GAMS

INFORMS INTERNATIONAL Beijing 2012

Fundamentals and Recent Developments of the GAMS System

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Beijing, China June 2012

Agenda

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

Algebraic Modeling System

What's that?

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

➔Simplified model building
➔Efficient solution process

AIMMS 3

AMPL

GAMS

. . .

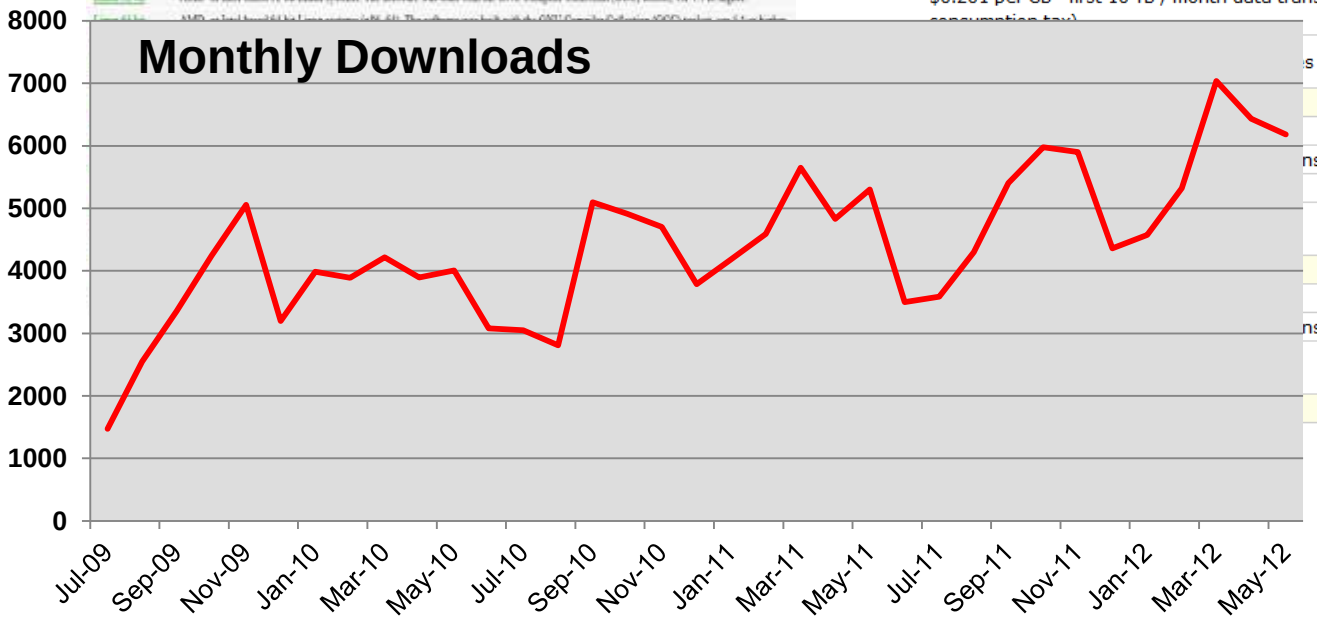
General Algebraic Modeling System

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

- Broad academic & commercial user community and network

Monthly System Downloads

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	23.800 GB	4.78
s consumption tax).	4,676 Requests	0.01
		4.79
nsfer out	39.512 GB	7.51
	1 Request	0.01
	18,087 Requests	0.02
		7.54
nsfer out	21.656 GB	5.41
	1,535 Requests	0.01
		5.42



Model Structure

4 (c) Regional farmer employment accounting rows:

$$-RESr + 3 \sum_{d \in r} \sum_{q} dFLq + \sum_{d \in r} \sum_{t} dFLt = 0, \quad \text{each } r$$

$$-\left[\begin{array}{c}\text{Regional farmer}\\ \text{employment}\\ \text{activity}\end{array}\right] + 3\left[\begin{array}{c}\text{Sum over districts}\\ \text{and quarters of}\\ \text{quarterly farmer}\\ \text{employment}\end{array}\right]^{37}$$

$$+\left[\begin{array}{c}\text{Sum over districts}\\ \text{and months of}\\ \text{monthly farmer employment}\end{array}\right]^{37} = 0$$

1 (d) Total employment accounting row in man-years:

$$-12LMAN + \sum_{t} LMANt = 0$$

$$-12\left[\begin{array}{c}\text{Total employment}\\ \text{in man-years}\end{array}\right] + \left[\begin{array}{c}\text{Sum over months of}\\ \text{total employment}\\ \text{in man-months}\end{array}\right] = 0$$

12 (e) Total monthly employment accounting rows in man-months:

$$-2.2LMANt + \sum_{d} dDLt + \sum_{d} dFLq + \sum_{d} dFLt = 0,$$

each t and q such that $t \in q$

$$-2.2\left[\begin{array}{c}\text{Total}\\ \text{employment}\\ \text{in month } t\end{array}\right]^{38} + \left[\begin{array}{c}\text{Sum over districts of}\\ \text{day labor employment}\\ \text{in month } t\end{array}\right]$$

$$+\left[\begin{array}{c}\text{Sum over districts of}\\ \text{quarterly farmer}\\ \text{employment in the}\\ \text{quarter containing}\\ \text{month } t\end{array}\right] + \left[\begin{array}{c}\text{Sum over districts}\\ \text{of monthly farmer}\\ \text{employment}\end{array}\right] = 0$$

[37] In irrigation districts the quarterly contract device is used for farmers, but in non-irrigated districts farmers are assumed to be available on a monthly basis, so that seasonal migration to irrigated areas may occur.

[38] The activities for hiring farmers and day laborers are stated in units of tens of man-days per month (or quarter), and there are 22 working days per month; hence the conversion factor of 2.2 is required in the first term of this equation.

Model Data

Table 3
Sequence of standard operations for cotton cultivation (days of unskilled labor, machinery services, and draft animal services required per hectare by month)

Cultivation month and operation	Mechanized		Partially mechanized			Non-mechanized	
	Unskilled labor	Machinery	Unskilled labor	Machinery	Animals	Unskilled labor	Animals
1st Preparatory tasks		0.12		0.12		1.0	2.0
Fallow		0.5		0.5		3.0	6.0
Cross-plowing						2.5	5.0
Harrowing		0.2		0.2		0.5	1.0
Land levelling		0.25		0.25		1.0	2.0
Canal cleaning	1.0		1.0			1.0	
2nd Irrigation ditches	1.0	0.2	1.0	0.2		2.0	2.0
Forming borders [a]		0.2		0.2		2.0	
Linking borders [b]	1.0		1.0				
Water application	2.0		2.0			2.0	
Harrowing		0.2		0.2		2.0	4.0
Seeding and fertilization	0.2	0.2	0.2	0.2		4.0	
Maintenance of field works		0.2	0.2			2.0	
3rd Thinning plants	4.0		4.0			4.0	
Cultivation		0.2	2.0		4.0	2.0	4.0
Weeding	6.0		6.0			6.0	
Applications of insecticides (2) [c]							

INFORMS Lanchester Prize 1973

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

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

Matrix Generator

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Y(248)'X(248)
   IF (X(248).LT.0.5.AND.X(248).GT..00) Y(248)'Z(248,1)*(1+X(248))
Y(249)'X(249)
   IF (X(249).LT.0.5.AND.X(249).GT..00) Y(249)'Z(249,1)*(1+X(249))
Y(250)'X(250)
   IF (X(250).LT.0.5.AND.X(250).GT..00) Y(250)'Z(250,1)*(1+X(250))
Y(251)'X(251)
   IF (X(251).LT.0.5.AND.X(251).GT..00) Y(251)'Z(251,1)*(1+X(251))
Y(252)'X(252)
   IF (X(252).LT.0.5.AND.X(252).GT..00) Y(252)'Z(252,1)*(1+X(252))
Y(253)'X(253)
   IF (X(253).LT.0.5.AND.X(253).GT..00) Y(253)'Z(253,1)*(1+X(253))
Y(254)'X(254)
   IF (X(254).LT.0.5.AND.X(254).GT..00) Y(254)'Z(254,1)*(1+X(254))
Y(255)'Y(266)+Y(267)
Y(256)'X(256)
   IF (X(256).LT.0.5.AND.X(256).GT..00) Y(256)'Z(256,1)*(1+X(256))
Y(257)'X(257)
   IF (X(257).LT.0.5.AND.X(257).GT..00) Y(257)'Z(257,1)*(1+X(257))
Y(258)'X(258)
   IF (X(258).LT.0.5.AND.X(258).GT..00) Y(258)'Z(258,1)*(1+X(258))
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Y(262)'X(262)
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Y(263)'X(263)
   IF (X(263).LT.0.5.AND.X(263).GT..00) Y(263)'Z(263,1)*(1+X(263))
Y(264)'X(264)
   IF (X(264).LT.0.5.AND.X(264).GT..00) Y(264)'Z(264,1)*(1+X(264))
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Y(266)'X(266)
   IF (X(266).LT.0.5.AND.X(266).GT..00) Y(266)'Z(266,1)*(1+X(266))
Y(267)'X(267)
```

```
CUMPPB
CUMPIB
CUMNEI
CUMONE
CUMTRO
CUMTHR
CUMFCU
CUMFIV
CUMLCT
CUMLCG
CUMOLS
CU b=
C= -
EXPORT
NETDII
NETDFI
WHKRMT
NETTRN
DFFCUR
DFFCAP
```

Matrix Generator Input

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   25     1     8     0     0     0     1      AGGREGAT
      0.12                    0.0165
ALA ALG ALV ARO AZU CAR CEG CHV FRI GAR JIT JON MAI MAT MEL P
PLU SAL SAN SOR SOT SOY TRI
    0.0286
     99999
AZU AZU    -0.25       1.0         0.0070     2627020.
JIT JIT    -0.4        1.0         0.1150     174752.
PEP PEP    -0.6        1.0         0.0590     19.
PLU PLU    -1800.      1.0         0.5770     85209.
CCC
CHI        1     -0.2
CHV         0.1500     14.459      1.0
FOR        6     -0.3
SOR         0.0630     285.818     1.0
CEG         0.0930     0.665       1.0
ALV         0.0100     226.109     1.0
ALA         0.0400     179.019     1.0
GAR         0.0990     1.427       1.0
MAI         0.0860     77.997      1.0
FEC        4     -0.3
FRI         0.1830     33.001      1.0
ARO         0.1220     196.197     1.0
PAP         0.0930     27.138      1.0
GAR         0.0990     0.158       1.0
GRA        2     -0.1
MAI         0.0860     132.804     1.0
TRI         0.0800     343.979     1.0
FRU        2     -2.0
SAN         0.0780     10.850      1.0
MEL         0.0680     6.9350       1.0
OLE        4     -1.2
SAL         0.0830     193.910     1.0
JON         0.2410     9.224       1.0
CAR         0.1550     72.490      1.0
SOY         0.1600     57.220      1.0
END
ALA         .02        0.0
ALV          .005       .01
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MPS File – Column Section

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X,ASKSC1  B,AS,,C1        -1,00000
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X,ASKSC3  A,TRA            7,56000
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X,ASKSAS  B,AS,,AS        -1,00000
X,ASKSAS  A,TRA            7,56000
X,ASKSS1  D,,,KS,P         0,15000
X,ASKSS1  R,,,KSS1         1,00000
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X,ASKSCN  R,,,KSCN         1,00000
X,ASKSCN  B,AS,,CN        -1,00000
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MPS Revision File

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BRANCH      *           MAJERR
NEXT
REVISE      REV5        TAPE14

                                          ***** CARD READ SUMMARY ****
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HEADER, CARD NO=      2    $COLUMNS
HEADER, CARD NO=      3    $  MODIFY
HEADER, CARD NO=      6    $RHS
HEADER, CARD NO=      7    $  MODIFY
HEADER, CARD NO=     18    $ENDATA
HEADER, CARD NO=     19    $NAME          REV1
HEADER, CARD NO=     20    $COLUMNS
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HEADER, CARD NO=     42    $ENDATA
HEADER, CARD NO=     43    $NAME          REV2
HEADER, CARD NO=     44    $COLUMNS
HEADER, CARD NO=     45    $  MODIFY
HEADER, CARD NO=     51    $ENDATA
HEADER, CARD NO=     52    $NAME          REV4
HEADER, CARD NO=     53    $RHS
HEADER, CARD NO=     54    $  MODIFY
HEADER, CARD NO=     68    $ENDATA
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HEADER, CARD NO=     70    $RHS
HEADER, CARD NO=     71    $  MODIFY
        CARD NO=     72    $    RHS1      CLA,V,01      5,03328
        CARD NO=     73    $    RHS1      CLA,V,02      5,03328
        CARD NO=     74    $    RHS1      CLA,V,03      5,03328
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        CARD NO=     77    $    RHS1      CLA,V,06      5,03328
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        CARD NO=     79    $    RHS1      CLA,V,08      5,03328
        CARD NO=     80    $    RHS1      CLA,V,09      5,03328
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        CARD NO=     82    $    RHS1      CLA,V,11      5,03328
        CARD NO=     83    $    RHS1      CLA,V,12      5,03328
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MPS Output

DATE 07/30/76 TIME 22.12.21 COLUMNS APEX-III 1.000 PAGE

PRINT OPTION = COMPLETE OUTPUT W/SPECIAL
NAME = CENTRAL OBJ = OBJ RHS = RHS1 BND = LIMITS TIVE = 28.18489
DIR = MAXIMIZE OBJ = CRHS = RNG = 1.0000 RPSRHS = 1.0000
0.0000 RPCHRHS = 0.0000

NUMBER	NAME	TYPE	STATUS	COL ACTIVITY	OBJ COEF	D UPPER	MARGINAL
101	CBE1V..	PL	LOWER	.	-47.80000	+INF	-6.46851
102	CBE2F..	PL	ACTIVE	.00087	-701.00000	+INF	.
103	CBE3C..	PL	ACTIVE	.	-10330.60000	+INF	.
104	CBE4F..	PL	LOWER	.	-2429.70000	+INF	-912.25118
105	CBE5C..	PL	LOWER	.	-9410.00000	+INF	-2342.38642
106	CBE6C..	PL	ACTIVE	.	-5118.00000	+INF	.
107	CBE7C..	PL	ACTIVE	.06067	-15.20000	+INF	.
108	CSG,V..	PL	ACTIVE	.	-231.57000	+INF	.
109	CSG,F..	PL	ACTIVE	.00226	-231.57000	+INF	.
110	CPO,V..	PL	ACTIVE	.	-139.67000	+INF	.
111	CPO,F..	PL	ACTIVE	.00002	-139.67000	+INF	.
112	CPO,C..	PL	ACTIVE	.00045	-139.67000	+INF	.
113	CEG,V..	PL	ACTIVE	.	-76.71000	+INF	.
114	CEG,F..	PL	ACTIVE	.00025	-76.71000	+INF	.
115	CEG,C..	PL	ACTIVE	.00128	-76.71000	+INF	.
116	CDA,CX.	PL	ACTIVE	.07685	12.91000	+INF	.
117	CDF,CX.	PL	LOWER	.	180.74000	+INF	-87.19134
118	CDC,CX.	PL	LOWER	.	167.83000	+INF	-256.39963
119	CDS,CX.	PL	ACTIVE	.06968	121.35000	+INF	.
120	CDL,CX.	PL	ACTIVE	.00225	91.66000	+INF	.
121	CWS,CX.	PL	ACTIVE	.00606	109.74000	+INF	.
122	CWL,CX.	PL	ACTIVE	.00748	77.46000	+INF	.

WB Old Slide 1

PLANNING PROBLEM AND OBJECTIVES INITIALLY OFTEN

UNSTRUCTURED

ILL-DEFINED

CONFLICTING

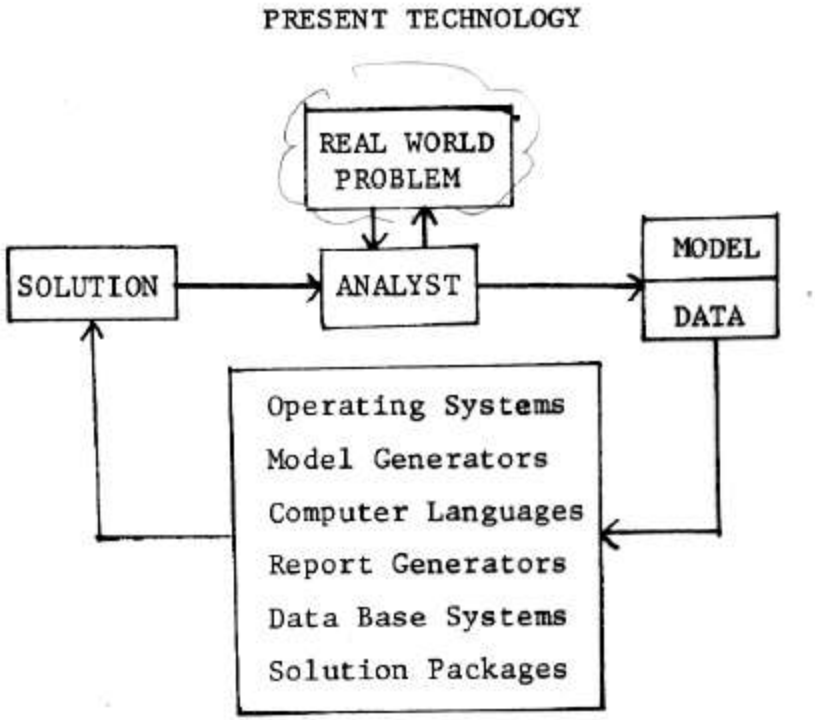
UNCERTAIN

CHANGING

EMOTIONAL

MATHEMATICAL MODEL USED TO RECOGNIZE AND FORMULATE PROBLEMS, DEFINE ISSUES AND EXPLORE SOLUTION SPACE

WB Old Slide 2



RESULT: - Drain of resources (technical, time, money)

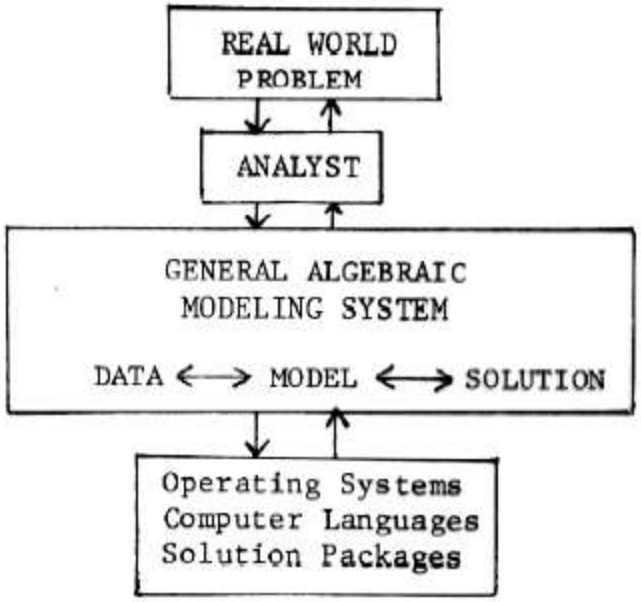
- Essentially no documentation

WB Old Slide 3

MAJOR CONSTRAINTS :

- COST
- SKILLS
- TIME
- TOOLS
- DOCUMENTATION
- TRUST
- .
- .
- .

WB Old Slide 4



RESULT:
- Limited drain of resources
- Same representation of models for humans and machines
- Model representation is also model documentation

WB Old Slide 5

DEVELOPMENT OF GAMS

Phase 1 (1978)

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

WB Old Slide 6

DEVELOPMENT OF GAMS

Phase 2 (1979)

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

WB Old Slide 7

DEVELOPMENT OF GAMS

Phase 3 (?)

- Automatic structure recognition
- Internal generation of *exact* point-derivatives
- Improved data-base design with e.g. unit analysis, and links to existing data bases
- Availability of GAMS on different machines
- World-wide availability of the system so that it can be used as a market for testing models and algorithms

GAMS at a Glance

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

- **Declarative:** Model Algebra
- **Procedural:** Programming Flow Control Features
  - Loop, For, While, Repeat
  - If, else, else…
  - Macros
  - Access to external programs/libraries
  - …

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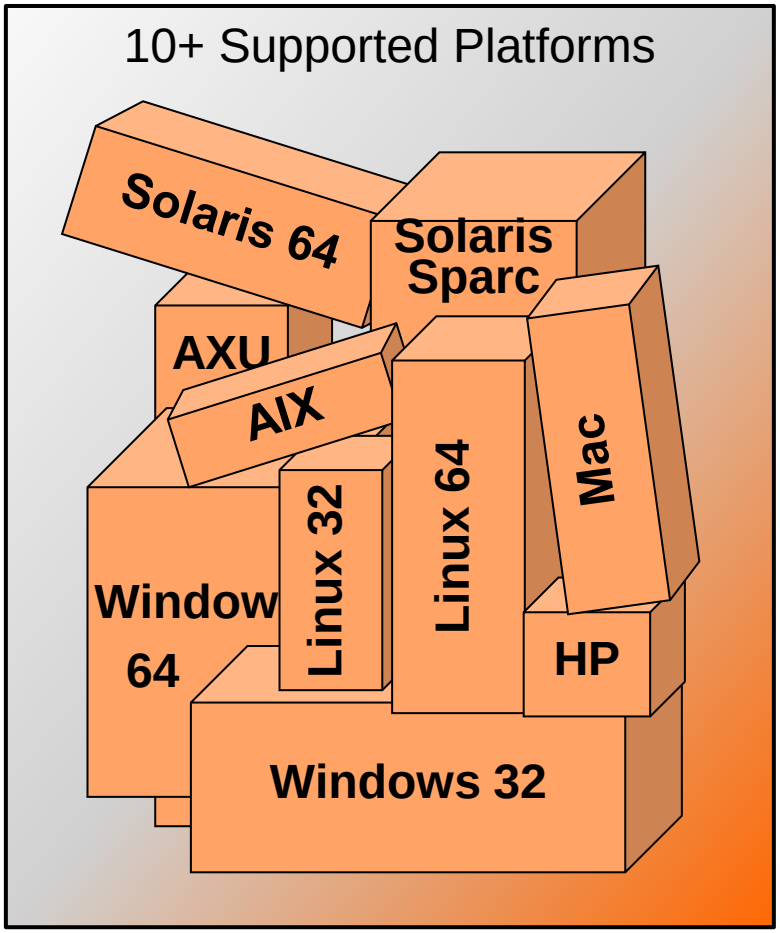

GAMS at a Glance

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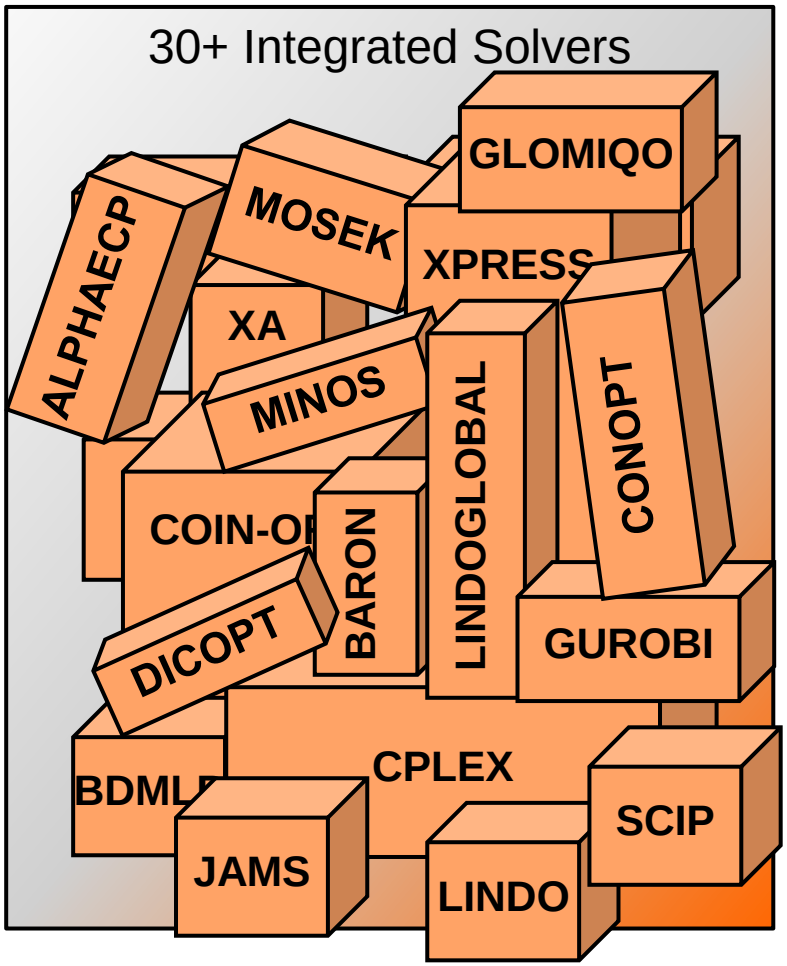

GAMS at a Glance

- Balanced mix of declarative and procedural elements
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- 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

System Overview

Interactive | **API / Batch**

Connectivity Tools

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

User Interfaces

GAMS Language Compiler and Execution System

Solvers

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

Productivity Tools

- **I**ntegrated **D**evelopment **E**nvironment (**IDE**)
- Integrated Data Browser and Charting Engine
- Model Libraries
- Benchmarking and Deployment
- Model Debugger and Profiler
- Transparent and reproducible Quality Assurance and Testing System
- Data and Model Encryption
- Grid Computing
- Scenario Reduction
- MPSGE for general equilibrium modeling

ALPHAECP, BARON, COIN, CONOPT, CPLEX, DECIS, DICOPT, GUROBI, KNITRO, LGO, LINDO, MINOS, MOSEK, OQNLP, PATH, SNOPT, XA, XPRESS, …

CAPRI

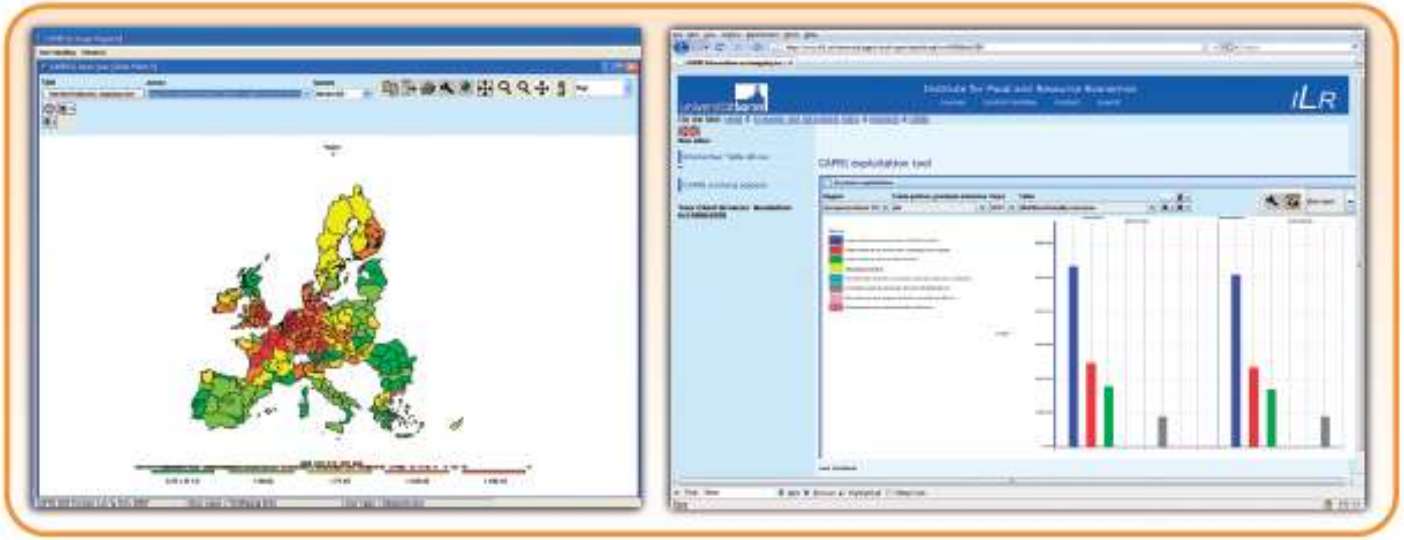
The CAPRI (Common Agricultural Policy Regional Impact) Modelling System

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

universitätbonn



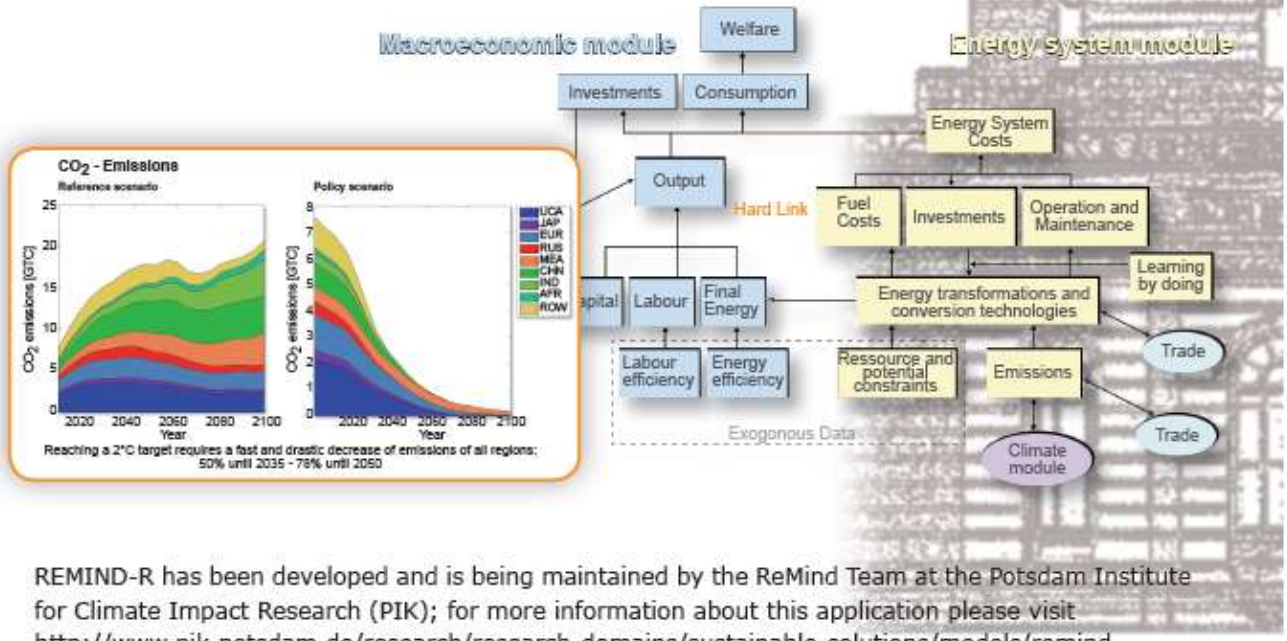
Screen shots from the CAPRI exploitation tool

REMIND-R

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



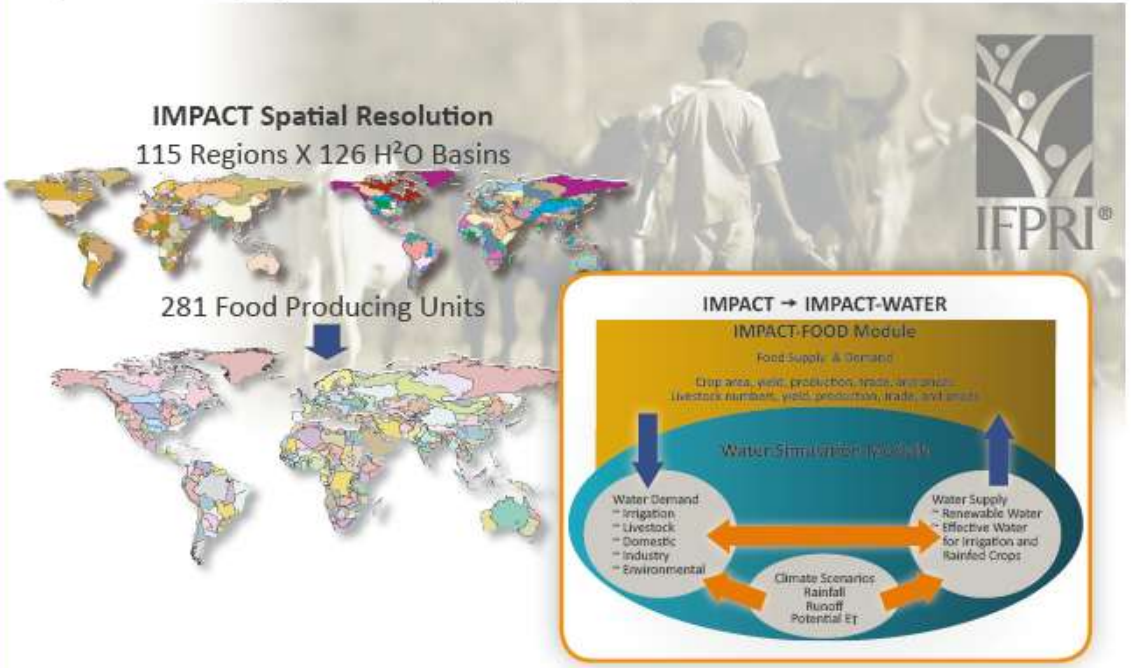
REMIND-R has been developed and is being maintained by the ReMind Team at the Potsdam Institute for Climate Impact Research (PIK); for more information about this application please visit http://www.pik-potsdam.de/research/research-domains/sustainable-solutions/models/remind

IMPACT

IMPACT - Modeling the Effects of Climate Change and Water Availability on Food Security

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

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



IMPACT and IMPACT-WATER have been developed at the International Food Policy Research Institute (IFPRI); for further information about this application please visit: http://www.ifpri.org/themes/impact.htm

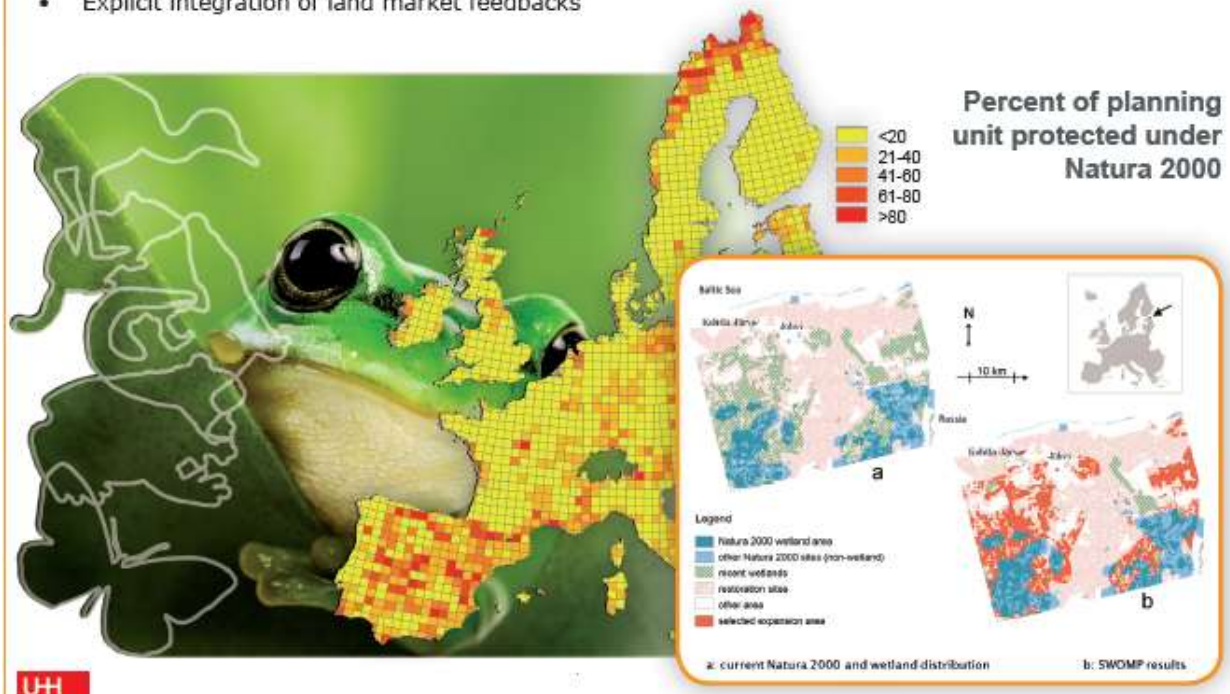
GAMS

HABITAT

HABITAT – a reserve selection tool for European wetland biodiversity conservation

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

- A set-covering problem formulated as a mixed integer program to find the cost-efficient allocation of nature reserves
- Integration of representation and persistence principles in the „conservation target" approach
- Endogenous calculation of reserve sizes
- Explicit integration of land market feedbacks



Universität Hamburg
DER FORSCHUNG | DER LEHRE | DER BILDUNG

For further information about this application please contact Kerstin Jantke <kerstin.jantke@zmaw.de>, Uwe Schneider <uwe.schneider@zmaw.de >, or visit: http://fnu.zmaw.de/

BALMOREL

BALMOREL - A Model for Analyzing the Energy Sector in an International Perspective

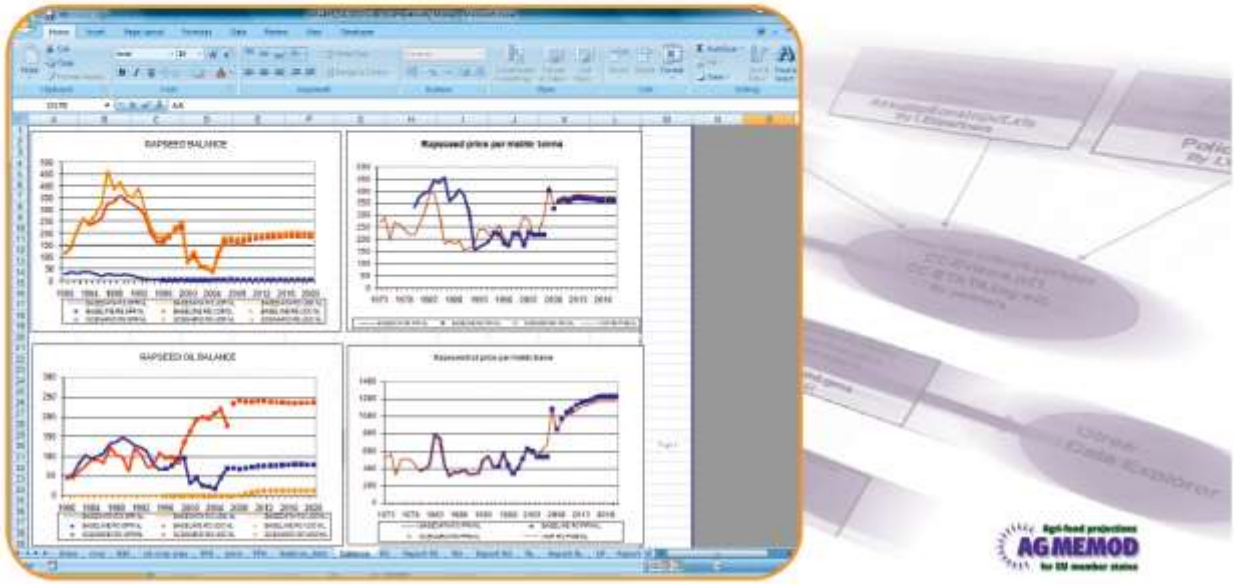
- A large partial equilibrium model
- Supports modeling and analysis of the energy sector with emphasis on the electricity, combined heat and power sectors
- Covers international and regional electricity trade with transmission constraints, costs and losses
- Handles policy measures like taxes, quotas,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

Danish grid, recommended reinforcements

AGEMOD

AGMEMOD – Agri-food projections for EU member states

- An econometric, dynamic, multi-product partial equilibrium model and additional tools.
- Allows projections and simulations in order to evaluate measures, programmes and policies in agriculture at the European Union (EU) level as well as at the (candidate) member states level.
- Data and all equations of the country models are stored in spreadsheets.
- AgMemod2GAMS checks data as well as the specified equations (distinguishing 17 different types of errors) and automatically generates GAMS code (more than 145.000 lines).
- Data and model experts are working with a consistent and stable instance of the models.
- xxGraph compares scenarios and makes all results available in spreadsheets.



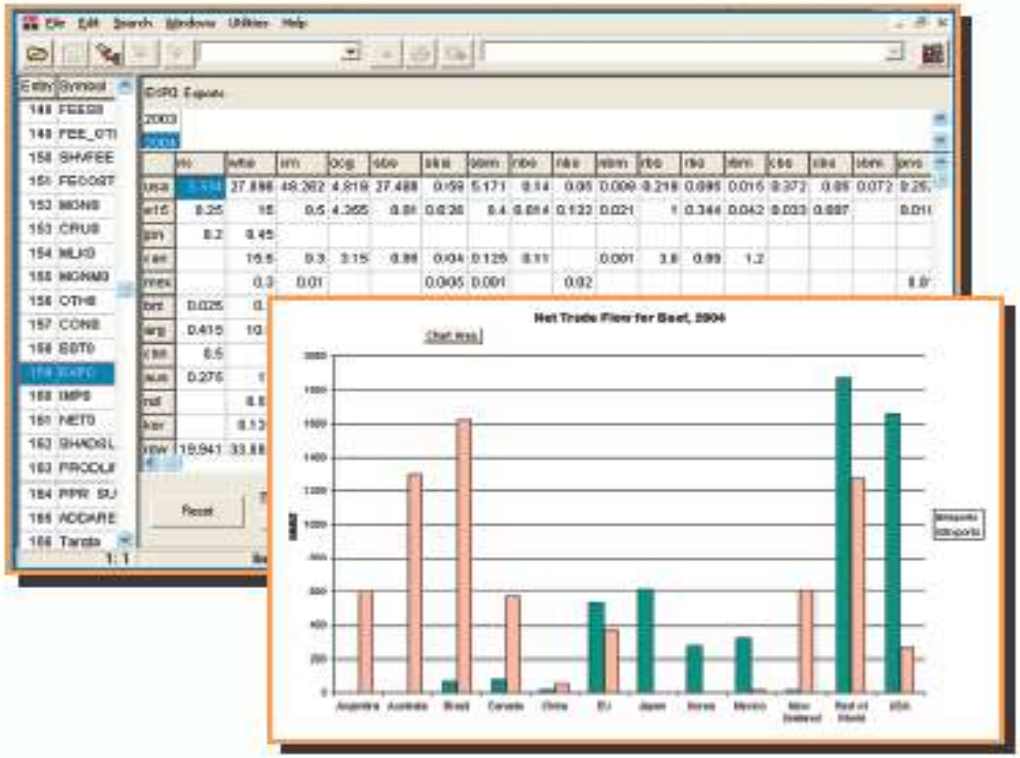
For more information please visit: **http://www.tnet.teagasc.ie/agmemod/**

Global Public Policy Modeling

Global Public Policy Modeling

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

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

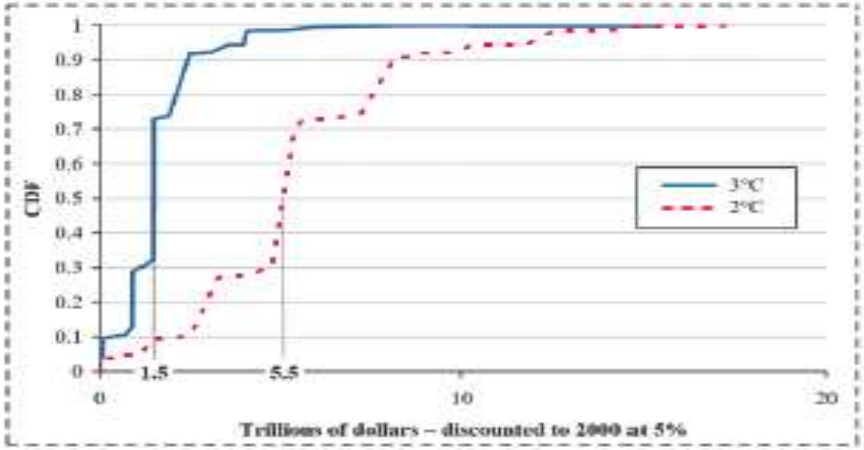


Climate Policy Modeling

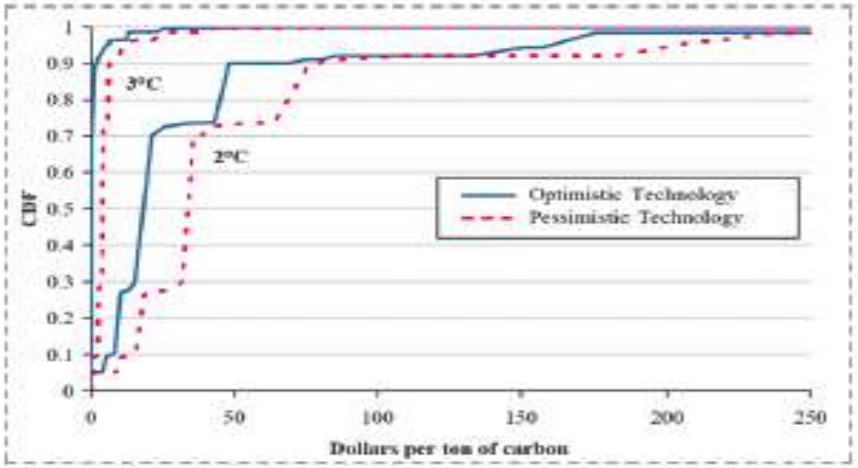
Climate Policy Modeling with GAMS

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

- The GAMS source code for MERGE is licensed by EPRI at zero cost and is available for public use. Current users include government & academic agencies worldwide. (See http://www.stanford.edu/group/MERGE/)
- MERGE is a multi-region, multi-commodity model combining both "top-down" and "bottom-up" elements of the global supply and demand for energy.
- A stochastic optimization formulation accommodates an explicit representation of uncertainty, although the model may also be operated in a deterministic mode.
- The model is solved using the CONOPT and MINOS nonlinear optimization solvers.



Gross Benefits from R&D Program under Alternative Temperature Constraints (50th percentile values highlighted)



Carbon Prices in 2010 with 2° and 3°C Temperature Caps

Moving Beyond Concentrations: The Challenge of Limiting Temperature Change" by Richard G. Richels, Alan S. Manne, and Tom M.L. Wigley (http://www.aei.brookings.org)

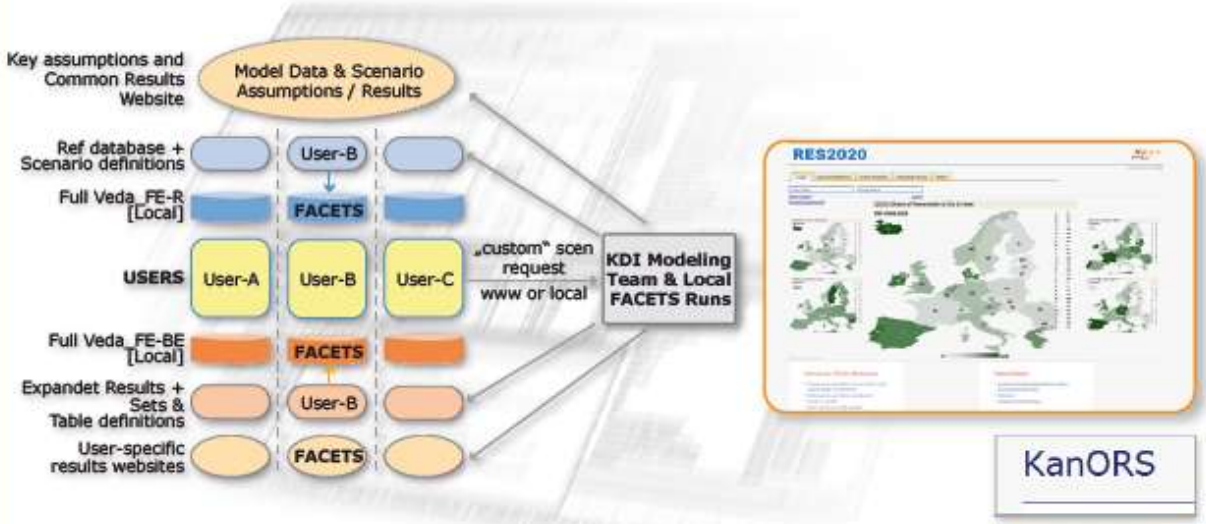
Facets

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

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

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

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



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

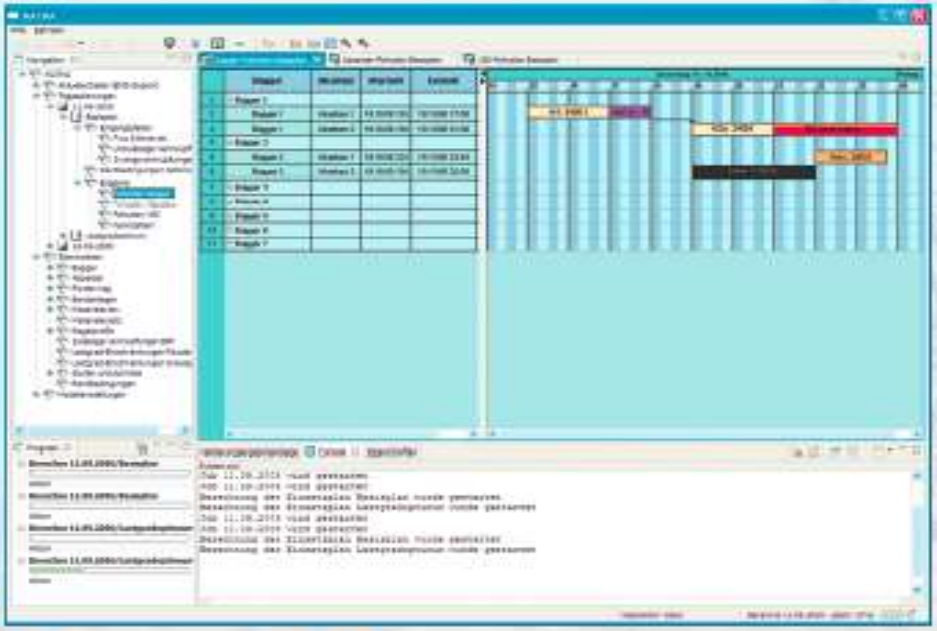
DWI DecisionWare, Inc.

ProCom Optimization Suite

ProCom® Optimization Suite

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

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



The Optimization Suite enables ProCom to provide the following services :

- Feasibility studies and analyses
- OR consulting and strategic planning
- Development of customized operational planning and control systems

ProCom®

Cutting Stock Optimization at GSE

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.

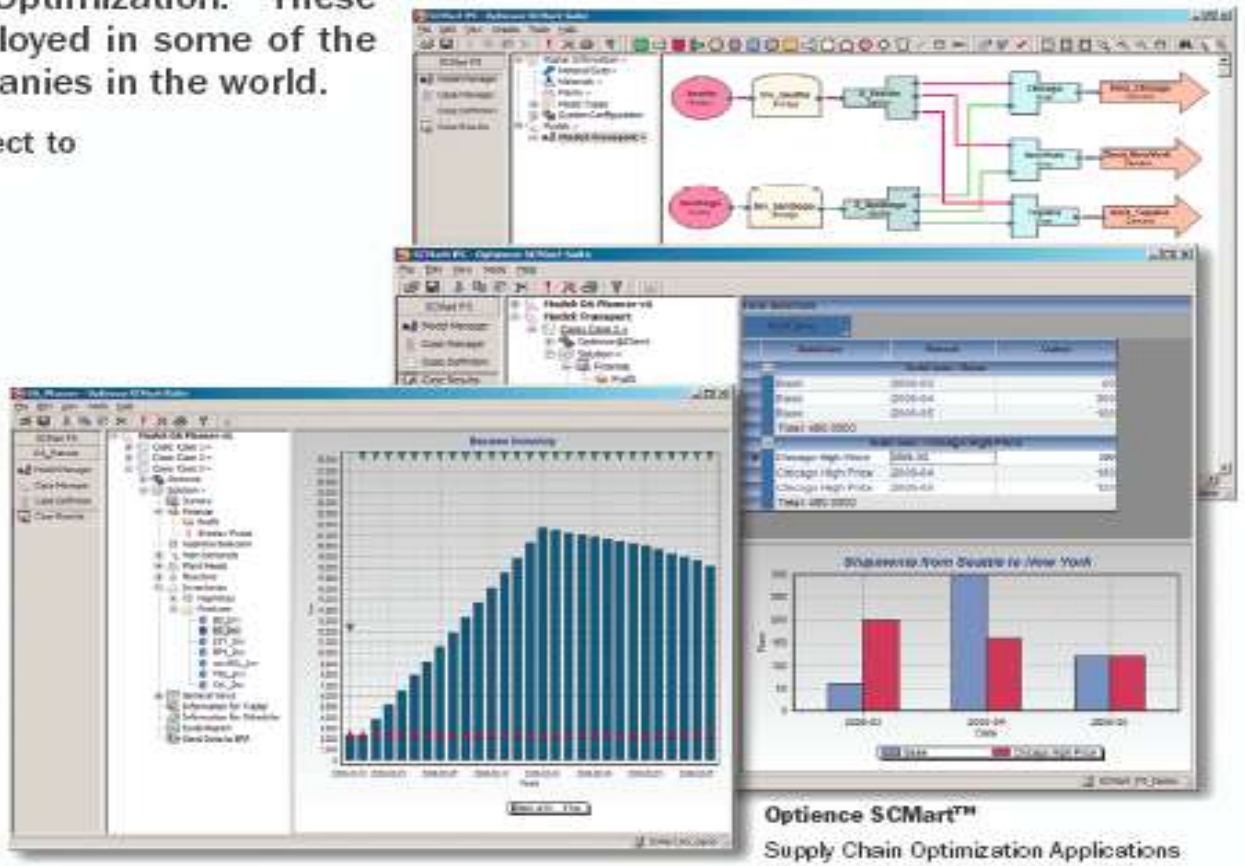
For more information please contact: www.gse-software.de

Optience Core Application Builder

Deploy Your GAMS Model in Optience Core Application Builder

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

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



Optience SCMart™
Supply Chain Optimization Applications

OPTIENCE
Strategic Solutions through Optimization Science

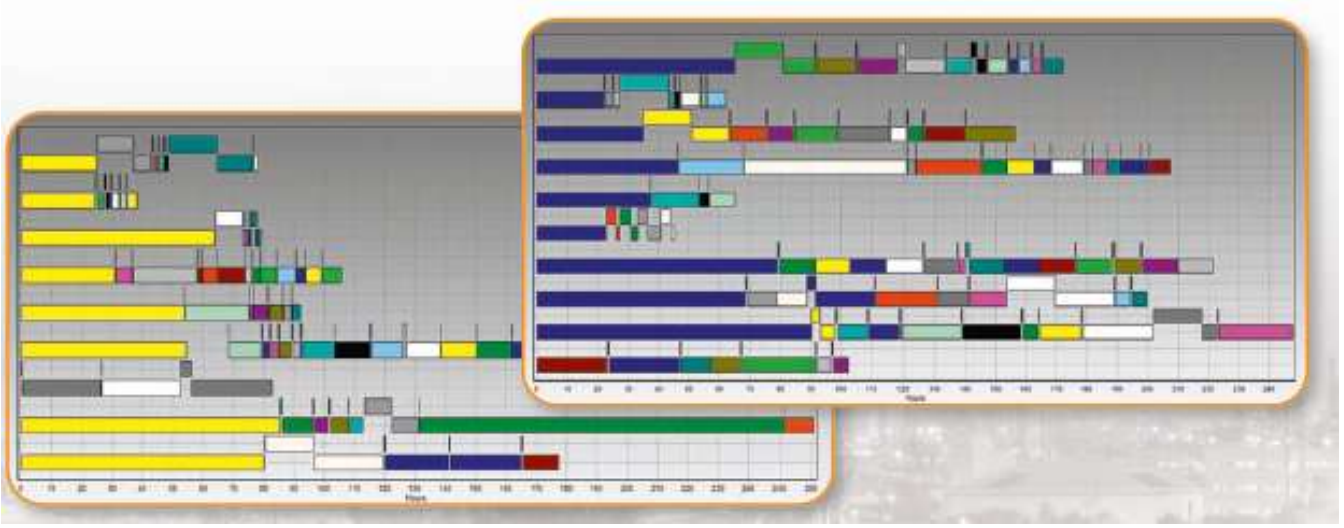
http://www.optience.com

Scheduling and Planning at BASF

Scheduling and Planning at BASF

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

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



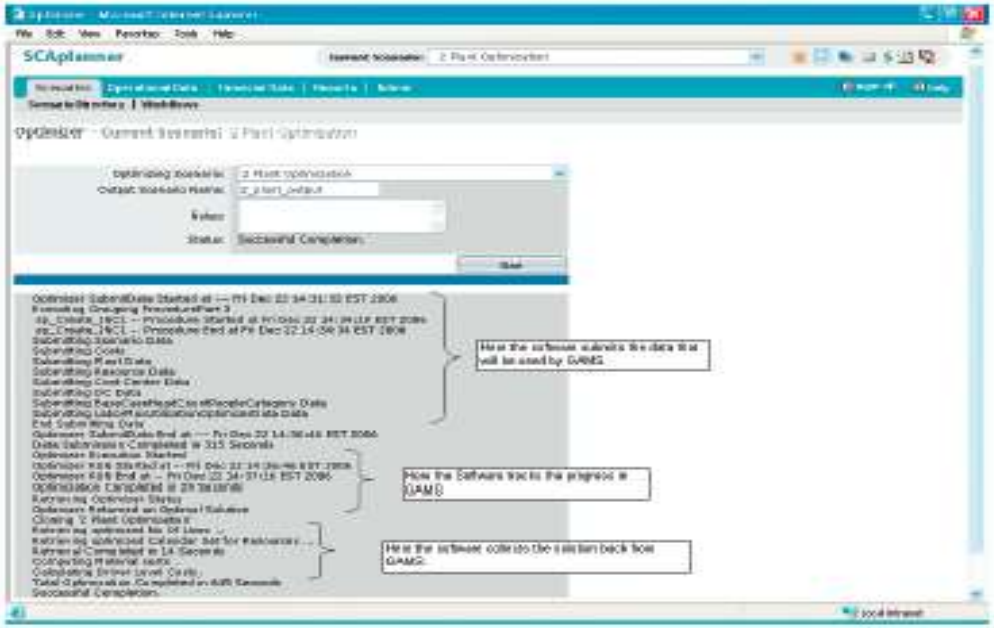
SCAplanner

SCAplanner Interacting With GAMS

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

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

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



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

SCA Technologies LLC

Intelligent Cost Management Solutions

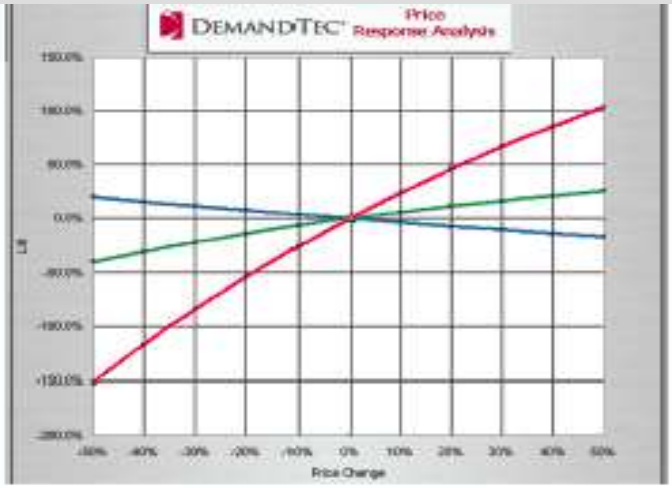
www.sca-tech.com

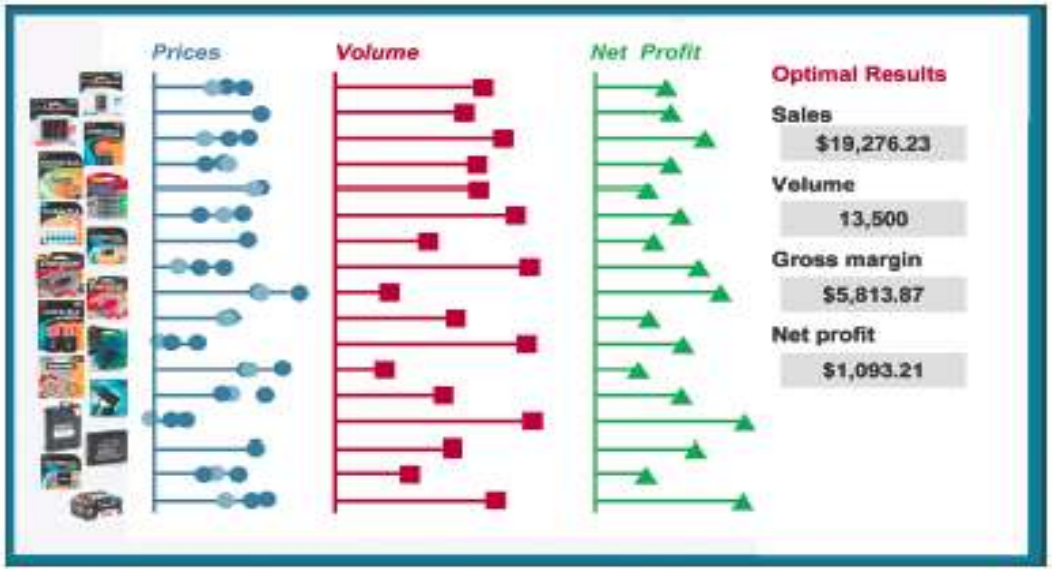
DemandTec

DemandTec Leverages GAMS to Drive Innovation in Retail and CPG Industries

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

- Model price elasticity, cross-price elasticity, and other merchandising causals to predict and influence demand given different merchandising conditions and strategies.
- Optimize prices and promotions to maximize sales, volume, or profit, while operating within the constraints of competitive pricing and other business rules.
- Accurately forecast the impact of merchandising strategies and tactics, taking into account cannibalization, halo effects, seasonality, trend, and other factors.

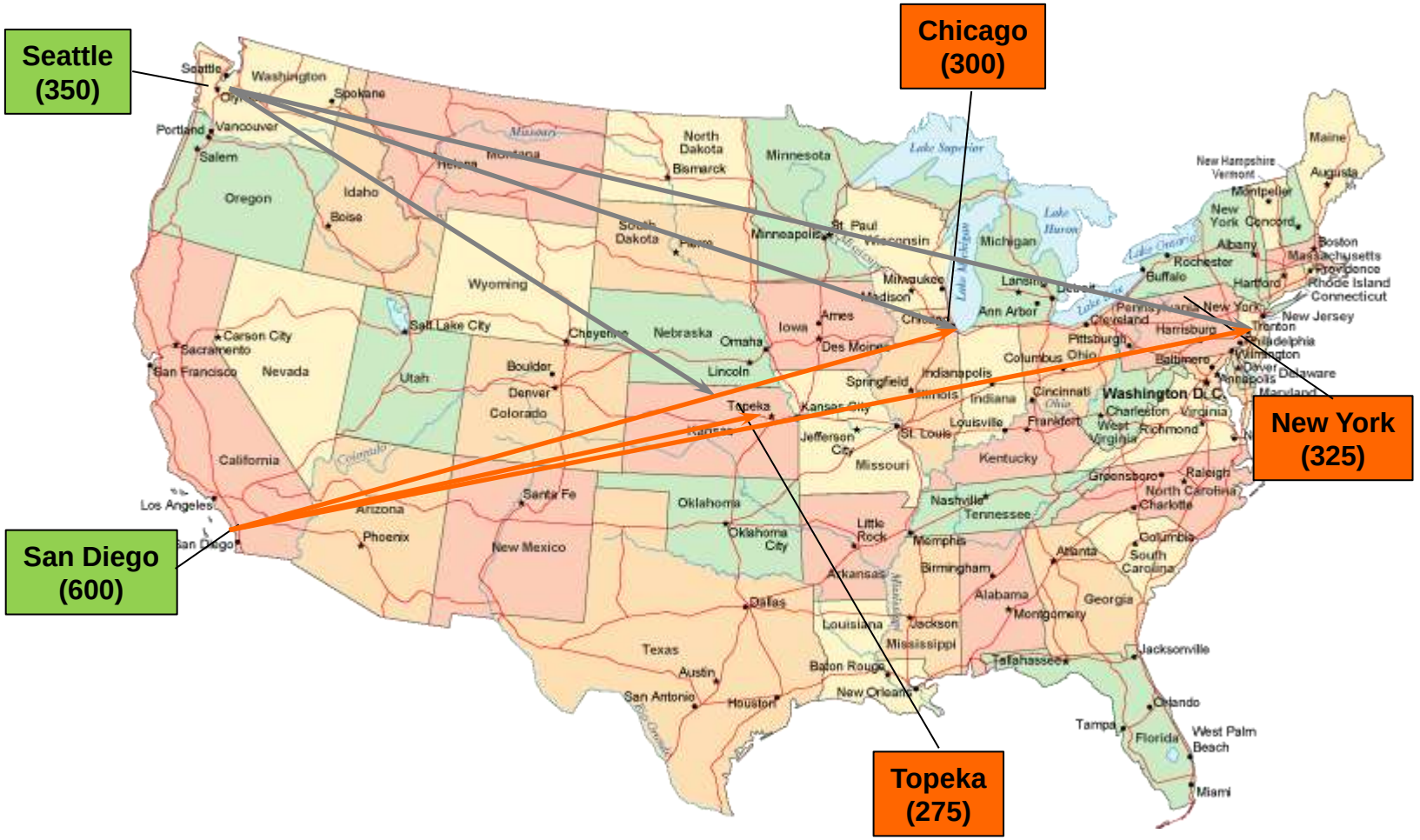




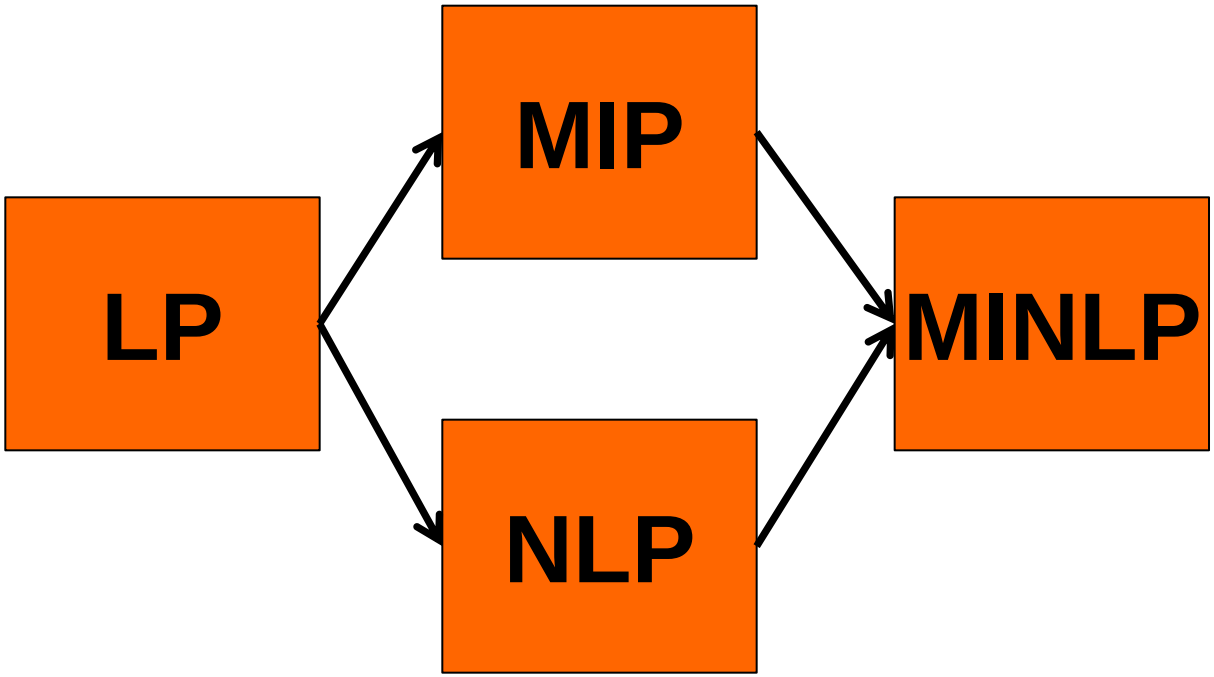
Agenda

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

A Simple Example: Transportation Model



A Simple Example: Modifications



A Simple Example: Algebra

Minimize	Transportation cost
subject to	Demand satisfaction at markets
	Supply constraints

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

A Simple Example: Minimum Shipment

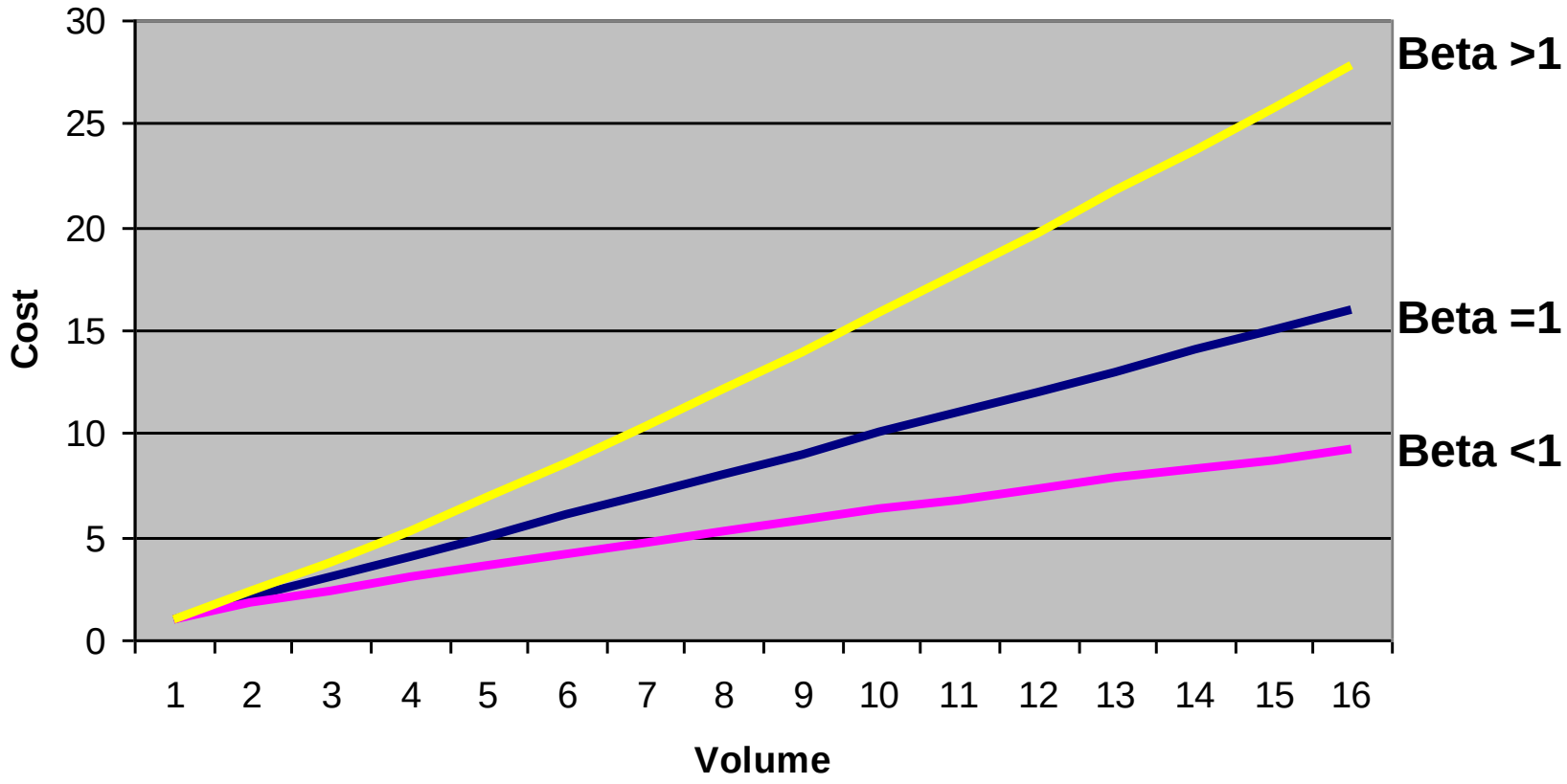
- Extension: Minimum Shipment
  - Ship at least 100 units or don't ship

- Continuous variable x(i,j)
- Binary variable ship(i,j)

- Coupling constraints:
  - if *ship* = 1 → $x \geq 100$: $x \geq 100 * ship$
  - *If ship* = 0 → $x = 0$: $x \leq bigM * ship$

A Simple Example: Economy of Scales

Cost = Volume^{beta}



Agenda

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

What is new: GAMS System

- Support for user-defined
  - Macros
  - Function libraries
- Asynchronous execution
- Extended Mathematical Programming (EMP)
- Stochastic EMP
- More and further details:
  http://www.gams.com/docs/release/release.htm

What is new: Platforms

- Support for MAC OS X
- Cross-platform licenses
- Wine (Linux, Mac**)**

What is new: Solvers

- **GloMIQO** : Branch-and-bound global optimization for mixed-integer quadratic models
- **Lindo**: Global and stochastic optimization
- **G**ather-**U**pdate-**S**olve-**S**catter

What is new: Interfaces

- **G**AMS **M**odeling **O**bject
- API's for various programming languages (C, Fortran, Delphi)
- Component libraries
- Better integration into Python
- .Net Integration ("*GAMS.NET*")

Agenda

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

Market Demands

- **Minimize risks** for (new) clients / management
  - Support rapid prototyping
  - Increase productivity
  - Deliver (expected) results
- **Do not lock users into a certain environment**
- **Protect user investments**
- **Provide cutting edge technology**

Provide cutting edge technology

- **Industry:** Reliable, high performance system for developing and deploying optimization applications
- **Academia (research tool):**
  - New modeling paradigms (e.g. SDP, bilevel, SP,…)
  - Emerging solution technology (e.g. MPEC)
  - New computing environments

Challenge 1

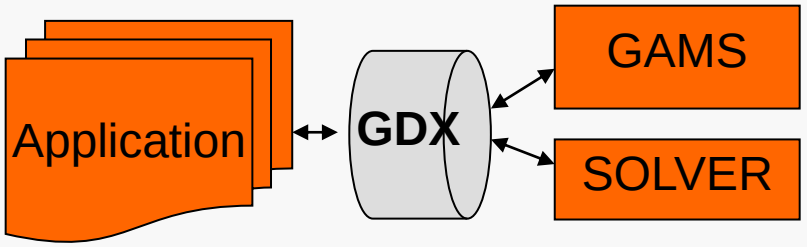
- Data transfer between different systems slow, error prone and bulky.
- Application (real time) require the capture of data instances that can be analyzed off-line in other environments.
- Management of name space mappings between different problems and their transformations into other data representations.
- Separate the model from its environment
- Search for a common low level high performance data container

GDX

Gams Data eXchange

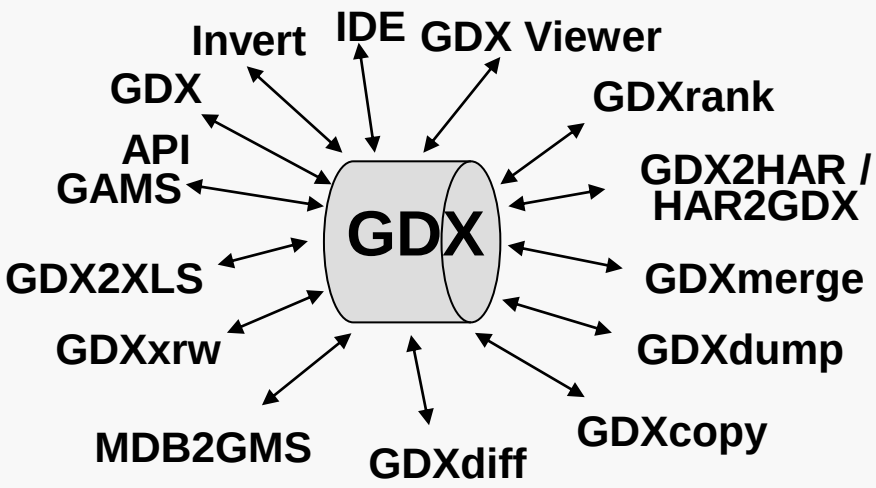
Gams Data eXchange

Binary Data Exchange

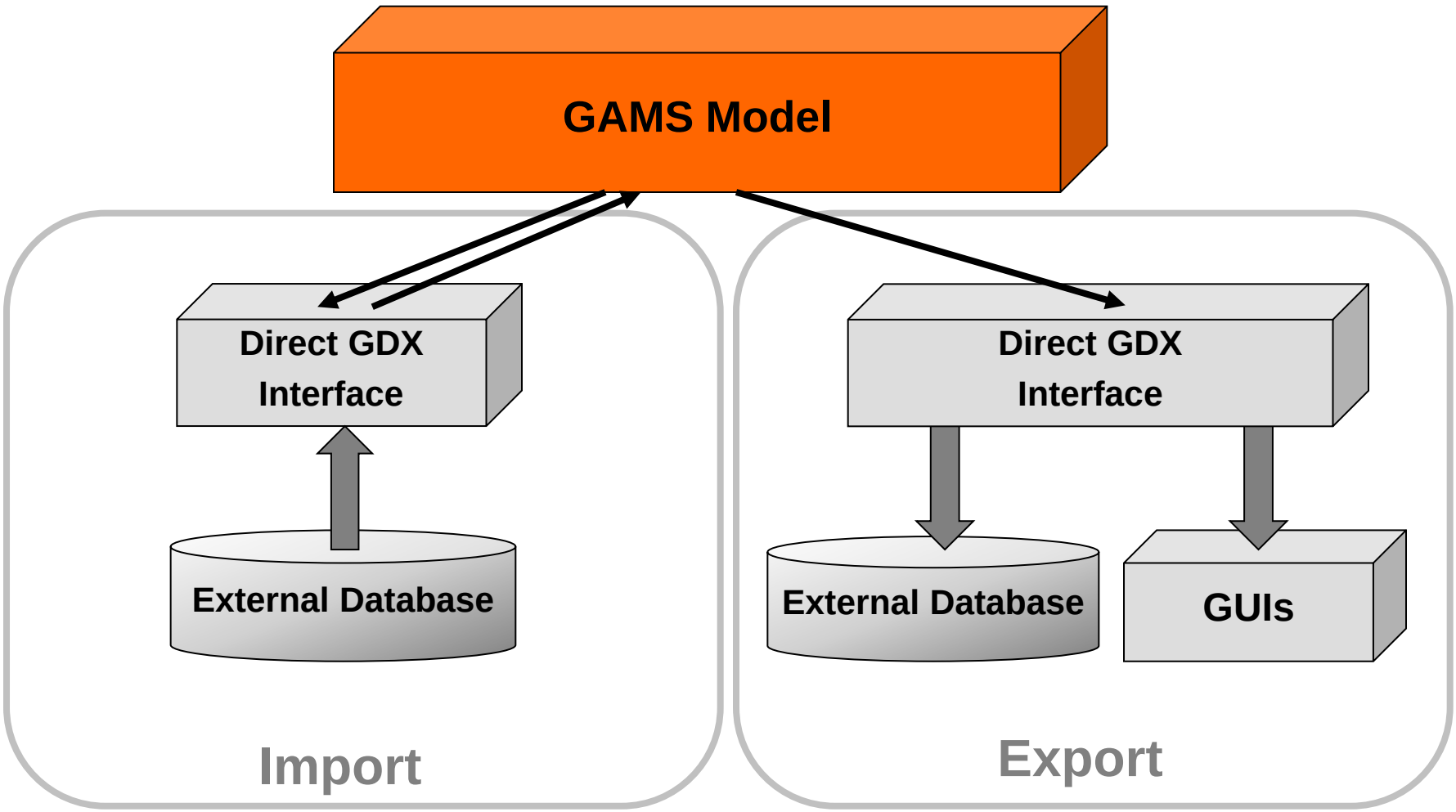


- Fast
- Compact in memory and/or disk space
- Tailored for large sparse data structures
- Platform independent
- Direct GDX interfaces
- API support for high-level programming languages
- No license required

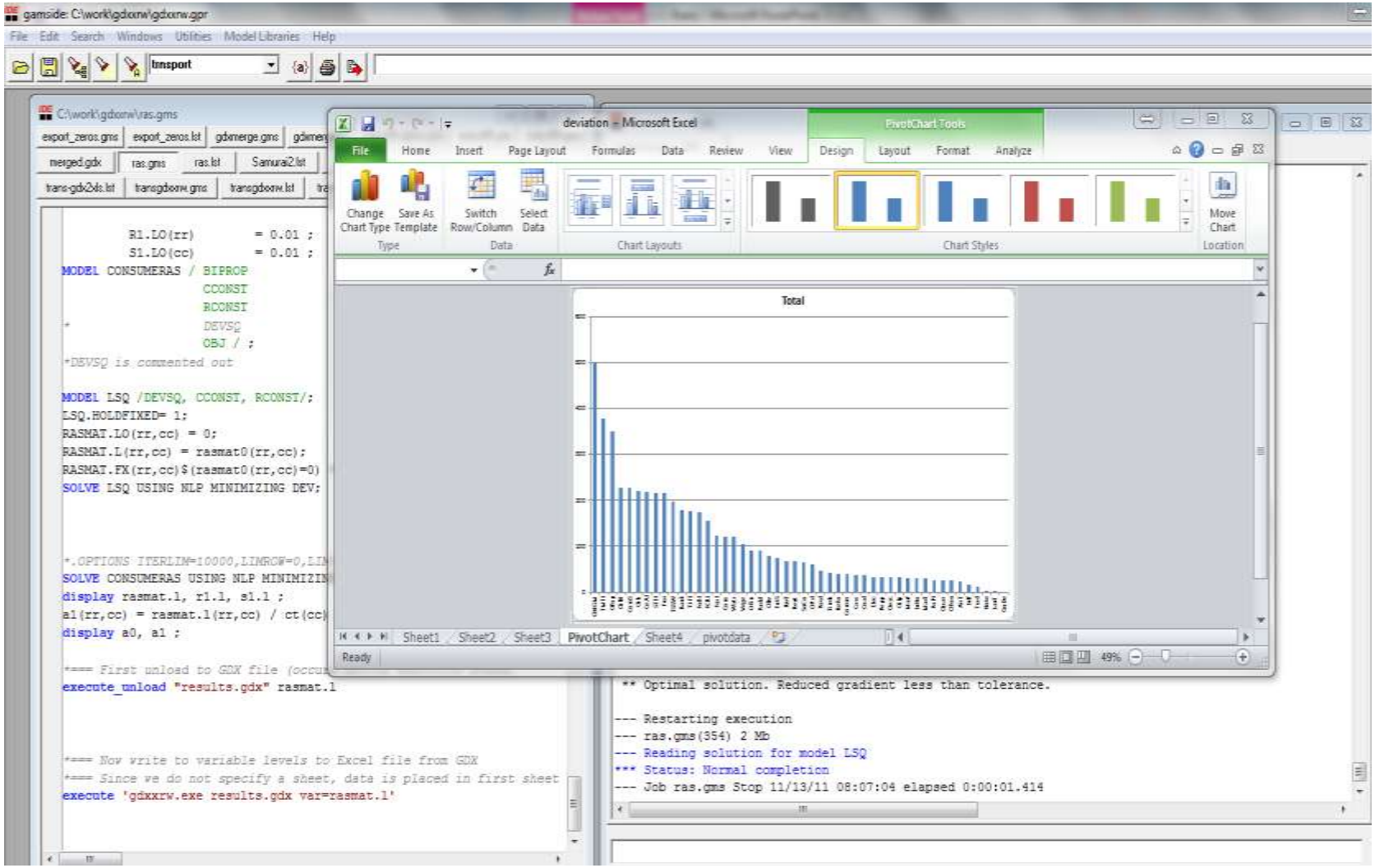
GDX Utilities



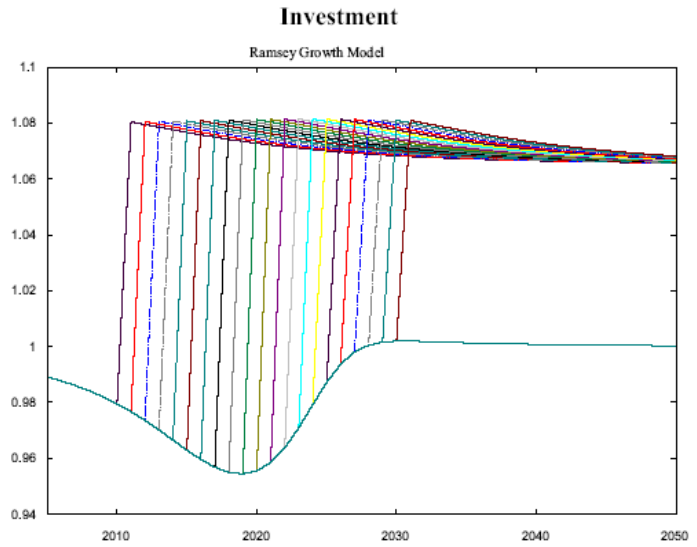
GDX: GAMS in Control

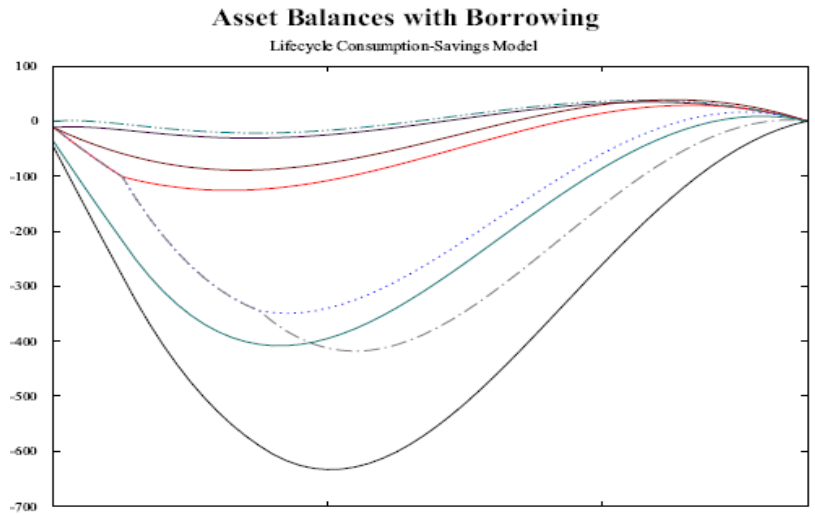


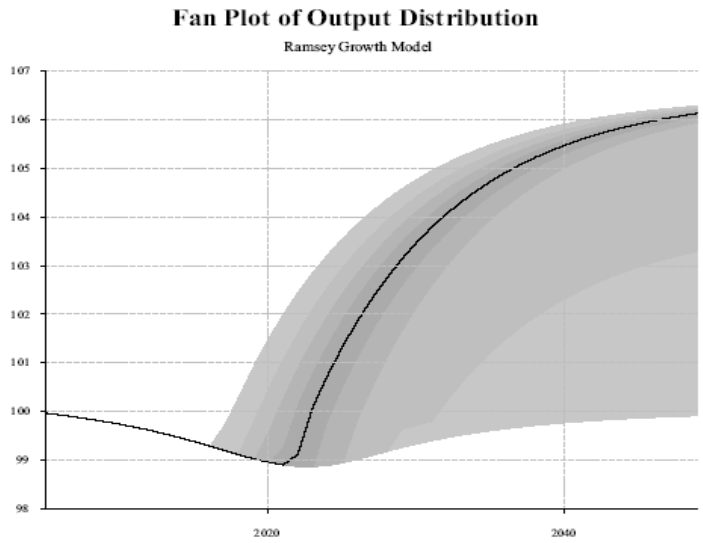
GDX: GAMS in Control

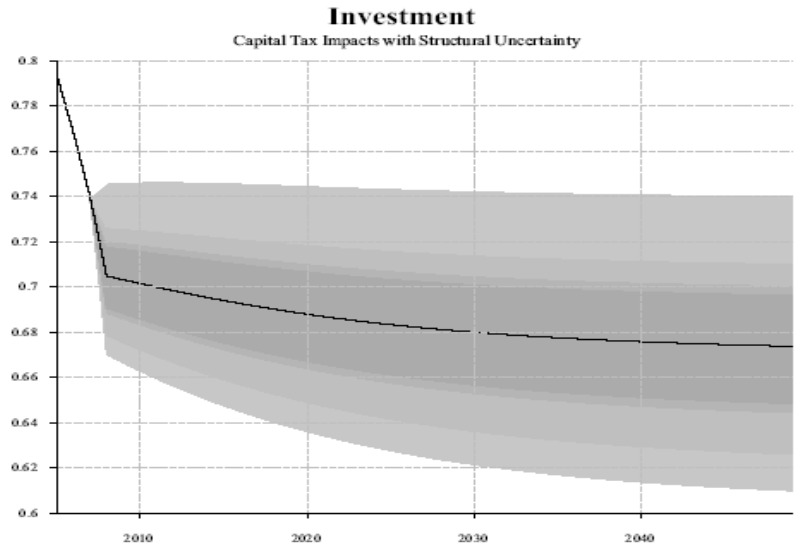


GDX: GNUPLOT

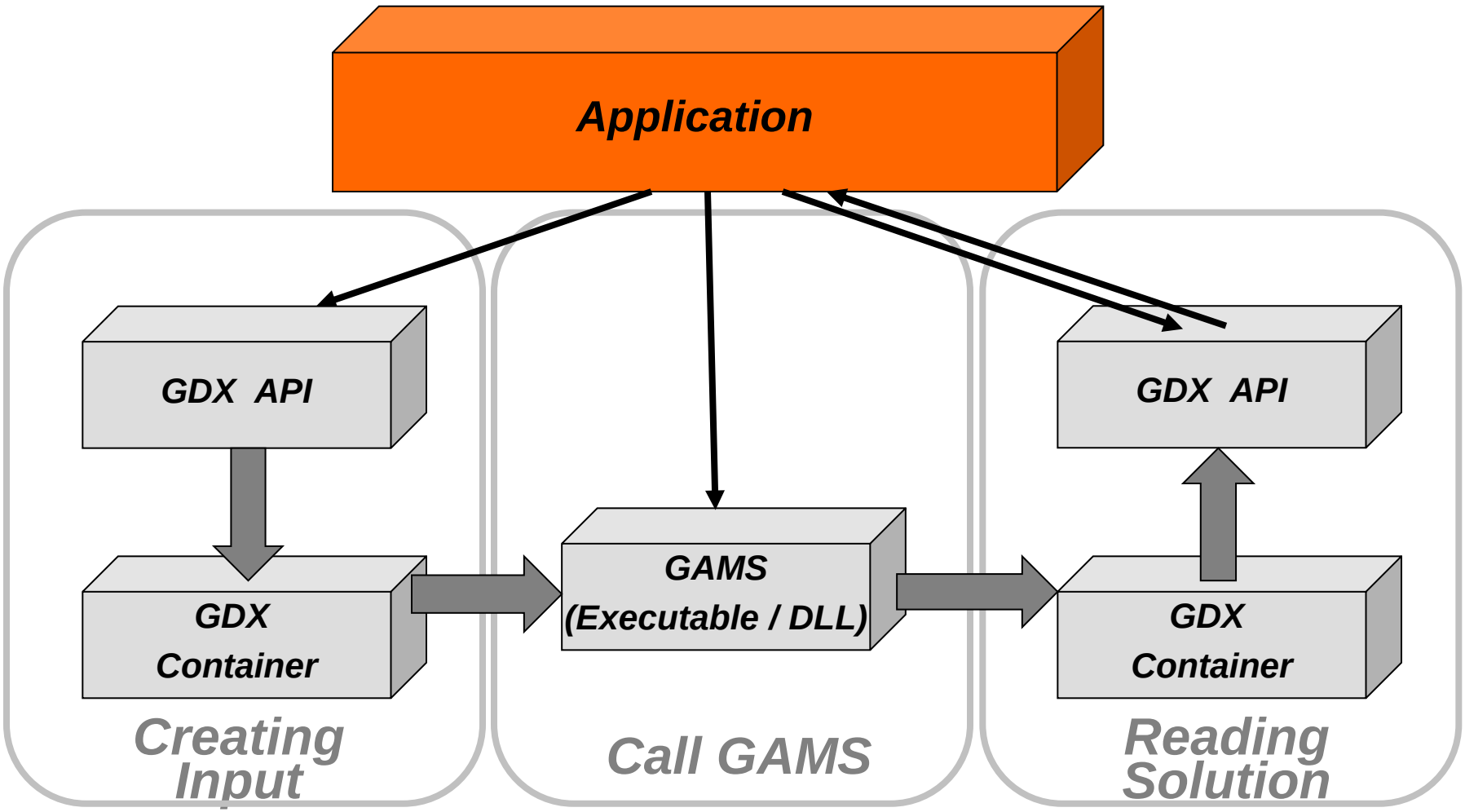

Investment
Ramsey Growth Model
1.1
1.08
1.06
1.04
1.02
1
0.98
0.96
0.94
2010
2020
2030
2040
2050


Asset Balances with Borrowing
Lifecycle Consumption-Savings Model
100
0
-100
-200
-300
-400
-500
-600
-700


Fan Plot of Output Distribution
Ramsey Growth Model
107
106
105
104
103
102
101
100
99
98
2020
2040


Investment
Capital Tax Impacts with Structural Uncertainty
0.8
0.78
0.76
0.74
0.72
0.7
0.68
0.66
0.64
0.62
0.6
2010
2020
2030
2040

GDX: *Application in Control*



GDX: Sudoku-Example (Datalib)

	c1	c2	c3	c4	c5	c6	c7	c8	c9	c10	c11	c12	c13	c14	c15	c16	c17	c18	c19	c20	c21	c22	c23	c24	c25
r1			12				21			11				7					3	17			9		24
r2					17	8		18			11						22				1	13	20		
r3	4	1	2	8	9				3				24	20			6							22	11
r4	21	22	24	23			4	10	5				9	18	1			15			3	8			
r5	11			7		24	6		2	23	17	4			12								15		
r6						17	9	21				15		19					18					16	14
r7				5		4	22	11		10				16	17			12		1	13	9	25		8
r8			6		3		18	1					14	21	7				9	23	19			2	
r9		9		17	8		15	25			12			4			2			11	20		21		
r10		13	7			23	3						20							10		18		4	22
r11	13		18		5	2							4			3				8		1		7	23
r12				16	23			7			1	25			5						24		14		
r13				11	25			12						23	21	20		14	4						
r14	8	12	20	19					23				22		11	24				6			17	10	
r15	14	2					8		19	25	6	16		3	9	11		5		12				20	15
r16	12	17						5		21	18		6			2	9			24	4		10		20
r17	2			1						3					25	19			21	22	16			24	
r18	20			24	16		10						17	1				23		5	18	25		3	
r19		8			14	25	17				24	9	19	5		6			20			11	23	1	
r20			11	25	6	20	1			7			16	14					10	15	17	12			21
r21	22	23				21		16				8			18	7		24				14	13		17
r22		7		15			20			6		24		2	14	13			11	3			5		25
r23	3	21		10		7	25	14	15	19				9		22		6			2				
r24	9					18	5				23	19	15		10			1					11		
r25		16			20	3		24	13	4				17						25		21	12	15	

Letters | Numbers

Solve | Clear solution

GDX: MATLAB

Figure 1: US dollar short rate scenarios

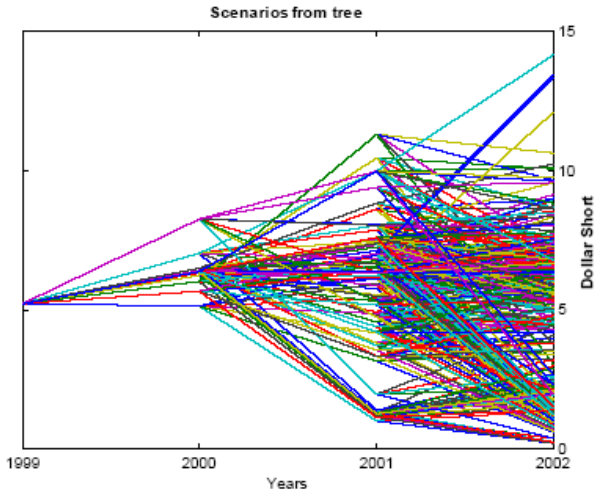
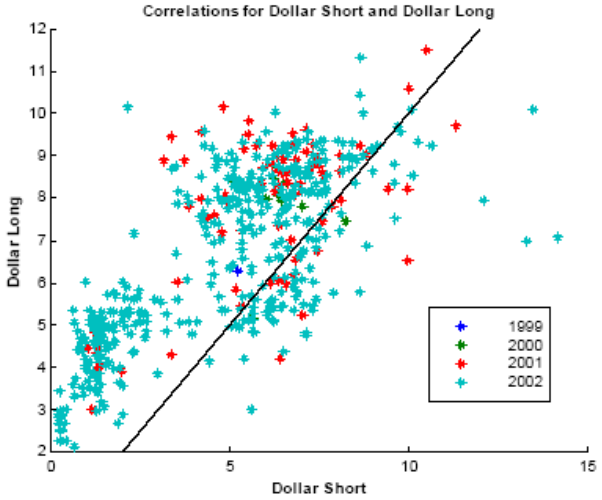
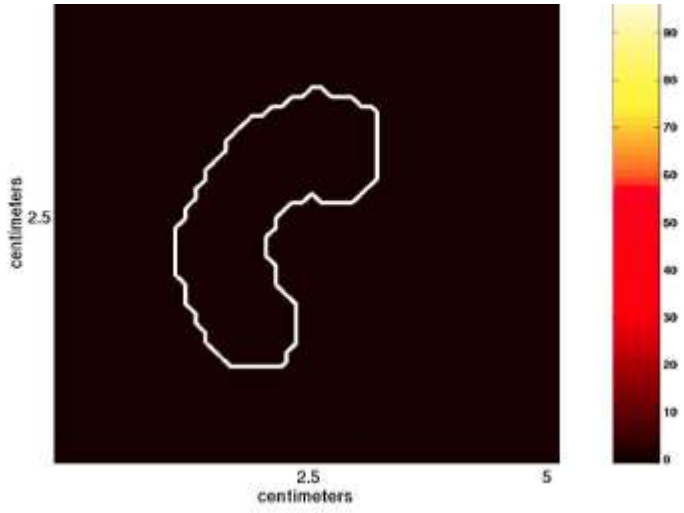
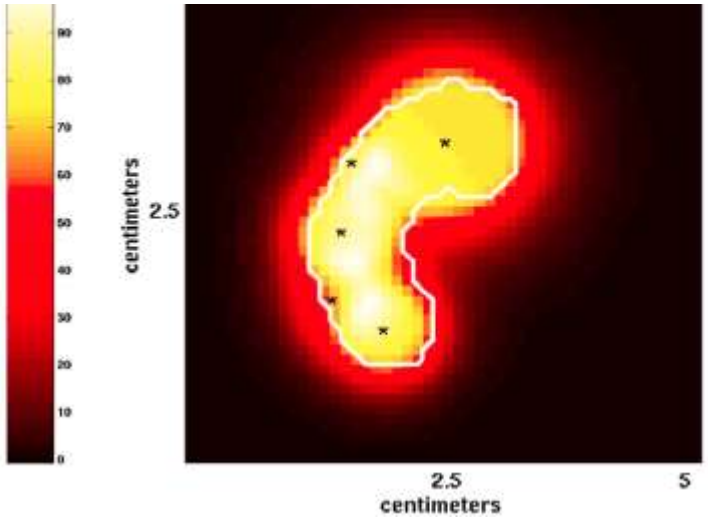


Figure 2: Short vs. long rates



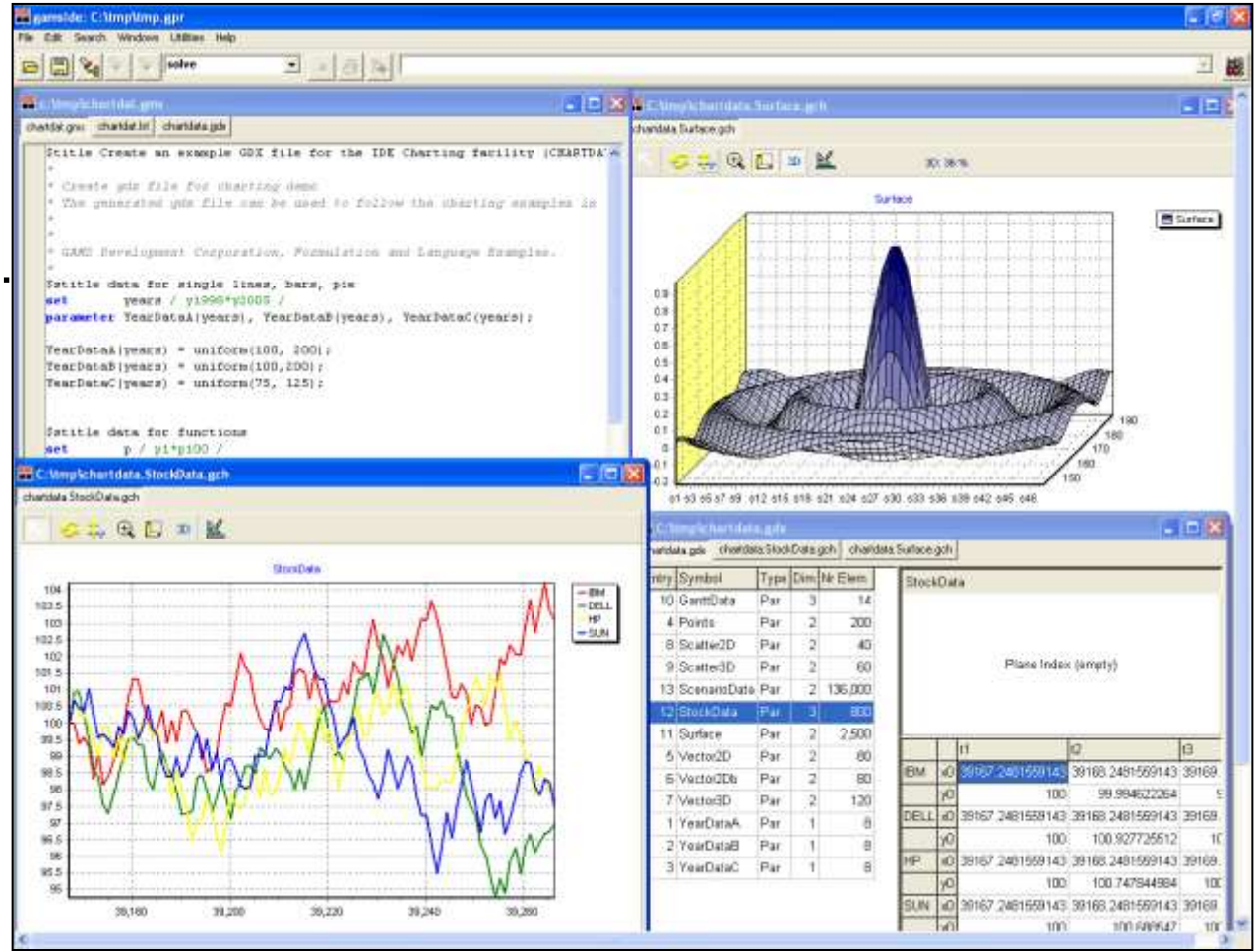




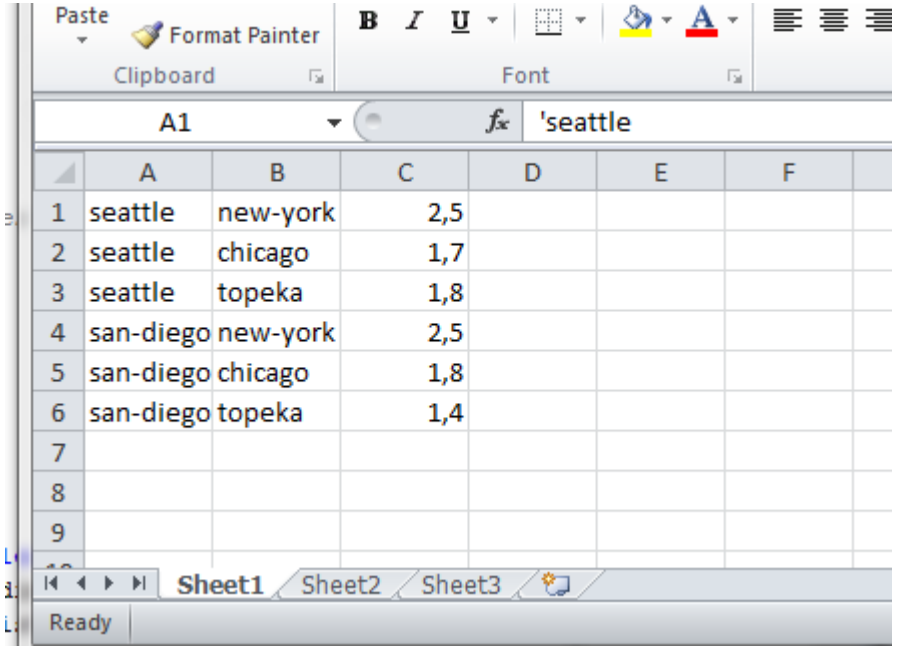
GDX: GDX and the IDE

Using the GDX Viewer

- GDX-Browser
- Data cube
- Drag and drop
- Search engine
- Export to Excel,…
- Charting Engine



GDX: GDXXRW




```
Parameter d(i,j) distance in thousands of miles;
$call GDXXRW dist.xlsx par=d rng=A1 rdim=2 cdim=0
$if errorlevel 1 $abort "Problem with file dist.xls!"
$gdxin dist
$load d
```

GDX: GDXDiff

GDX file differ

Input file one

C:\InformsSD2009\cplex.gdx

Input file two

C:\InformsSD2009\xpress.gdx

Difference file

Eps: 1e-8

RelEps: 0.0

Ignore Set text

Field to compare: All fields

FldOnly

DiffOnly

OK

Cancel

canaldiv: Differences

Level

Marginal

Lower

Upper

		dif1	dif2
05-mr	apr	0.044400	0.016300
	jul	0.216000	0.244100
06-sad	may	0.332000	0.331352
	jun	0.332000	0.328327

GDX: CSV Output (gdxdump)

```
gdxdump results symb=x format csv
```

```
"Dim1","Dim2","Val"
"seattle","new-york",50
"seattle","chicago",300
"seattle","topeka",0
"san-diego","new-york",275
"san-diego","chicago",0
"san-diego","topeka",275
```

Challenge 2

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

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

→ How to automate the transformations by annotations of existing optimization models that convey model structure to the solver.

EMP

Extended Math. Programming

EMP: Current state: Model-Side

- Traditional problem format

$$\min_{x} c(x) \quad s.t.\ A_1(x) \le b_1,\ A_2(x) = b_2$$

- Support for complementarity constraints
- Interactions between models possible
  - Series of models
  - Scenario analysis / parallel model runs (grid)
  - Iterative sequential feedback
  - Decomposition

EMP: Less-traditional concepts

- Global Optimization
  - **BARON, LINDOGLOBAL**
    - Proven global optimum
    - Require full problem algebra – point derivatives not enough
    - Achieved by model rewriting / syntax translation (CONVERT)
- Solving non-integer models as MCPs
  - **PATHNLP**
    - Reformulation via KKT conditions (1st and 2nd order deriv.)
- MP with Equilibrium Constraints (MPEC)
  - **NLPEC**
    - Solves MPECs via reformulation as NLPs
    - NLP problems are written out and processed by GAMS

EMP: New solution concepts

- Embedded Complementarity Systems
- Disjunctive Programs
- Bilevel Programs
- Extended Nonlinear Programs
- Variational Inequalities
- Stochastic Programming
- …

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

EMP: Some Helpful Facts

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

EMP: What now?

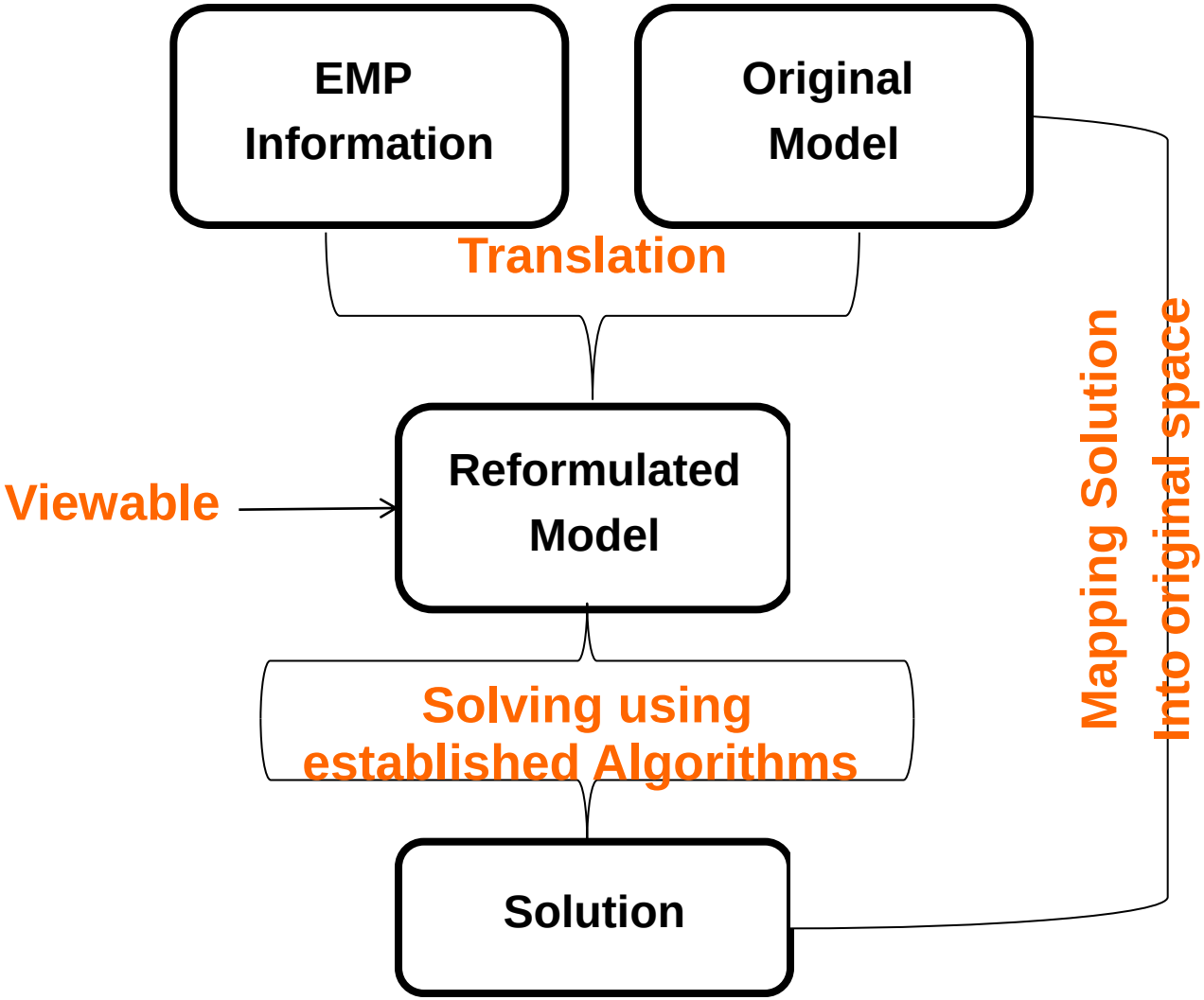
Do not:

- overload existing GAMS notation right away !
- attempt to build new solvers right away !

But:

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

EMP: GAMS "Solver" JAMS



EMP: Information File + Summary Log

```
randvar om1 discrete 0.25 1
                     0.25 2
                     0.25 3
                     0.25 4
randvar om2 discrete 0.3333 1
                     0.3334 2
                     0.3333 3
chance E1 0.6
chance E2 0.6
```

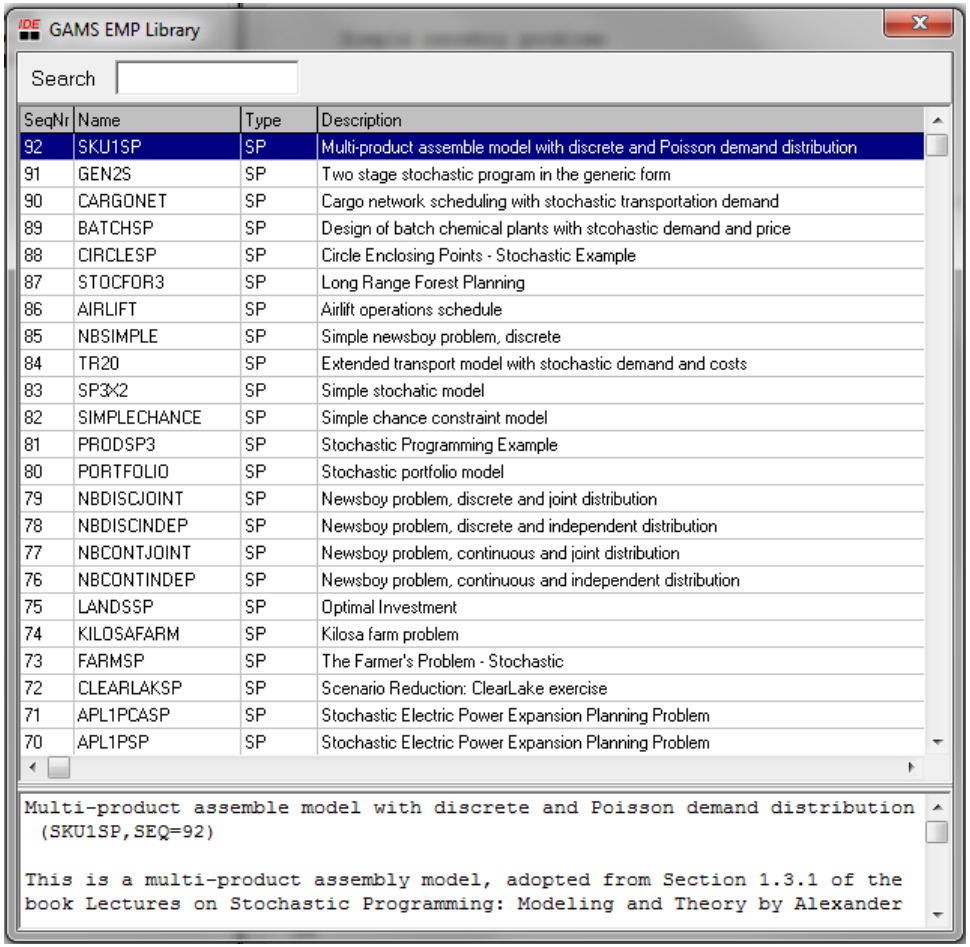
```
--- EMP Summary
    Logical Constraints = 0
    Disjunctions        = 7
    Adjusted Constraint = 0
    Flipped Constraints = 0
    Dual Variable Maps  = 0
    Dual Equation Maps  = 0
    VI Functions        = 0
    Equilibrium Agent   = 0
    Bilevel Followers   = 0
```

EMP: Examples

GAMS EMP-Library

- Distributed with GAMS

- SP:
  - Single-Stage
  - Multi-Stage
  - Chance Cons.



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

Challenge 3

- Building and maintaining solver specific links in different programming languages became a huge resource sink and made the introduction of new features difficult

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

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

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

GMO

Gams Modeling Object

Gams Modeling Object (GMO)

GAMS' Next-Generation Model API

- Why a new model API?
- What do we need it to do?
- What does it look like? How is it put together?
- How did we do it?
- When are we going to be finished?

GMO: Solver Links – Different Perspectives

GAMS User

- Standardized solver interface allows “hassle free” replacement of solvers: *option nlp=conopt;*

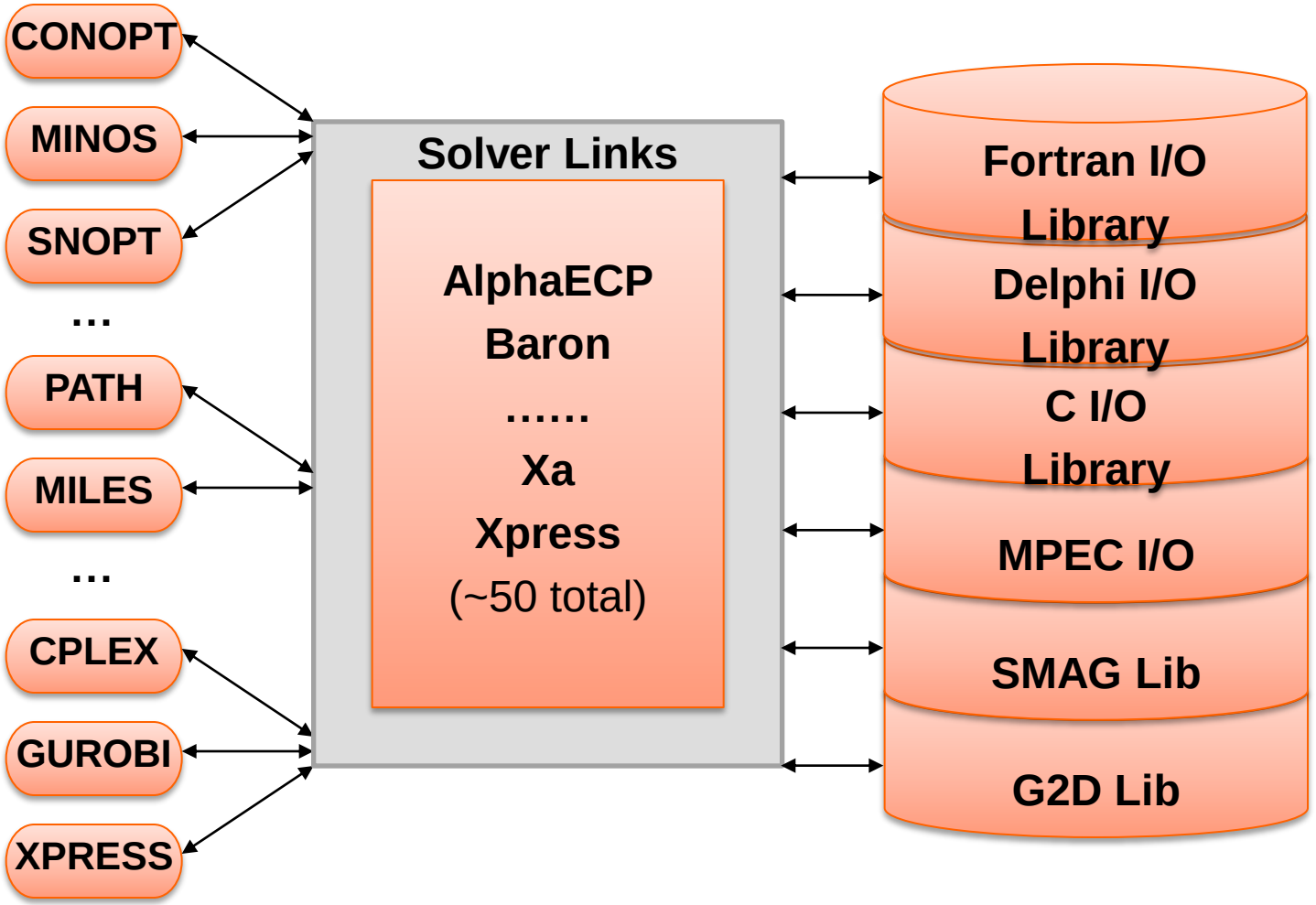
…nothing will change

Solver & Solver-link Developer

- IO Library provides access to
  - Matrix
  - Function/Gradient/Hessian evaluations
  - Solution file writer
  - Output handling
  - GAMS Options (e.g. resource limit)
  - Problem attributes (SOS, semicont, semiint, priorities, scales)
  - Utility routines
  - problem rewriting, matrix reordering

…our focus here

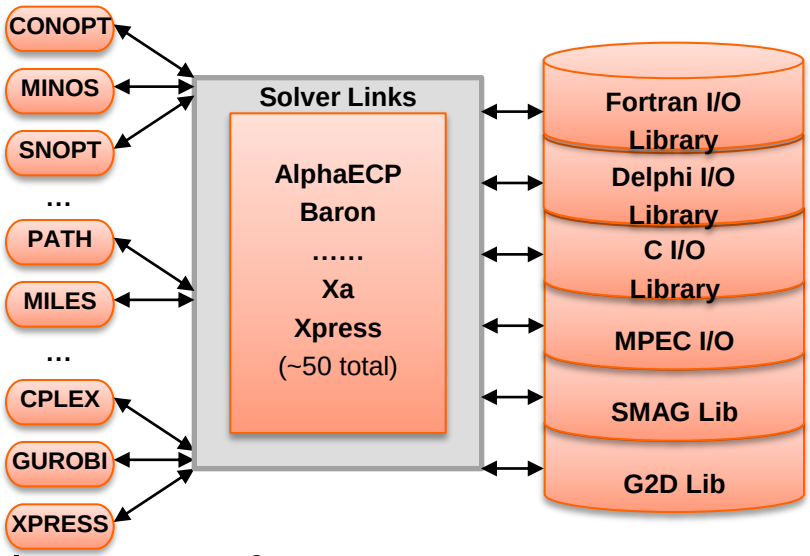
GMO: Reuse - what's that?!?



GMO: Multiple I/O Libraries

Advantages

- proven over many years
- all platforms supported
- all GAMS-features available

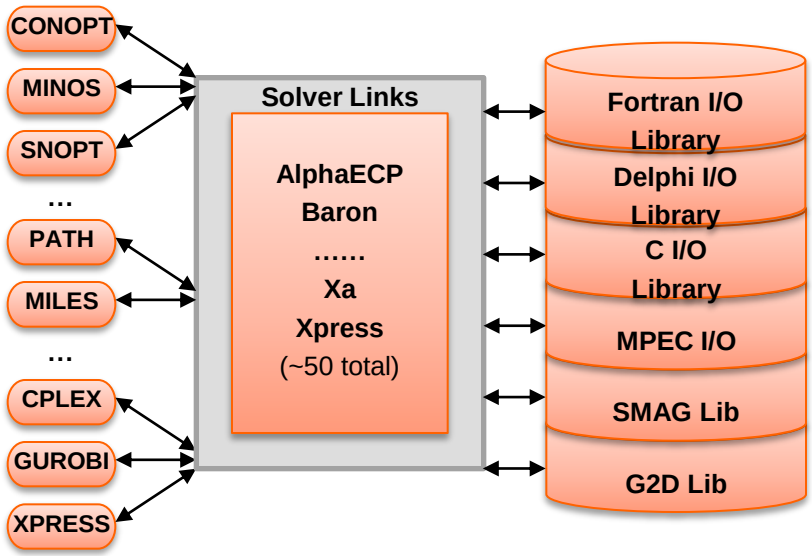


- written by language experts, use all language features
- resulted in high-quality links across solvers and platforms
  → has been one factor in our success

GMO: Multiple I/O Libraries

Disadvantages

- inconvenient & expensive to maintain
- Not always intuitive to use
- Outdated design – I/O, STOP

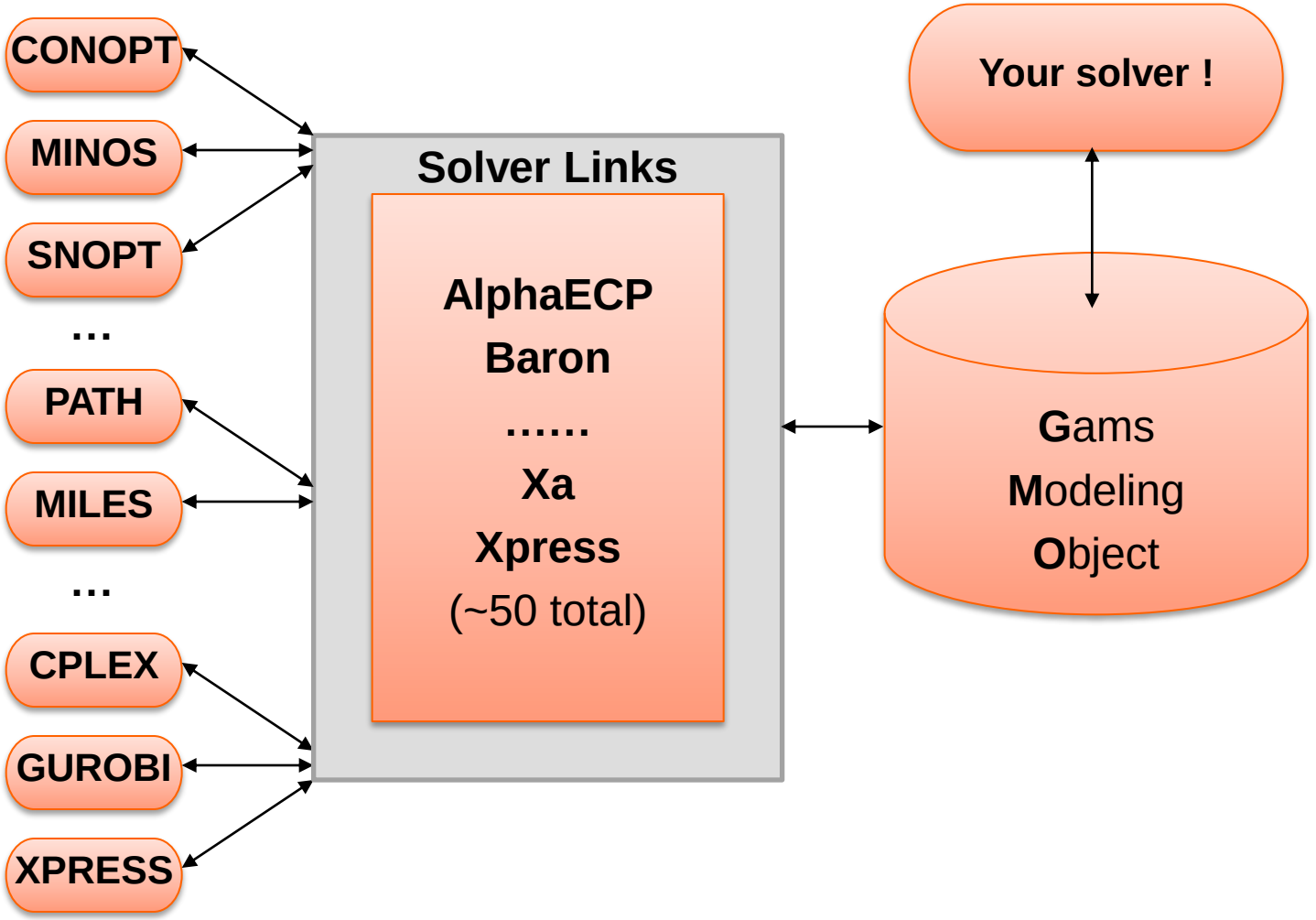


- feature-poor (e.g. no automatic reformulation of objective func/var)
- linking your solver (without buddy at GAMS) is very difficult

GMO: Checklist

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

GMO: Summary

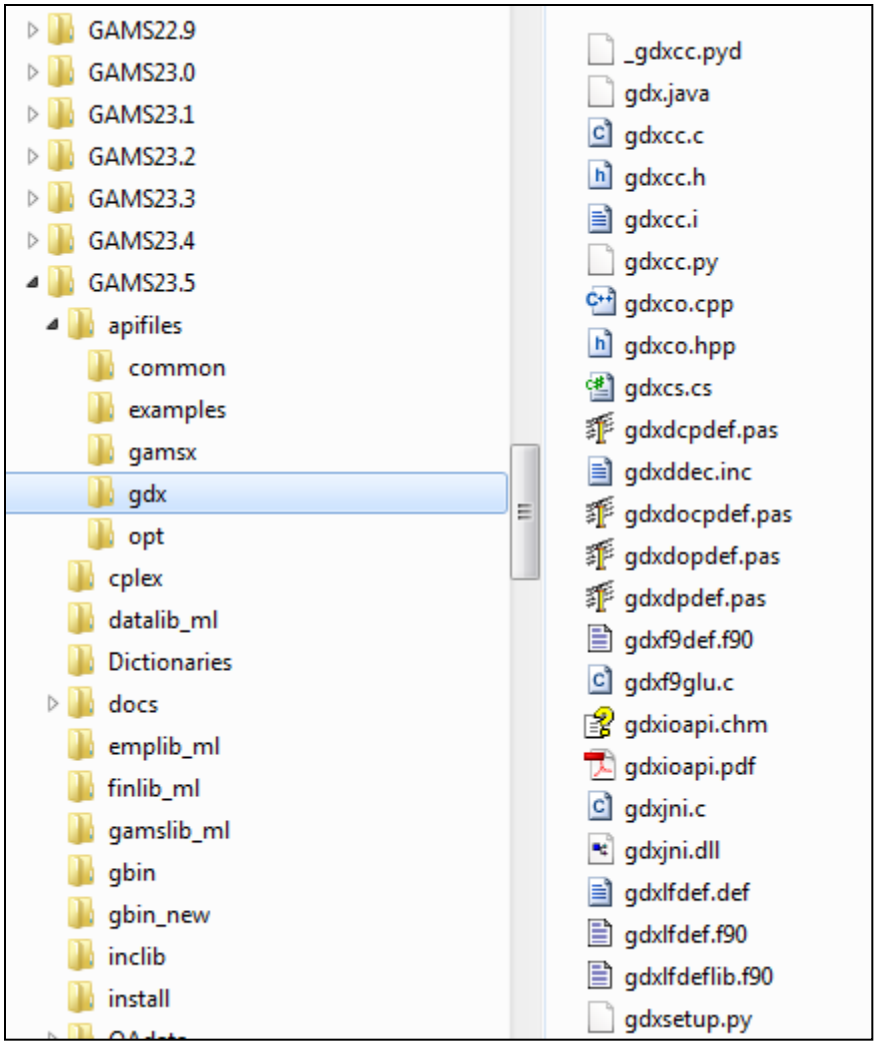

CONOPT
MINOS
SNOPT
…
PATH
MILES
…
CPLEX
GUROBI
XPRESS
Solver Links
AlphaECP
Baron
……
Xa
Xpress
(~50 total)
Your solver !
Gams
Modeling
Object

GMO: Implement Once, Run Everywhere

- All GMO coding done in a single language and style
  - Allows code sharing with other components
  - Allows for shared development
- All GMO coding is platform-independent
  - Makes writing code faster, more reliable
  - Maintenance is simplified
- Platform-dependent code isolated in utility libraries
  - Makes adding a new platform easier
  - Maintenance is simplified
  - Unit testing is easy and effective

Distributed GAMS APIs

- Component Libraries
  - GAMS
  - GDX
  - Option
- Supported languages
  - C, C++, C#
  - Delphi
  - Fortran
  - Java
  - VBA, VB.Net
  - Python
- Examples/Documentation



Challenge 4

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

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

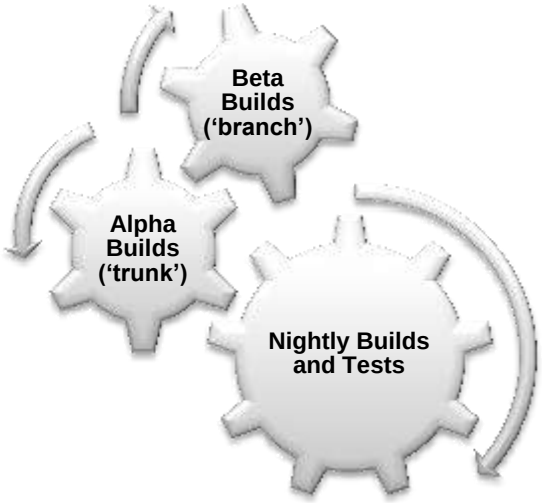
QA
Quality Assurance

Key components of SQA

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

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

  - → Public Test Libraries
  - → Performance comparison tools
  - → Solution verification tools
  - → Proactive Software Development Lifecycle



Quality Assurance at GAMS

Quality Test Models Library

- Include tests to verify proper behavior of the system
- More than 550 quality test models (included in the distribution), each containing numerous pass/fail tests
- Continuous quality improvement using automated and reproducible tests (> 20.000 solves for each platform)
- Automatic generated test summaries with different levels of information

Quality Assurance at GAMS

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

- Requires changes to the model of the clients to allow automated pass/failure tests
- Includes:
  - Ability to solve (= no bugs)
  - Returns the same solution back
  - Similar or better performance
- Gives clients assurance that their application will also work with new GAMS releases
- Improves communication between development team and clients (specific wishes)

Summary

What is GAMS

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

Market Demands:

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

Challenges and Solutions

- GDX
- GMO
- EMP
- Quality Assurance

Thank You !

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