Programming Example
80	PORTFOLIO	SP	Stochastic portfolio model
79	NBDISCJOINT	SP	Newsboy problem, discrete and joint distribution
78	NBDISCINDEP	SP	Newsboy problem, discrete and independent distribution
77	NBCONTJOINT	SP	Newsboy problem, continuous and joint distribution
76	NBCONTINDEP	SP	Newsboy problem, continuous and independent distribution
75	LANDSSP	SP	Optimal Investment
74	KILOSAFARM	SP	Kilosa farm problem
73	FARMSP	SP	The Farmer's Problem - Stochastic
72	CLEARLAKSP	SP	Scenario Reduction: ClearLake exercise
71	APL1PCASP	SP	Stochastic Electric Power Expansion Planning Problem
70	APL1PSP	SP	Stochastic Electric Power Expansion Planning Problem

```
Multi-product assemble model with discrete and Poisson demand distribution
 (SKU1SP,SEQ=92)

This is a multi-product assembly model, adopted from Section 1.3.1 of the
book Lectures on Stochastic Programming: Modeling and Theory by Alexander
```

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 !

<u>USA</u>

GAMS Development Corp.
1217 Potomac Street, NW
Washington, DC 20007
USA

Phone: +1 202 342 0180
Fax: +1 202 342 0181

http://www.gams.com
sales@gams.com
support@gams.com

<u>Europe</u>

GAMS Software GmbH
Eupener Str. 135-137
50933 Cologne
Germany

Phone: +49 221 949 9170
Fax: +49 221 949 9171

http://www.gams.com
info@gams.de
support@gams.com