GAMS

Rapid Development of Optimization-based Decision Support Applications

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EURO XXII PRAGUE

July 11th 2007

Agenda

- GAMS Development / GAMS Software
- GAMS at a Glance
- Recent Enhancements
- Summary

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GAMS

- Roots: Research project World Bank, 1976
- Pioneer in Algebraic Modeling Systems
- Went commercial in 1987
- GAMS Development Corp. (Washington, D.C)
- GAMS Software GmbH (Cologne)

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

Typical Application Areas *

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

*** Illustrative examples in the GAMS Model Library**

GAMS Solutions Specialists Network

TELEGYR SYSTEMS

UNIVERSITY APPS. INC.

Verbund

JK

OPTIENCE

ETSAP

EcoMod Net

Profit Point Inc.

PCS

VA TECH SAT

SAT AUTOMATION

COPENHAGEN ECONOMICS

BARKAWI

ECOPLAN

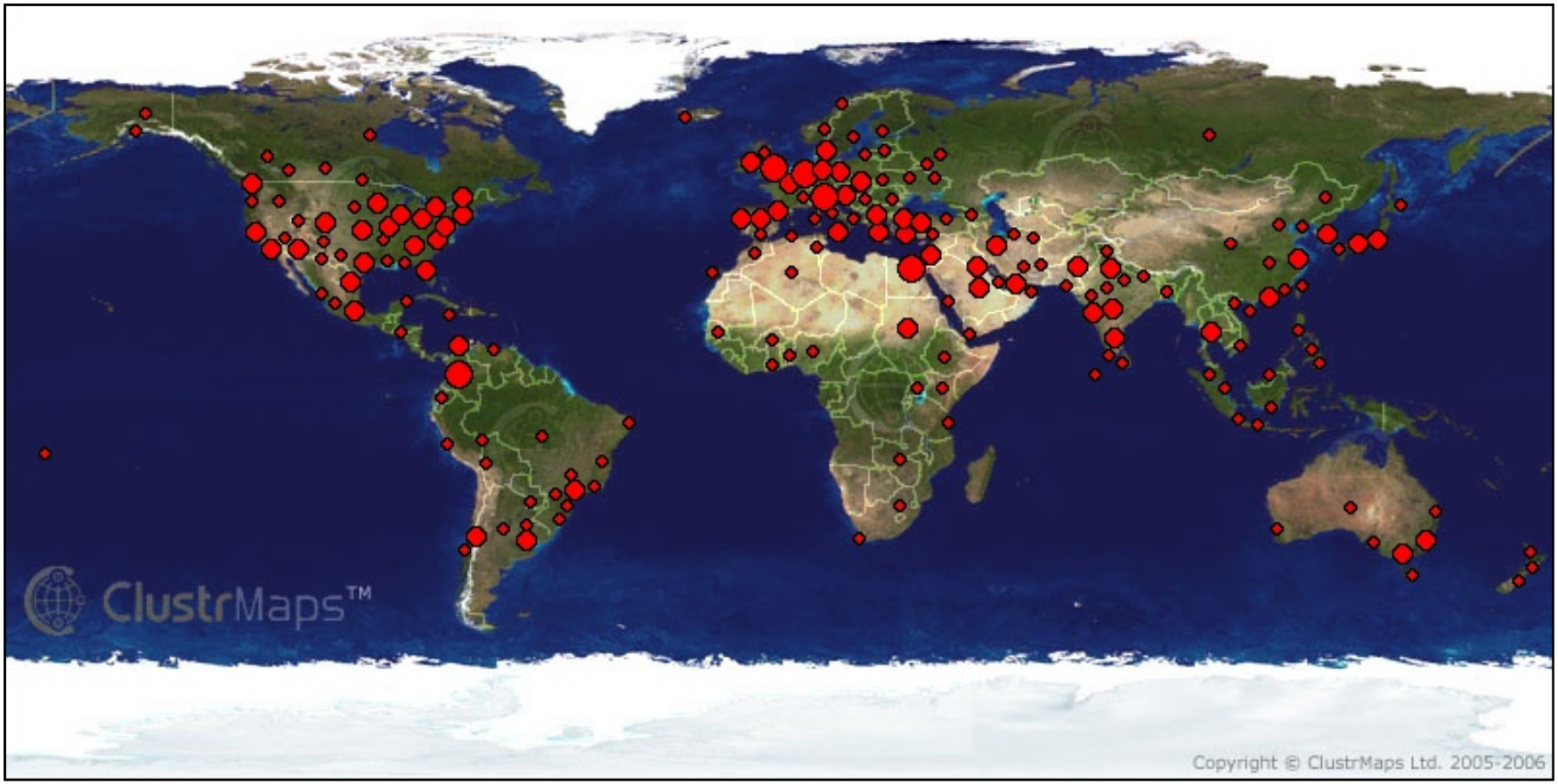
iiT

BALMOREL

Companies with wide experience in GAMS modeling

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

Academic + Commercial Users Worldwide



Downloads

Total Downloads of Distribution 22.5 since 2007-06-01: 2308

Sorted by Platform:

- 2 AIX
- 6 AXU
- 51 Darwin
- 39 Linux64
- 107 Linux32
- 16 Solaris (x86)
- 13 Solaris (Sparc)
- 1821 Windows32
- 253 Windows64

~ 500 downloads per Week

Algebraic Modeling Languages

- High-level programming languages for large scale mathematical optimization problems
- Algebraic formulation
  - § Syntax similar to mathematical notation
  - § Does not contain any hints how to process it
- Do not solve optimization problems directly, but call appropriate external algorithms (solvers)

Goals

- Support of decision making process
- Efficient handling of mathematical optimization problems
- Simplify model building and solution process
- Increase productivity and support maintainable models

Agenda

- GAMS Development / GAMS Software
- **GAMS at a Glance**
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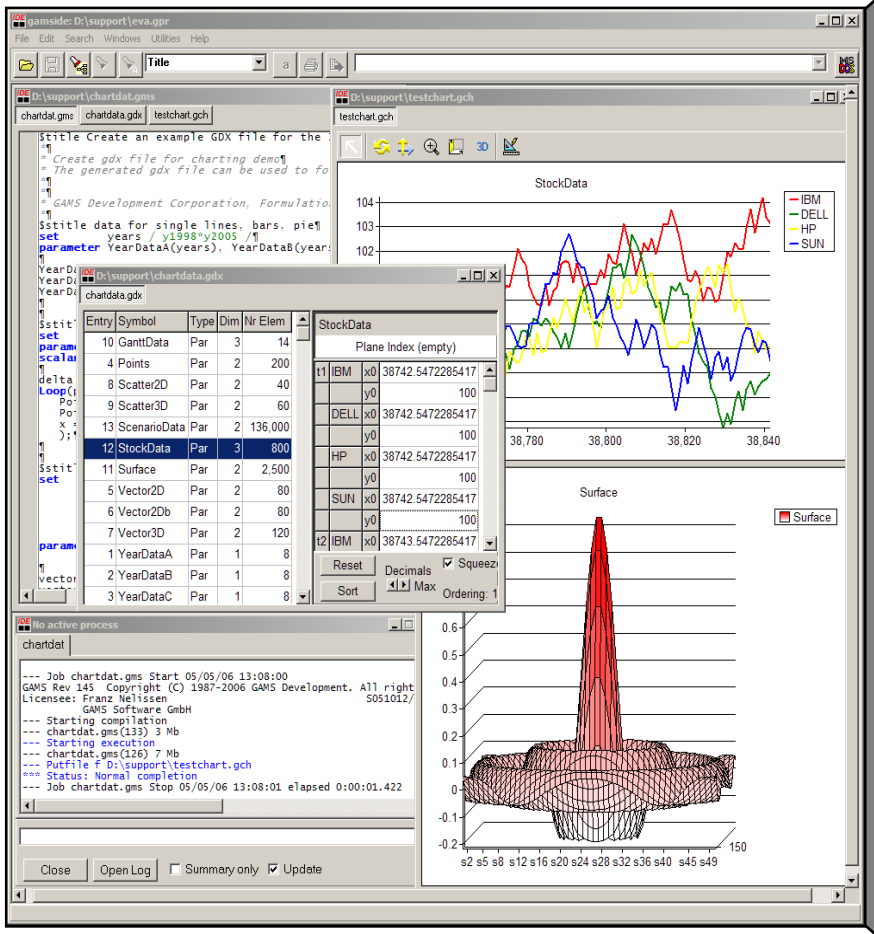
GAMS at a Glance

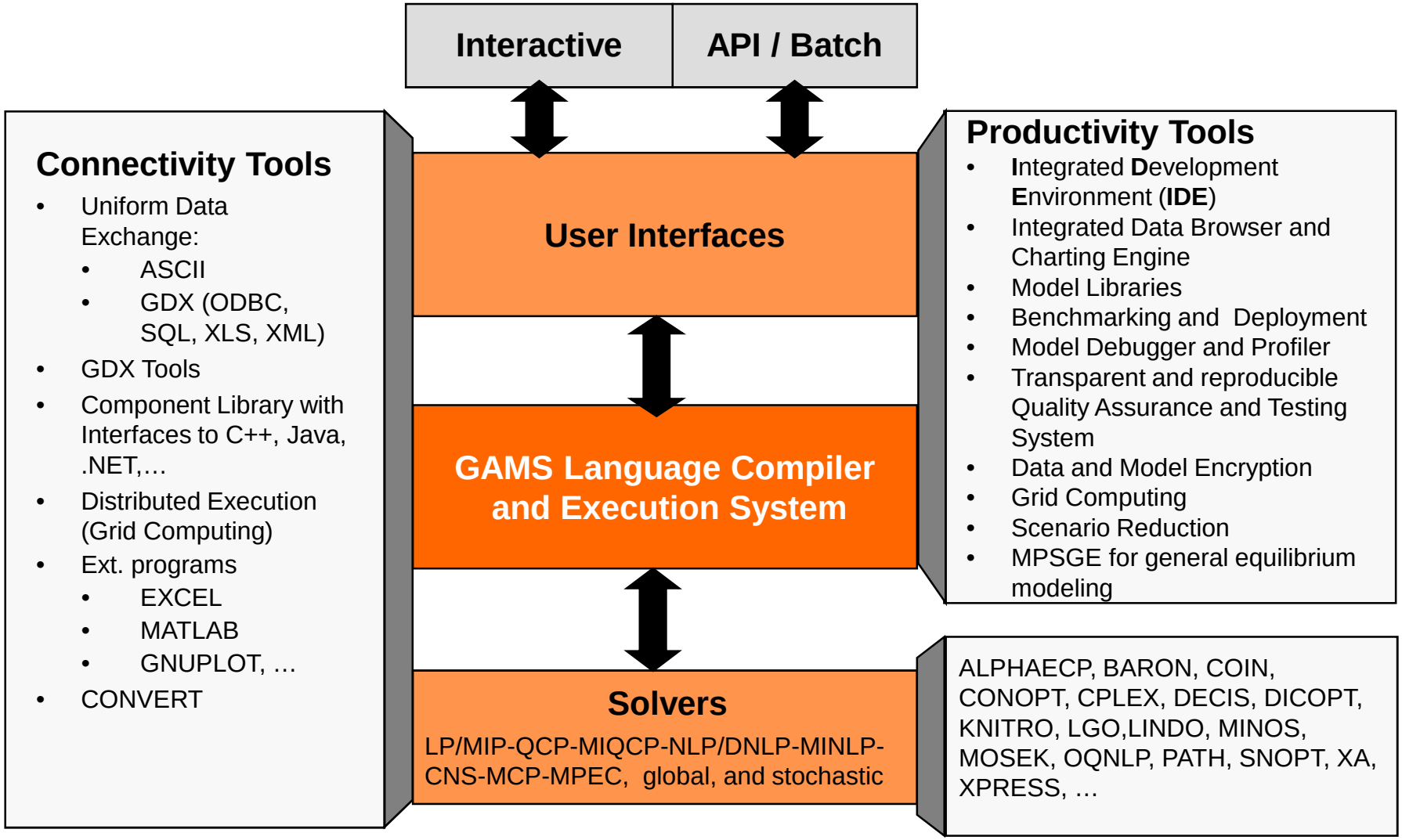


General **A**lgebraic **M**odeling **S**ystem:
Algebraic Modeling Language, Integrated Solver, Model Libraries, Connectivity- & Productivity Tools

Design Principles:

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

System Overview



Multiple Solvers & Platforms

Solver/Platform availability - 22.5 June 1, 2007											
	x86 MS Windows	x86_64 MS Windows	x86 Linux	x86_64 Linux	Sun Sparc SOLARIS	Sun Intel SOLARIS	HP 9000 HP-UX 11[1]	DEC Alpha Digital Unix 4.0	IBM RS-6000 AIX 4.3	Mac PowerPC Darwin	SGI IRIX[2]
ALPHAECP	✔	✔	✔	✔	✔	✔		✔	✔	✔	
BARON 7.8	✔	32bit	✔	32bit					✔		
BDMLP	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
COIN	✔	32bit	✔	✔						✔	
CONOPT 3	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
CPLEX 10.1	✔	✔	✔	✔	✔	✔	10.0	8.1	✔		9.1
DECIS	✔	✔	✔	✔	✔		✔	✔	✔		✔
DICOPT	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
KNITRO 5.1	✔	32bit	✔	✔						✔	
LINDOGLOBAL 4.1	✔	✔	✔	✔	✔					✔	
LGO	✔	✔	✔	✔	✔	✔	✔	✔		✔	✔
MILES	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
MINOS	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
MOSEK 4	✔	✔	✔	✔	✔		3.2			✔	
MPSGE	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
MSNLP	✔	✔	✔	✔	✔		✔			✔	
NLPEC	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
OQNLP	✔	32bit	✔	32bit							
OSL V3	✔	32bit	✔	32bit	✔		V2		✔		V2
OSLSE	✔	32bit	✔	32bit	✔				✔		
PATH	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
SBB	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
SNOPT	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
XA	✔	32bit	✔	✔	✔		✔	✔	✔		
XPRESS 17.10	✔	32bit	✔	32bit	✔		16.10		✔		
[1]GAMS distribution for HP 9000/HP-UX is 22.1.											
[2]GAMS distribution for SGI IRIX is 22.3.											
Contributed Plug&Play solvers											
AMPLwrap	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	
DEA	✔	✔	✔	✔	✔	✔		✔	✔		
Kestrel	✔	32bit	✔	32bit	✔						
For backward compatibility we maintain older versions of operating systems and solvers. Please call.											

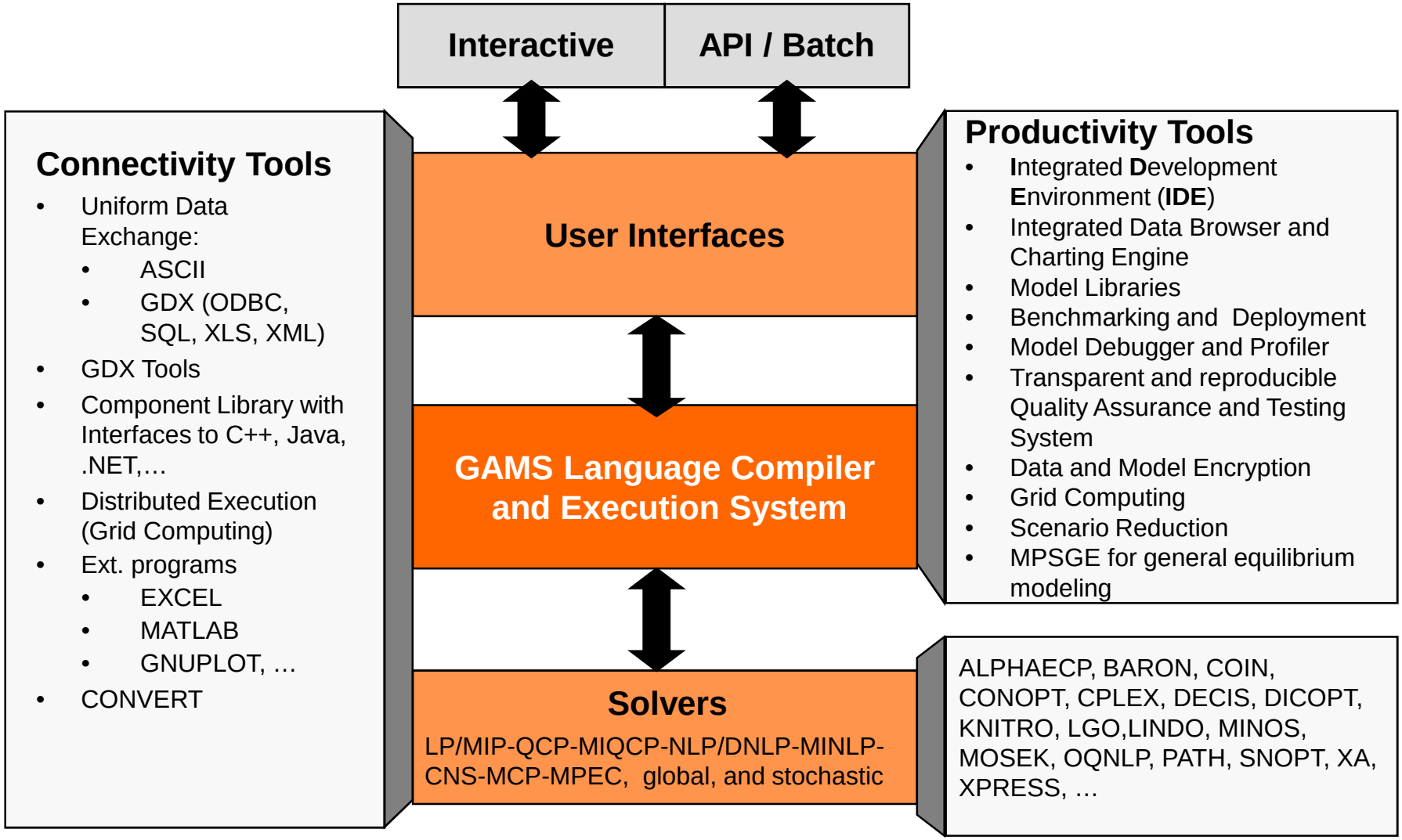
Multiple Model Types

- LP Linear Programs
- MIP Mixed Integer Programs
- QCP Quadratically Constrained Programs
- MIQCP Quadratically Constrained MIPs
- NLP Nonlinear Programs
- DNLP NLP with Discontinuous Derivatives
- MINLP Mixed Integer Nonlinear Programs
- MCP Mixed Complementarity Programs
- MPEC NLP with Complementarity Constraints
- CNS Constrained Nonlinear Systems
- Stochastic Optimization
- Global Optimization

Multiple Solver & Model Types

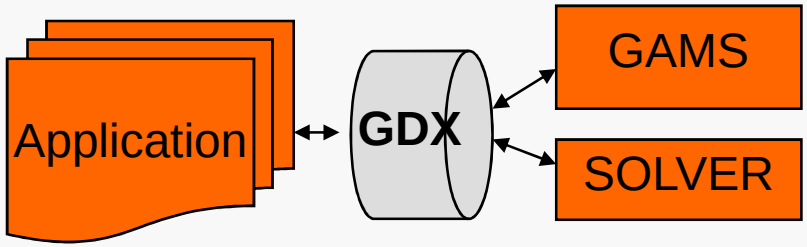
Solver/Model type availability - 22.5 June 1, 2007												
	LP	MIP	NLP	MCP	MPEC	CNS	DNLP	MINLP	QCP	MIQCP	*Stock.*	*Global*
ALPHAECP								✔		✔		
BARON 7.8	✔	✔	✔				✔	✔	✔	✔		✔
BDMLP	✔	✔										
COIN	✔	✔										
CONOPT 3	✔		✔			✔	✔		✔			
CPLEX 10.1	✔	✔							✔	✔		
DECIS	✔										✔	
DICOPT								✔				
KNITRO 5.1	✔		✔				✔		✔			
LINDOGLOBAL 4.1	✔	✔	✔				✔	✔	✔	✔		
LGO	✔		✔				✔		✔			✔
MILES				✔								
MINOS	✔		✔				✔		✔			
MOSEK 4	✔	✔	✔				✔		✔	✔		
MPSGE												
MSNLP			✔				✔		✔			✔
NLPEC				✔	✔							
OQNLP			✔				✔	✔	✔	✔		✔
OSL V3	✔	✔										
OSLSE	✔										✔	
PATH				✔		✔						
SBB								✔		✔		
SNOPT	✔		✔				✔		✔			
XA	✔	✔										
XPRESS 17.10	✔	✔							✔			
Contributed Plug&Play solvers												
AMPLwrap	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
DEA	✔	✔										
Kestrel	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔

System Overview



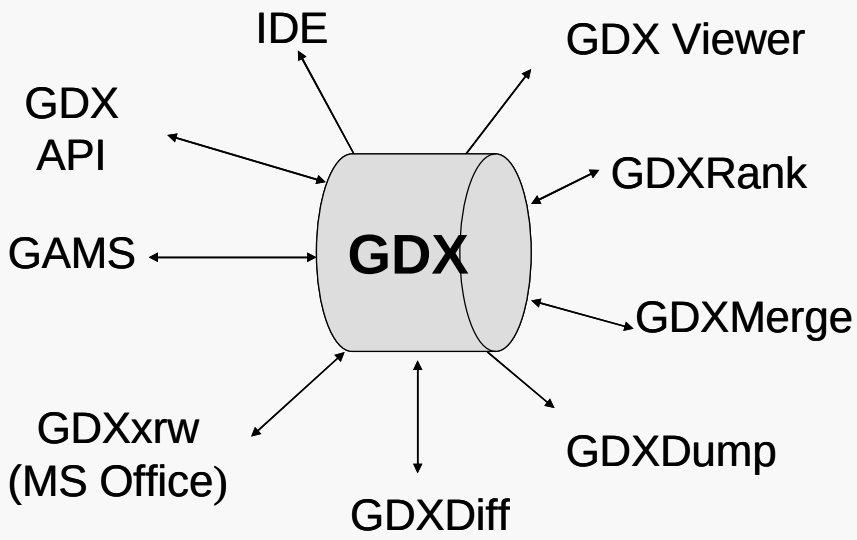
Gams Data eXchange

Binary Data Exchange

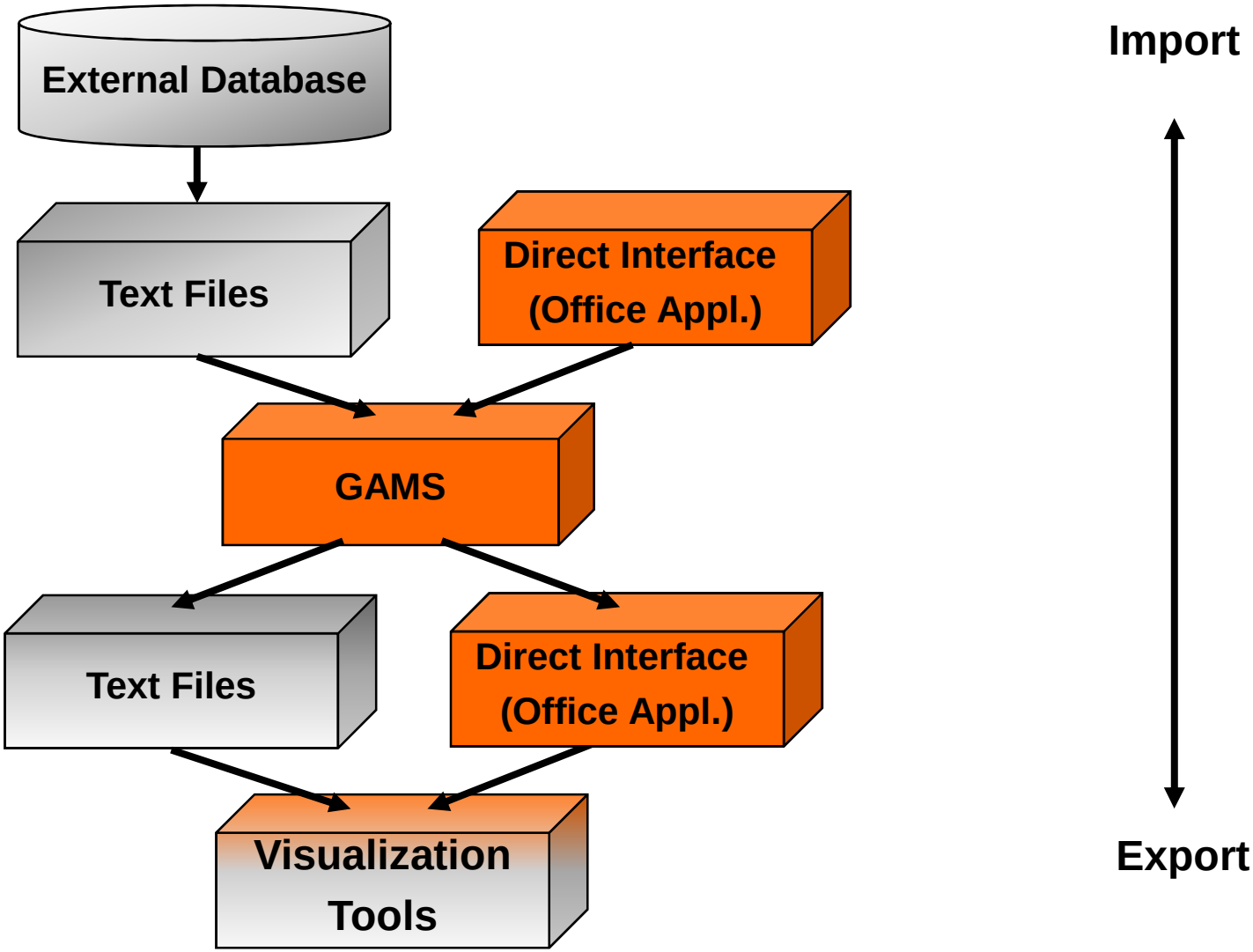


- Fast exchange of data
- Syntactical check on data before model starts
- Data Exchange at any stage (Compile and Run-time)
- Platform Independent
- Direct Excel connectivity
- General API
- Scenario Management Support
- Full Support of Batch Runs

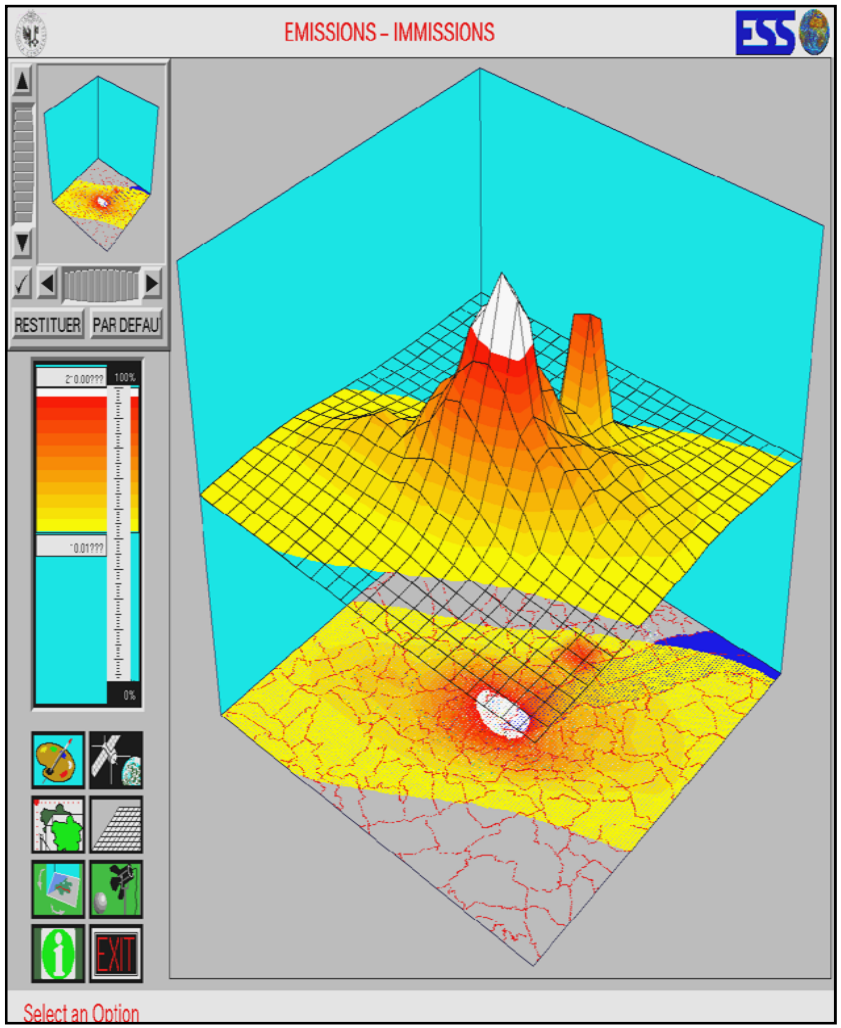
GDX Tools

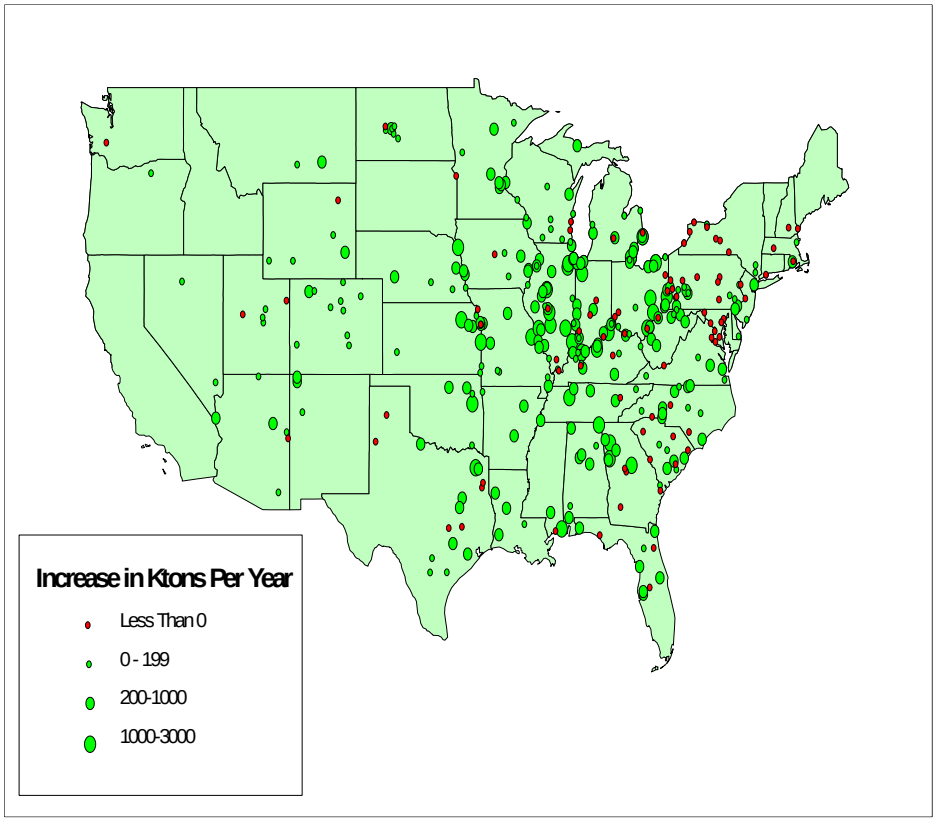


GAMS in Control



Interfacing with GIS Applications





Interfacing with MATLAB

Figure 1: US dollar short rate scenarios

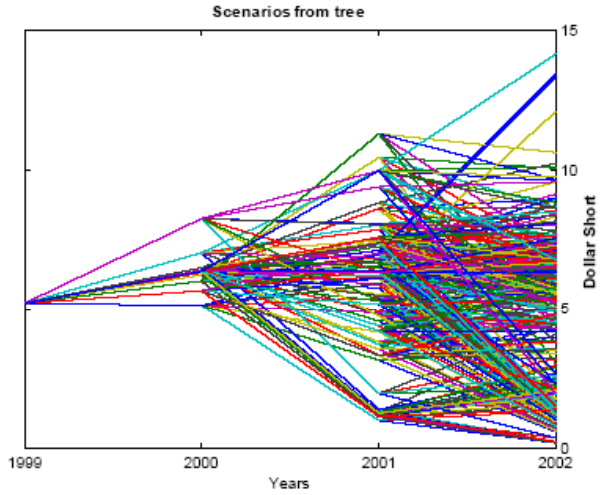
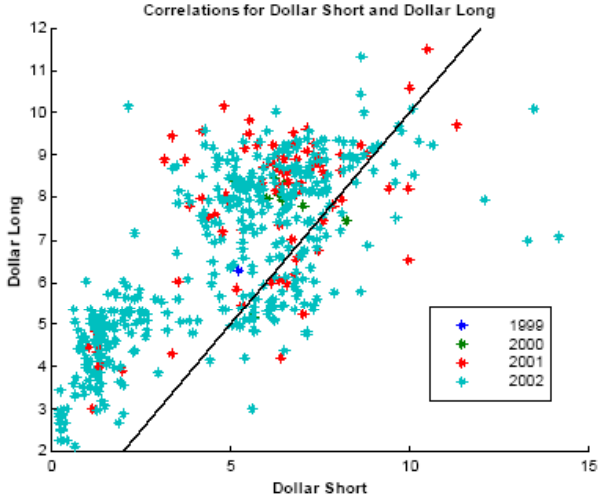
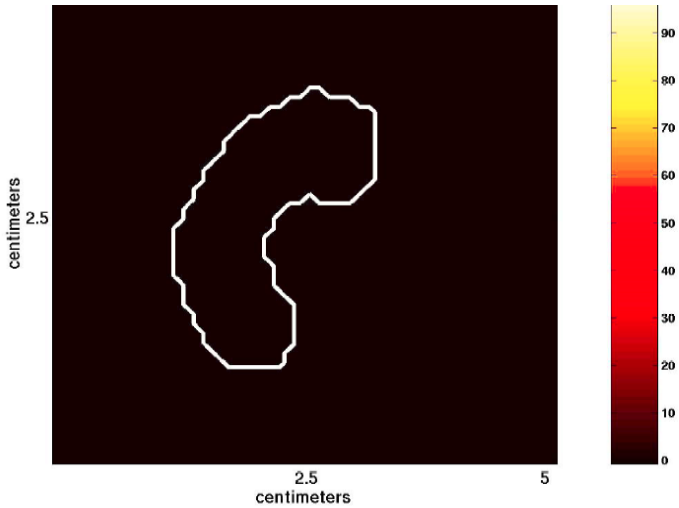
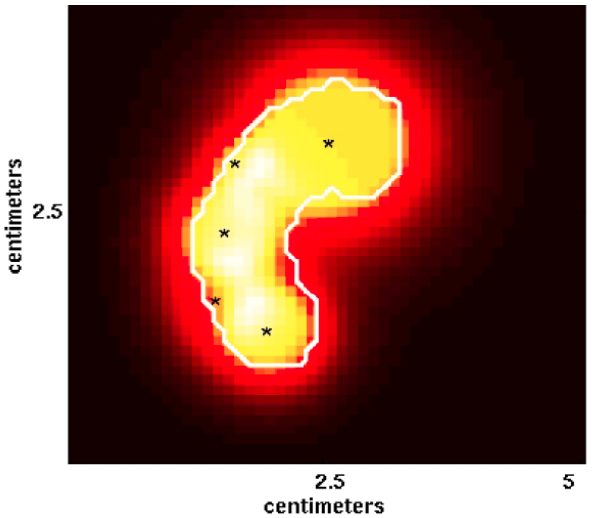


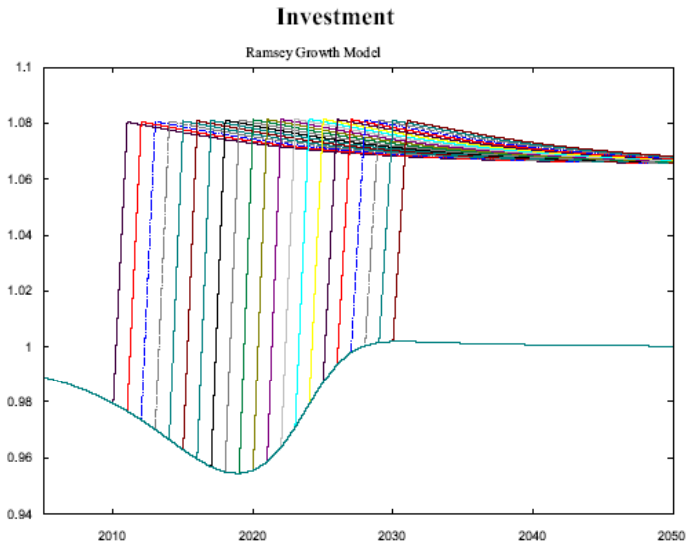
Figure 2: Short vs. long rates

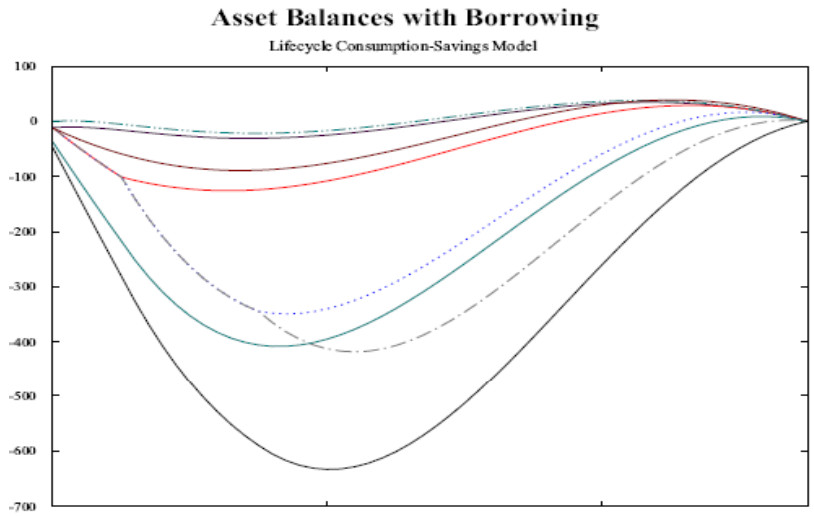


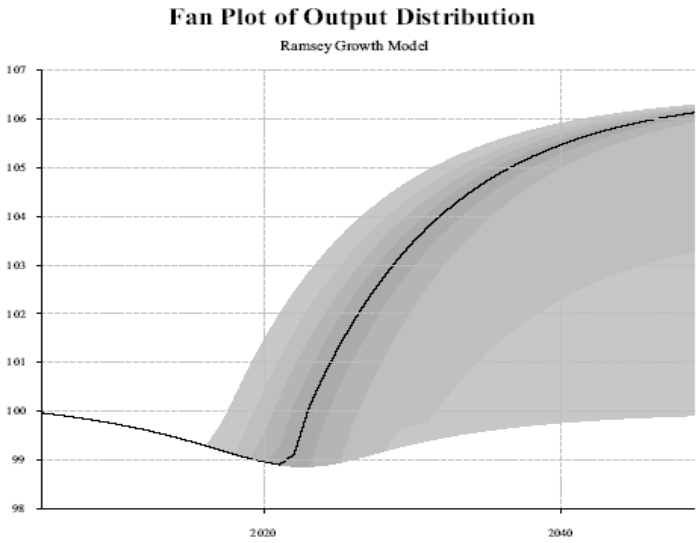


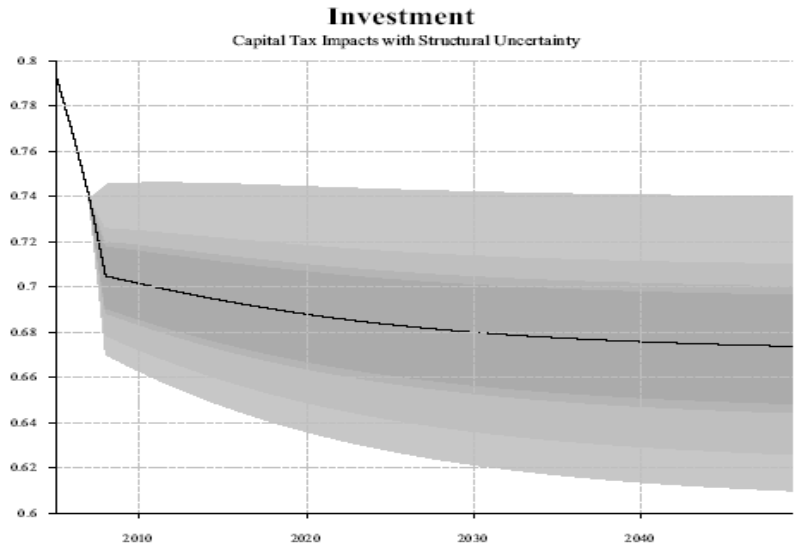


Interfacing with GNUPLOT









Interfacing with Web Applications

Cadet Schedules with Constraint Violations, AYT 2001-1

Header Information

Select Constraint Type: 3 FREE HOUR CONSTRAINT

Filter by:

Free Hour Violations: 43

Design Group Violations: 4

Unbalanced Schedule Violations: 7

Cadets With Schedule Violations — FREE HOUR CONSTRAINT

Course	Total Enrollment	Name	SSN	Grad Yr	Reviewed
EM362A		BASS, WILLIE C.	[redacted]	2002	
PH365		BROWN, JAMEY A.		2002	
EM362A		BUNTING, BRIAN M.		2002	
EM301A		CHONOWSKI, DAVID P.		2002	
EN302		COOPER, GRAIG W.		2002	
EM301A		CULLUMBER, CRAIG M.		2002	
EM362A		DONNELL, TYLER R.		2002	
EM362A		EDGAR, BENJAMIN T.		2002	

Cadets: 43

Details

Course Hours

Name: BASS, WILLIE C.

FOS1: Civil Engineering Major

FOS2:

Eng Seq Activity Code(s): CSWV

TQPA: 2.414

CQPA: 2.699

(3) 1 Day

(3) 2 Day

Hour	Course	Violation	Override
A	PE310		
B	MA364		
C	PL300		
D	PL300		
E	EM362A	FREE HOUR CONSTRAINT	
F	EM362A	FREE HOUR CONSTRAINT	

Z Hour

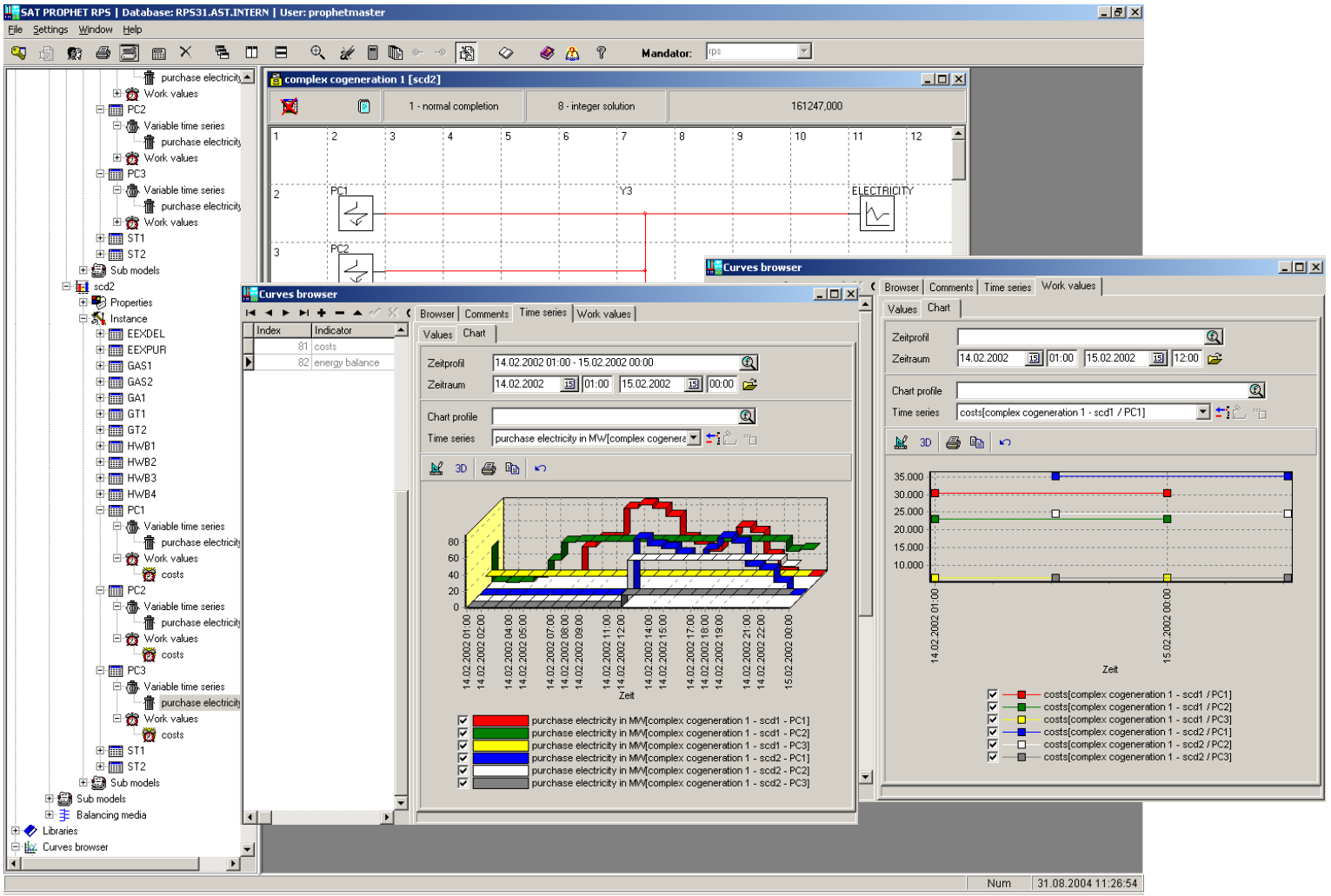
Hour	Course	Violation	Override
G	SS307		
H	HI301		
I	EM364A		
J	EM364A		
K	, R		
L			

Schedule

OK

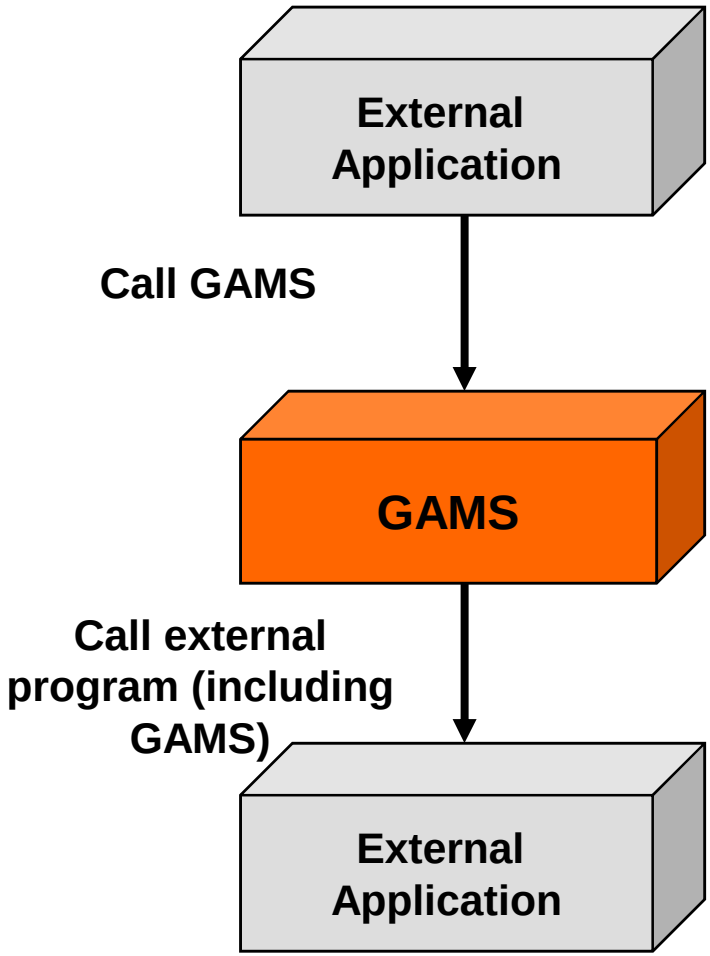
Close

Interfacing with Individual Front Ends



SAT-PROPHET

Application in Control



Programming Language or other Application

Application

Samurai Sudoku

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W
1																							
2			8						6						2						3		
3		4	7						5	1				3	7						8	9	
4				5	8		1	9								5	7		3	1			
5				9		5		6								9		5		4			
6					1		6										8		9				
7				3		7		2								4		7		3			
8				4	5		3	1								2	4		7	6			
9		5	3						2	4				1	3						7	4	
10			6						3			2			4						2		
11											4		6										
12										3				8									
13											3		8										
14			5						7			1			8						1		
15		2	4						9	1				7	2						9	8	
16				9	8		2	6								9	7		6	2			
17				2		4		9								3		2		4			
18					2		7										6		3				
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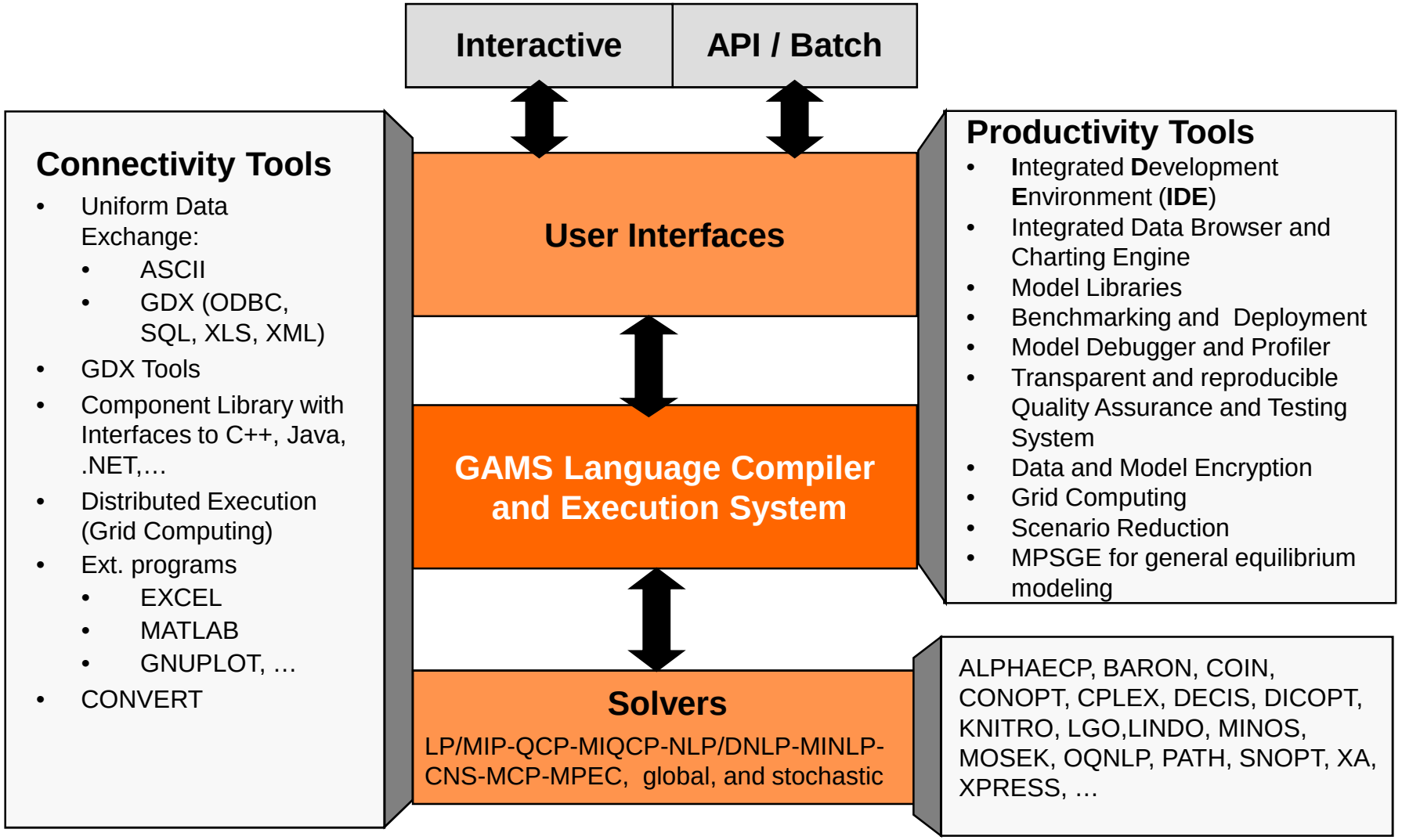
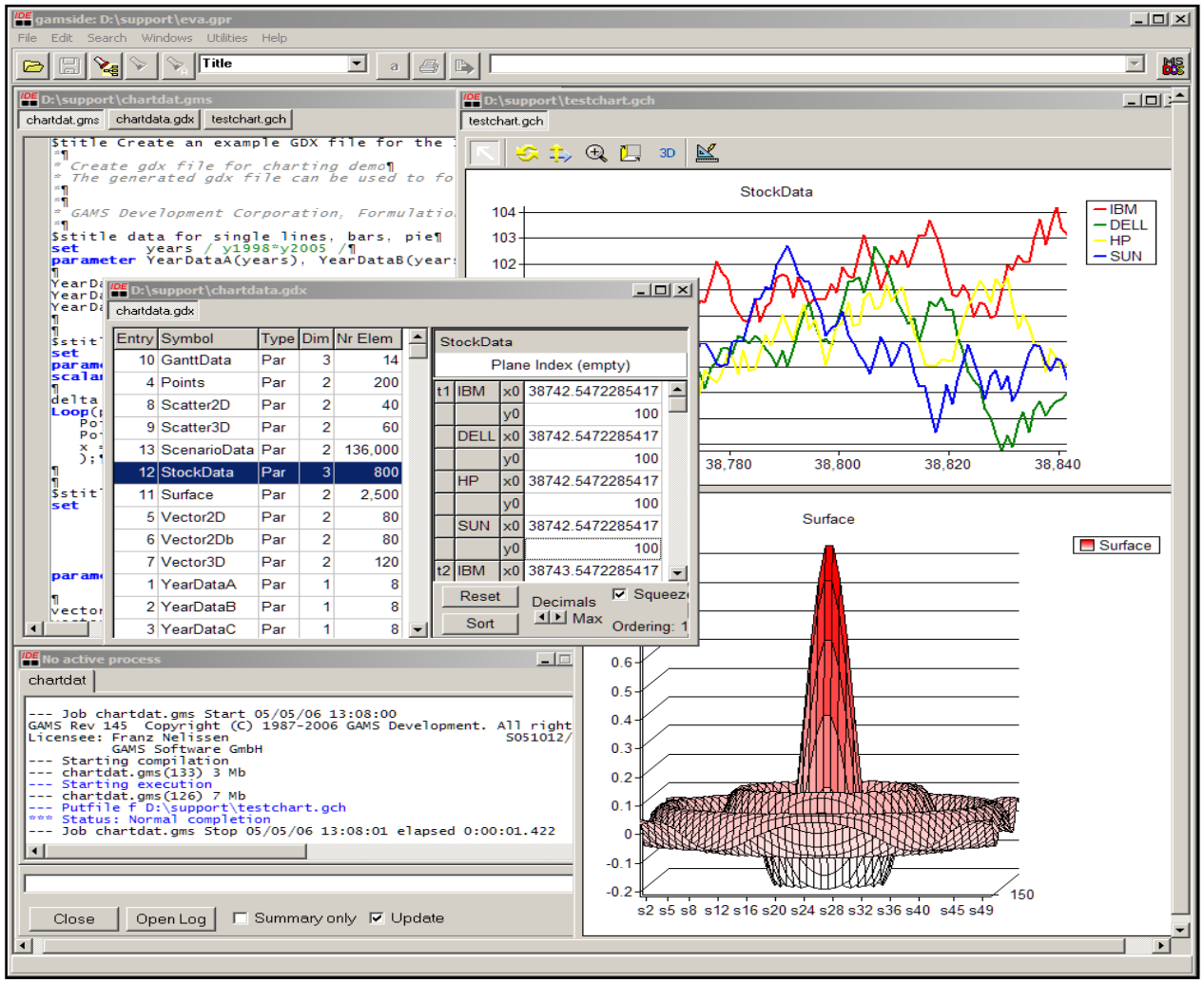
20				8	5		3	4								2	4		9	1			
21		6	1						5	8				1	7						4	5	
22			2						3						4						2		
23																							

System Overview



GAMS Integrated Development Environment



GAMS Model Libraries

GAMS Model Library Version 27.0

Search

SeqNr	Name	Application Area	Type	Contributor	Description
001	TRNSPORT	Management Science and OR	LP	Dantzig, G B	A Transportation Problem
002	BLEND	Management Science and OR	LP	Dantzig, G B	Blending Problem I
003	PRODMIX	Management Science and OR	LP	Dantzig, G B	A Production Mix Problem
004	WHOUSE	Management Science and OR	LP	Dantzig, G B	Simple Warehouse Problem
005	JOBT	Management Science and OR	LP	Dantzig, G B	On-the-Job Training
006	SROUTE	Management Science and OR	LP	Dantzig, G B	The Shortest Route Problem
007	DIET	Micro Economics	LP	Dantzig, G B	Stigler's Nutrition Model
008	AIRCRAFT	Management Science and OR	LP	Dantzig, G B	Aircraft Allocation Under Uncertain Demand
009	PRODSCH	Management Science and OR	MIP	CDC	APEX - Production Scheduling Model
010	PDI	Management Science and OR	LP	ARCNET	ARCNET Production Distribution and Inventory
011	UIMP	Management Science and OR	LP	Ellison, E F	UIMP - Production Scheduling Problem
012	MAGIC	Management Science and OR	MIP	Garver, L L	Magic Power Scheduling Problem
013	FERTS	Micro Economics	LP	Choksi, A M	Egypt - Static Fertilizer Model
014	FERTD	Micro Economics	MIP	Choksi, A M	Egypt - Dynamic Fertilizer Model
015	MEXSS	Micro Economics	LP	Kendrick, D	Mexico Steel - Small Static
016	MEXSD	Micro Economics	MIP	Kendrick, D	Mexico Steel - Small Dynamic
017	MEXLS	Micro Economics	LP	Kendrick, D	Mexico Steel - Large Static
018	WEAPONS	Management Science and OR	NLP	Bracken, J	Weapons Assignment
019	BID	Micro Economics	MIP	Bracken, J	Bid Evaluation
020	PROCESS	Chemical Engineering	NLP	Bracken, J	Alkylation Process Optimization
021	CHEM	Chemical Engineering	NLP	Bracken, J	Chemical Equilibrium Problem
022	SHIP	Engineering	NLP	Bracken, J	Structural Optimization
023	LINEAR	Econometrics	DNLP	Bracken, J	Linear Regression with Various Criteria
024	LEAST	Econometrics	NLP	Bracken, J	Nonlinear Regression Problem
025	LIKE	Econometrics	NLP	Bracken, J	Maximum Likelihood Estimation
026	CHANCE	Agricultural Economics	NLP	Bracken, J	Chance Constrained Feed Mix Problem
027	SAMPLE	Statistics	NLP	Bracken, J	Stratified Sample Design
028	PINDYCK	Energy Economics	NLP	Pindyck, R S	Optimal Pricing and Extraction for OPEC
029	ZLOOF	Management Science and OR	GAMS	Zloof, M M	Relational Database Example
030	VIETMAN	Micro Economics	MIP	Manne, A S	Vietoriscz Manne Fertilizer Model 1961
031	ALUM	International Trade	MIP	Brown, M	World Aluminum Model
032	MARCO	Micro Economics	LP	Aronofsky, J	Mini Oil Refining Model

```
A Transportation Problem (TRNSPORT,SEQ=1)
```

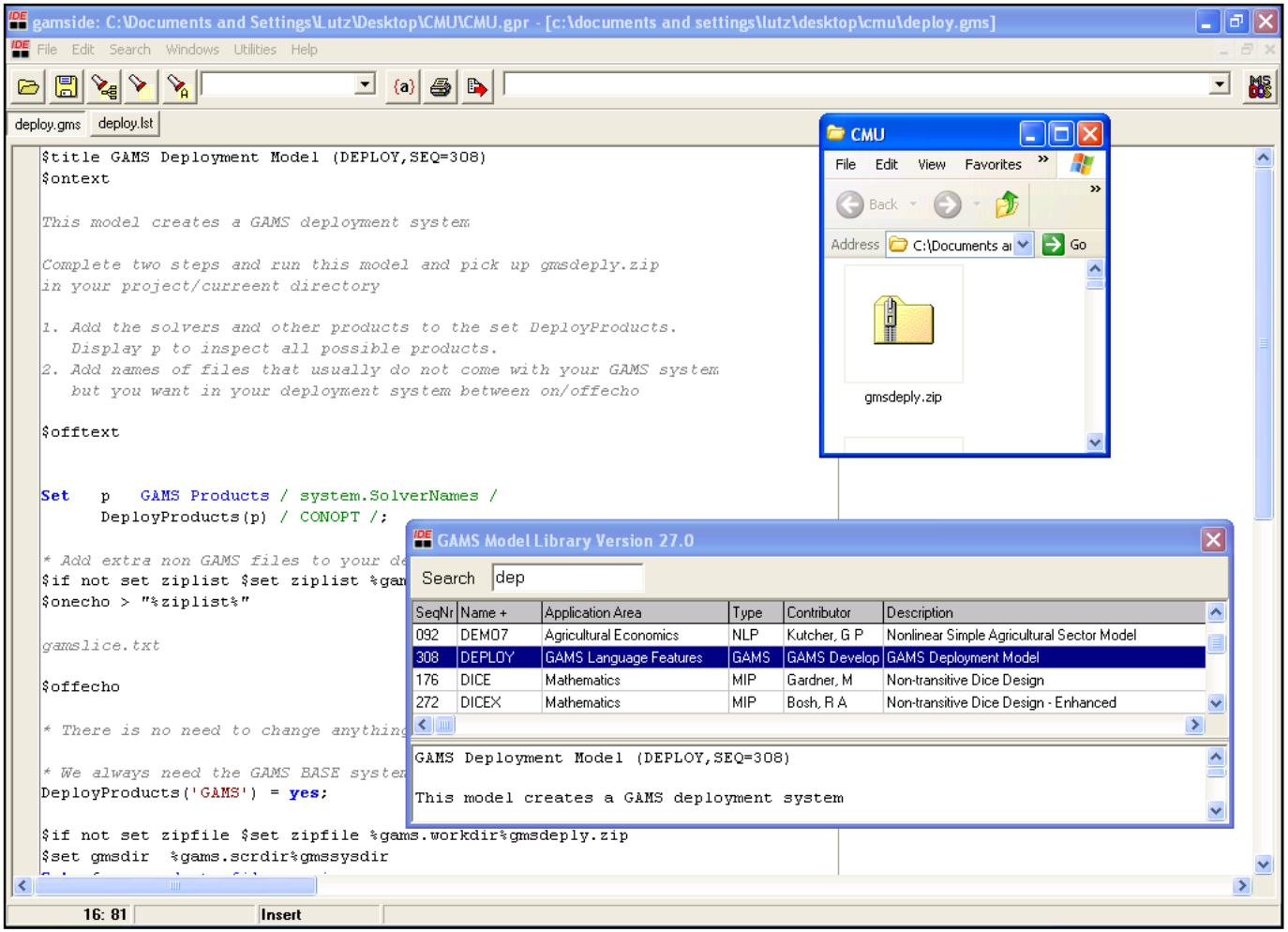
Transparent Software Quality Assurance (SQA)

Elements:

1. Software configuration management (SCM)
2. Test libraries (available online):
   - GAMS Model Library
   - GAMS Quality Test Models Library
   - à Solved for all relevant solvers: More than 5.000 tests for each platform
3. (Automated) Client Model Testing

Goal: Continuous quality improvement using automated and reproducible tests

Deployment


gamside: C:\Documents and Settings\Lutz\Desktop\CMU\CMU.gpr - [c:\documents and settings\lutz\desktop\cmu\deploy.gms]
File Edit Search Windows Utilities Help
deploy.gms deploy.lst
$title GAMS Deployment Model (DEPLOY,SEQ=308)
$ontext
This model creates a GAMS deployment system
Complete two steps and run this model and pick up gmsdeply.zip
in your project/curreent directory
1. Add the solvers and other products to the set DeployProducts.
Display p to inspect all possible products.
2. Add names of files that usually do not come with your GAMS system
but you want in your deployment system between on/offecho
$offtext
Set p GAMS Products / system.SolverNames /
DeployProducts(p) / CONOPT /;
* Add extra non GAMS files to your de
$if not set ziplist $set ziplist %gam
$onecho > "%ziplist%"
gamslice.txt
$offecho
* There is no need to change anything
* We always need the GAMS BASE syste
DeployProducts('GAMS') = yes;
$if not set zipfile $set zipfile %gams.workdir%gmsdeply.zip
$set gmsdir %gams.scrdir%gmssysdir
16: 81
Insert
CMU
File Edit View Favorites
Back
Address C:\Documents a
Go
gmsdeply.zip
GAMS Model Library Version 27.0
Search dep
SeqNr Name + Application Area Type Contributor Description
092 DEMO7 Agricultural Economics NLP Kutcher, G P Nonlinear Simple Agricultural Sector Model
308 DEPLOY GAMS Language Features GAMS GAMS Develop GAMS Deployment Model
176 DICE Mathematics MIP Gardner, M Non-transitive Dice Design
272 DICEX Mathematics MIP Bosh, R A Non-transitive Dice Design - Enhanced
GAMS Deployment Model (DEPLOY,SEQ=308)
This model creates a GAMS deployment system

Agenda

- GAMS Development / GAMS Software
- GAMS at a Glance
- **Recent Enhancements**
- Summary

Release Notes

New Solvers

- **COIN-OR Solvers** (http://www.coin-or.org/)
  - MINLP solver: CoinBonmin
- **AlphaECP**
  - MINLP solver
  - Extended Cutting Plane method by T. Westerlund and T. Lastusilta (Abo Akademi University, Finland)
- **LINDOGLOBAL**
  - finds proven optimal solutions to non-convex MINLP
  - Global Optimization Solver from Lindo Systems, Inc.

New solver binaries

- **BARON, CONOPT, CPLEX, MOSEK, XPRESS,…**

Performance Analysis

- Solver **robustness** and **correctness**
- Solver **efficiency**
- **Quality of solution** (nonconvex and discrete models)

è Cross comparison of solver resource requirements and quality of solution

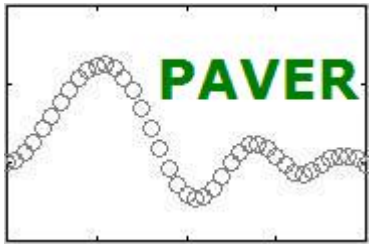
Benchmarking

- **BENCH -"solver"**

```
--- BENCH SUMMARY:

  Solver     Modstat Solstat       Objective       ResUsd  Examiner
  ------------------------------------------------------------------
  CPLEX            1       1        153.6750        0.078       P/P
  COINCBC          1       1        153.6750        0.000       P/P
  COINGLPK         1       1        153.6750        0.000       P/P
  MOSEK            1       1        153.6750        0.062       P/P
  XPRESS           1       1        153.6750        0.062       P/P
```

- **PAVER – Server**
  Performance Analysis and Visualization for Efficient Reproducibility
  http://www.gamsworld.org/performance/paver/



Paver: Visualization

Performance Profiles (Dolan and More, 2002):

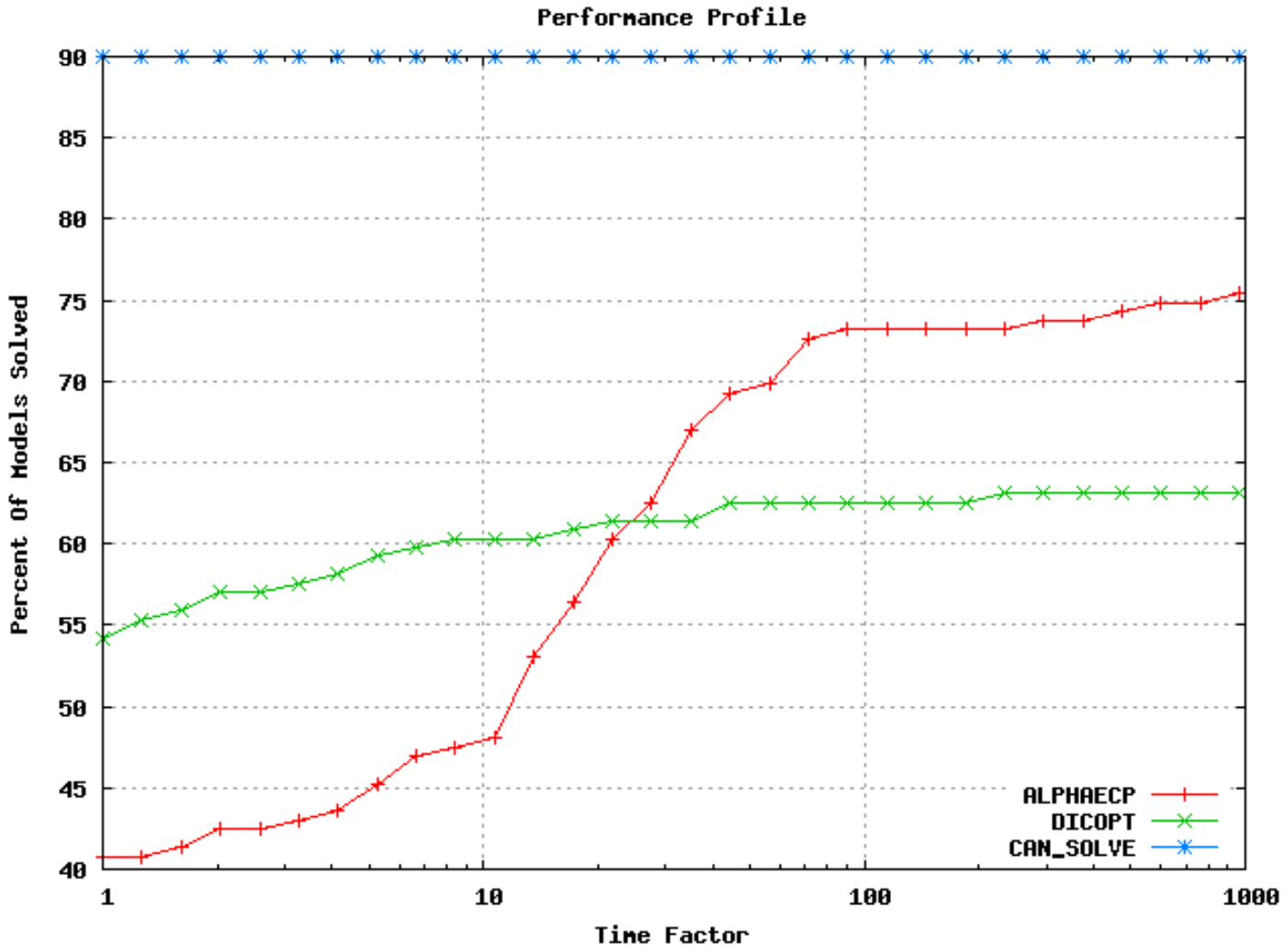
- **Performance metric**: ratio of current solver time over best time of all solvers

$$\rho(p,s) := \frac{t_{p,s}}{\min_{s' \in \mathcal{S}} t_{p,s'}}$$

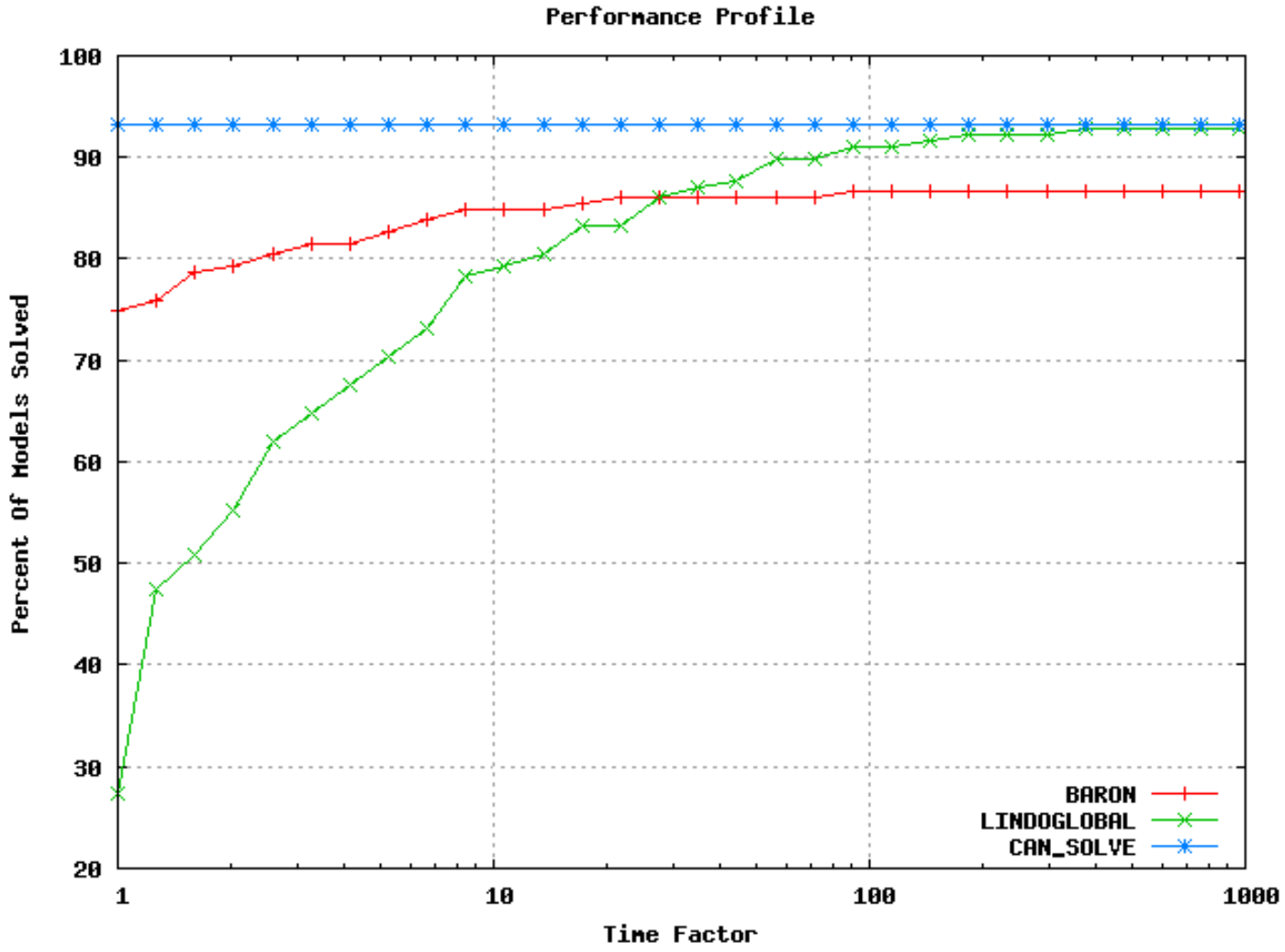
- **Cumulative distribution function** for performance metric: probability of success if given τ times fastest time (τ=ratio)

$$P_s(\tau) := \frac{|\{p \in \mathcal{P} : \rho(p,s) \leq \tau\}|}{|\mathcal{P}|}$$

PAVER: AlphaECP vs. Dicopt



PAVER: Lindoglobal vs. Baron



Solver Technology

è Tremendous algorithmic and computational progress

- **LP** in fact only restricted by available memory
- **MIP**
  - Some small (academic) problems still unsolvable
  - Commercial problems in most case docile
- **NLP/MINLP**
  - Predictions are problem and data specific, global vs. local solutions

è Further progress using Multiple Threads / Grid Computing

Multiple Threads / SMP

- **CPLEX**
  - **parallel extension** for B&B and interior point solver
  - options *threads, barthreads, mipthreads, strongthreadlim*
  - **concurrent optimizer** options lpmethod, qpmethod, startalg
  - academic license includes 4 threads
- **MOSEK**
  - **parallel extension** for the interior solver comes free of charge
  - option *MSK_IPAR_INTPNT_NUM_THREADS*
  - **concurrent optimizer** options MSK_IPAR_CONCURRENT_*
- **XPRESS**
  - **parallel extension** for B&B and interior point solver
  - options *threads, barThreads, mipThreads, sbThreads*
  - academic license includes 4 threads
- **XA (XAPAR)**

Grid Computing

Imagine…

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

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

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

Grid Computing

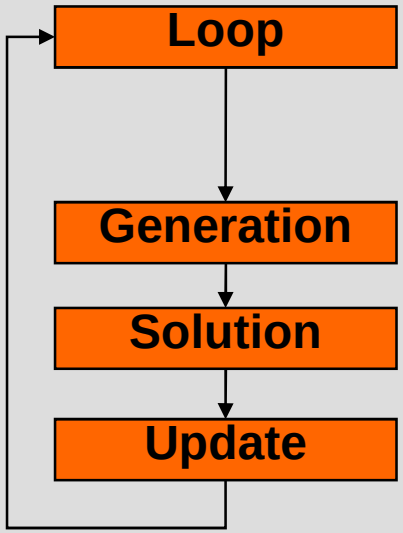
What is Grid Computing?

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

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

Simple Serial Solve Loop

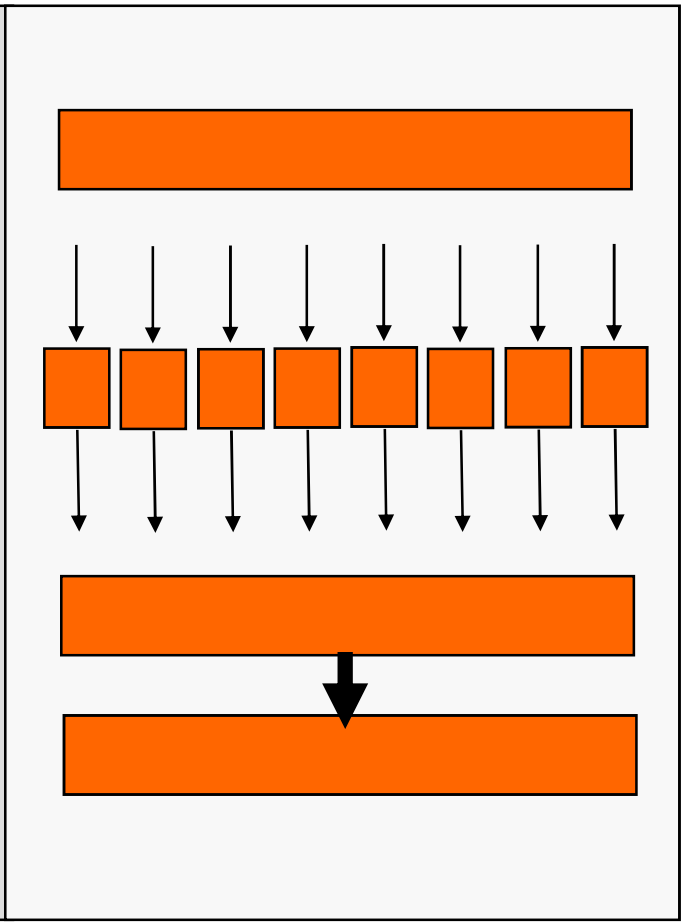
```
Loop(p(pp),
   ret.fx = rmin +(rmax-rmin)
     /(card(pp)+1)*ord(pp) ;
   Solve minvar min var using miqcp;
   xres(i,p)          = x.l(i);
   report(p,i,'inc') = xi.l(i);
   report(p,i,'dec') = xd.l(i)
  );
```



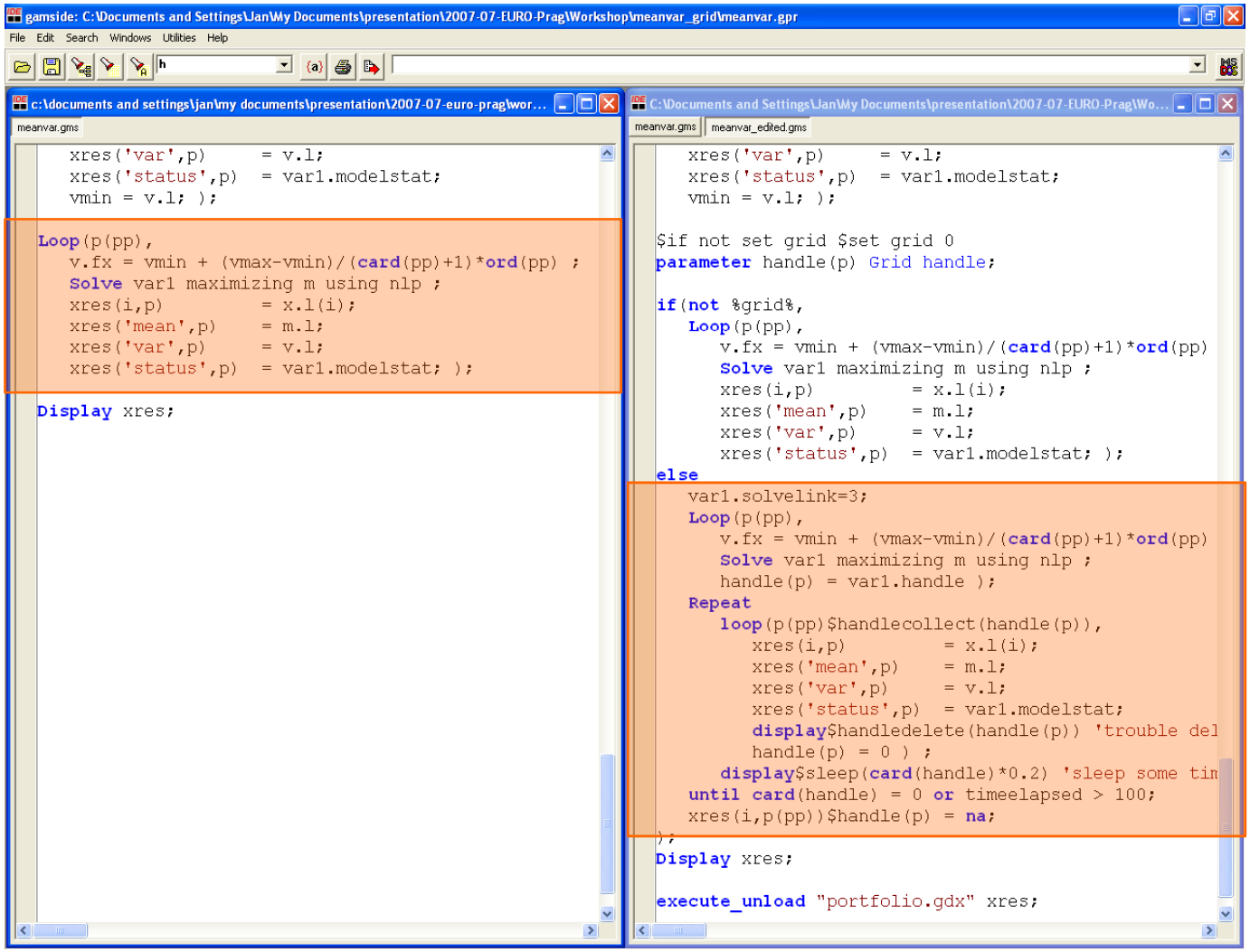
How do we get to parallel and distributed computing?

GRID Specific Enhancements

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



Minor Changes to Model

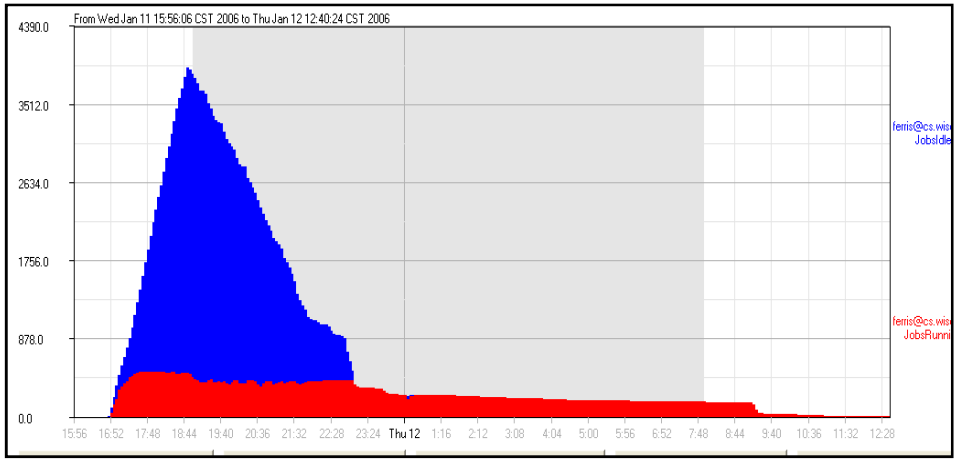


GAMS & Grid Computing

- **Scalable**:
  - support of massive grids, **but also**
  - multi-cpu / multiple cores desktop machines
  - “1 CPU - Grid”

- Platform **independent**

- Only **minor changes** to model required



- **Separation** of model and solution method
  à Model stays **maintainable**

SUNgrid

www.network.com

- On-demand grid computing service operated by Sun Microsystems
- Access to enormous computing power over Internet
- Opteron-based servers with 4 GB of RAM per CPU
- Solaris 10 OS, and Sun Grid Engine 6 software.
- $1 per CPU-hour

- **GAMS on the SUN Grid**
  - GAMS distribution 22.5 for Solaris 10
  - COIN-OR solvers will be available

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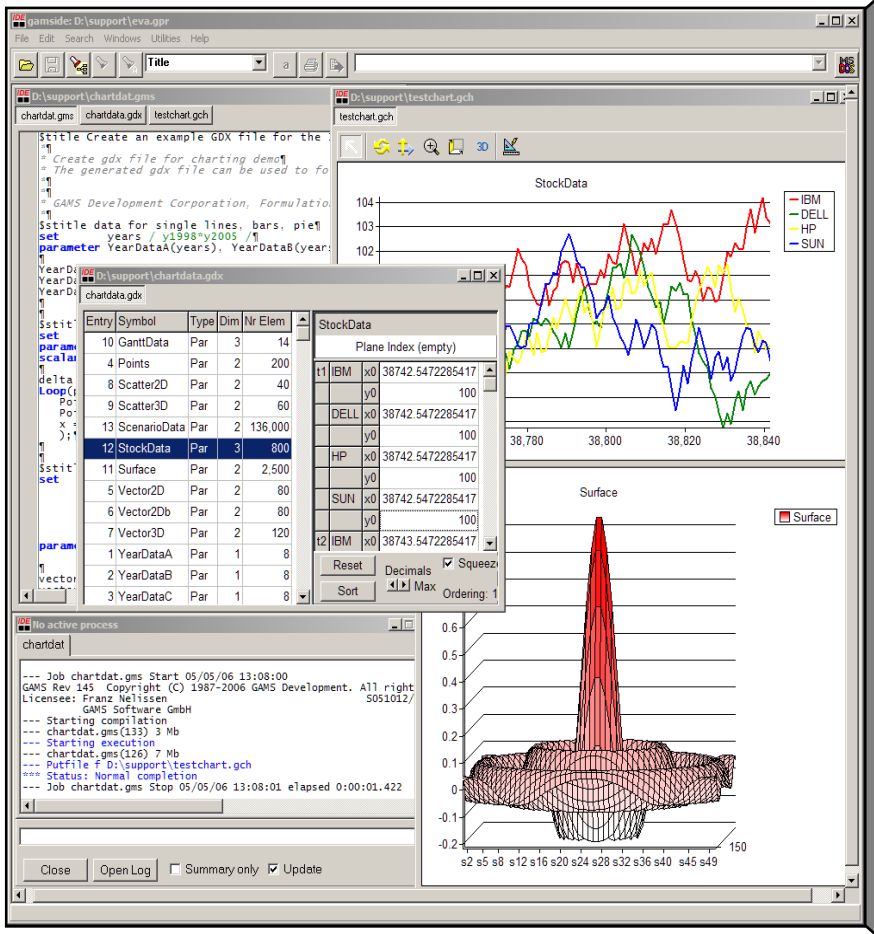
Benefits for Users



- Robust and scalable state-of-the-art modeling technology
- Tailored for complex, large-scale modeling applications
- Productivity gains through rapid development environment
- Broad academic and commercial network
- Proven reliability (30+ years of experience)
- Protection of investments through platform and solver independency

Benefits for Different User Groups

Researcher	• Projects • Product maintenance	• Commercial network • Quality assurance
Model Developer	• Rapid prototyping • Higher productivity	• Robust & scalable solution • Academic network
Consultants & Solution Provider	• Rapid prototyping • Tailored solutions	• Benchmarking • Extended support
Innocent User	• Works in different environments • Lots of different interfaces	• Robust and reliable system
Management	• Protection of investments • Low cost • Maintainable applications	• Independence: - Solver - Platform - Interface

Contacting GAMS

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