Rapid Application Prototyping using GAMS

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Welcome/Agenda

- GAMS Development / GAMS Software
- Working with GAMS – A Guided Tour
- Model Development
- Model Deployment and Maintenance

Agenda

- GAMS Development / GAMS Software
- Working with GAMS – A Guided Tour
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GAMS Development / GAMS Software

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

- Professional **software tool provider**
- Operating in a **segmented niche market**
- Broad **academic** & **commercial** user base and network

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

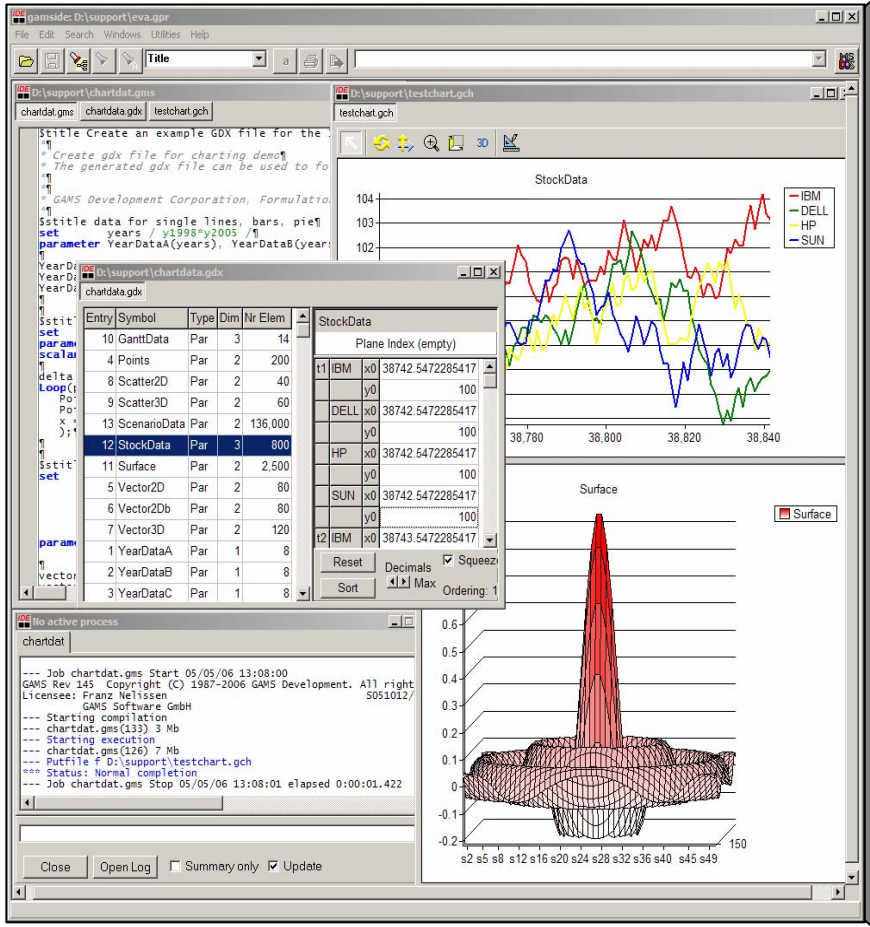
Network of Application Partners

ETSAP
TELEGYR® SYSTEMS
COWI
OPTIENCE
BARKAWI
COPENHAGEN ECONOMICS
UNIVERSITY APPS, INC.
iiT
VA TECH SAT
SAT AUTOMATION
profitpoint
PCS
CGR
Verbund
JK
EcoMod Net
Nacopt

Agenda

- GAMS Development / GAMS Software
- **Working with GAMS – A Guided Tour**
- Model Development
- Model Deployment and Maintenance

GAMS at a Glance

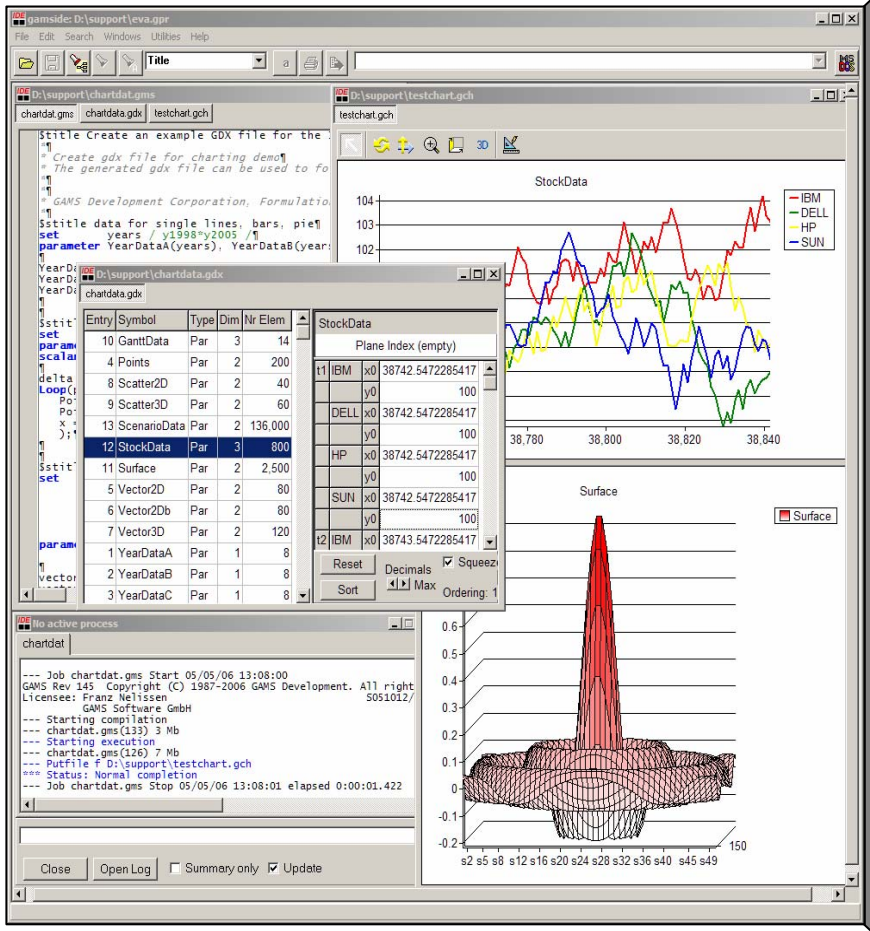


General **A**lgebraic **M**odeling **S**ystem:
Algebraic Modeling Language, Integrated Solver, Model Libraries, Connectivity- & Productivity Tools

Design Principles:

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

More GAMS Features



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

System Overview

Interactive | **API/Batch**

Connectivity Tools

- Uniform Data Exchange:
  - ASCII
  - GDX (ODBC, SQL, XLS, XML)
- GDX Tools
- Data API
- Ext. programs
  - EXCEL
  - MATLAB
  - GNUPLOT, ...
  - C, Delphi, ...

User Interfaces

GAMS Language Compiler and Execution System

Solvers

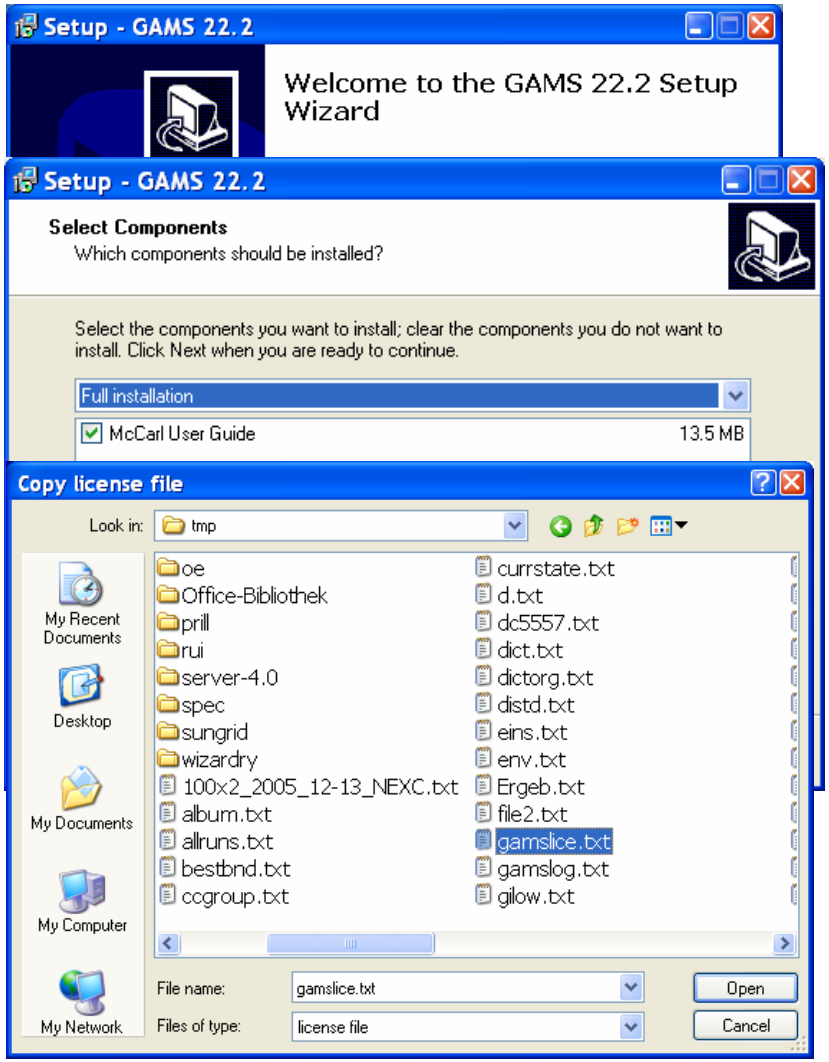
LP-MIP-QCP-MIQCP-NLP-MINLP-CNS-MCP-MPEC
MPSGE, global, and stochastic optimization

Productivity Tools

- **I**ntegrated **D**evelopment **E**nvironment (**IDE**)
- Model Debugger and Profiler
- Model Libraries
- Data Browser
- Charting Engine
- Benchmarking
- Deployment System
- Quality Assurance and Testing

BARON, COIN, CONOPT, CPLEX, DECIS, DICOPT, KNITRO, LGO,MINOS, MOSEK, OQNLP, PATH, SNOPT, XA, XPRESS, ...

Hands-on! Installing GAMS



Hands-on! Testing the installation

gamside: C:\Documents and Settings\bussieck\My Documents\gamsdir\project.gpr

File Edit Search Windows Utilities Help

New Ctrl+N
Open Ctrl+O
Open in Editor
Open in project directory
Reopen Alt+R
Open in New Window Shift+Ctrl+O
View in Explorer

Model Library
Project

Open GAMS Model Library
Open User Model Library

Run F9
Compile Shift+F9

Save Ctrl+S

GAMS Model Library Version 24.0

Search indus89

SeqNr	Name	Application Area	Type	Contributor	Description
305	HERVES	Engineering	DNLP	Meeraus, W H	Herves (Transposable Element) Activity Calculations
069	HHFAIR	Macro Economics	NLP	Fair, R C	Household Optimization Problem by Fair
274	HHMAX	Applied General Equilibrium	NLP	Hosoe, N	A Household Maximization Problem
095	HIMMEL11	Mathematics	NLP	Himmelblau,	Himmelblau Test Problem Number 11
036	HIMMEL16	Mathematics	NLP	Himmelblau,	Area of Hexagon Test Problem
262	HOLIDAY	GAMS Language Features	GAMS	GAMS Develop	US Holiday and Leave Chart
099	HOUSE	Mathematics	NLP	Borland	House Plan Design
264	HS62	Mathematics	NLP	Hock, W	Hock - Schittkowski Problem 62
167	HYDRO	Engineering	NLP	Wood, A J	Hydrothermal Scheduling Problem
079	IBM1	Management Science and OR	LP	IBM	Aluminum Alloy Smelter Sample Problem
160	ICUT	Mathematics	MIP	GAMS Develop	Integer Cut Example
110	IMMUN	Finance	NLP	Dahl, H	Financial Optimization: Risk Management
059	IMSL	Mathematics	LP	IMSL Inc	Piecewise Linear Approximation
090	INDUS	Agricultural Economics	LP	Duloy, J H	Indus Agricultural Model
181	INDUS89	Agricultural Economics	LP	Ahmad, M	Indus Basin Water Resource Model

```
Indus Basin Model Revised - IBMR  (INDUS89,SEQ=181)

This file contains the basic data and definition of the surfa
```

gamside: C:\Documents and Settings\bussieck\My Documents\gamsdir\project.gpr

File Edit Search Windows Utilities Help

c:\documents and settings\bussieck\my documents\gamsdir\indus89.gms

indus89.gms indus89.lst

```
$TITLE Indus Basin Model Revised - IBMR  (INDUS89,SEQ=181)
$ontext
This file contains the basic data and definition of the surface water
system. Data is complete for year 1988. Some parameters could be
computed for future years using growth rates provided in this file,
others had to be estimated and entered. Enter the year for which the
setup is desired in set isr (set isr should have only one entry).


Ahmad, M, and Kutcher, G P, Irrigation Planning with Environmental
Considerations - A Case Study of Pakistans's Indus Basin. Tech. rep.,
The World Bank, 1992.

changes for year 2000 runs
  growth of crop yields set to a maximum of 3 %
  insert this line after growthcy parameter
```

No active process

indus89

```
Iteration:  4085   Dual objective     =        115074.076725
Iteration:  4183   Dual objective     =        114925.604909
Removing shift (17).

Optimal solution found.
Objective :      114873.655552

--- Restarting execution
--- indus89.gms(3621) 0 Mb
--- Reading solution for model wsisn
--- indus89.gms(3621) 4 Mb
*** Status: Normal completion
--- Job indus89.gms Stop 06/29/06 04:59:12 elapsed 0:00:02.724
```

Close Open Log Summary only Update

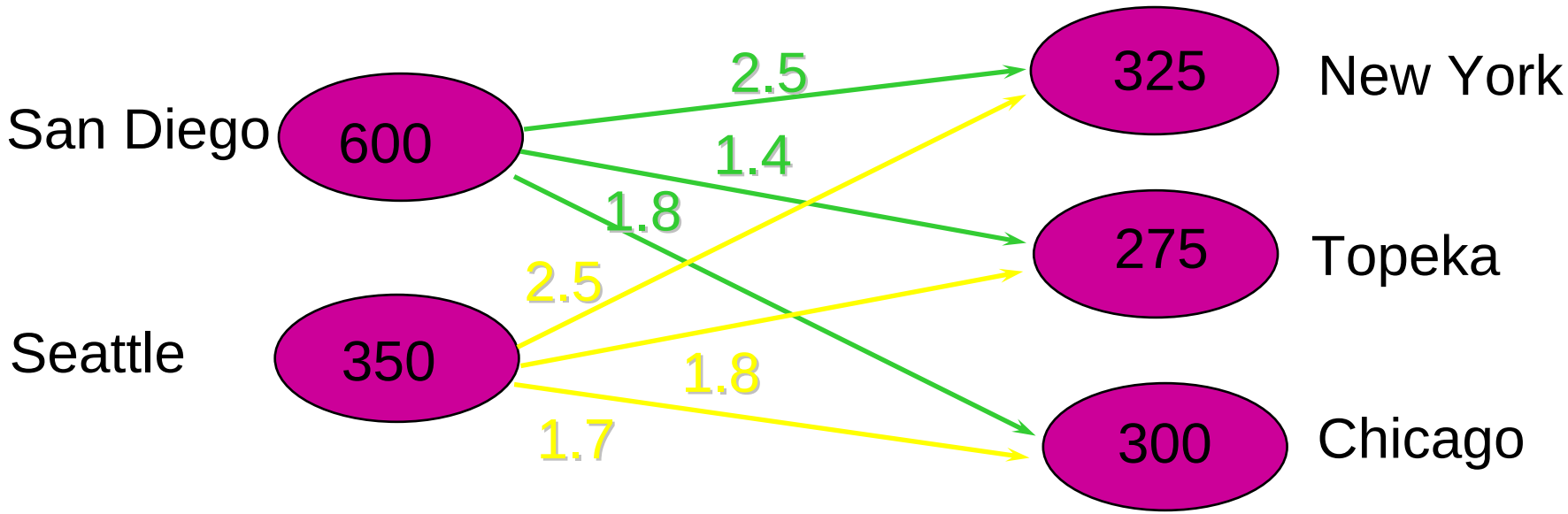
1: 1 Insert

Hands-on! Testing the installation

lewis.gams.com - PuTTY

```
$gamslib indus89
Model indus89.gms retrieved
$gams indus89
--- Job indus89 Start 06/29/06 05:01:20
GAMS Rev 145  Copyright (C) 1987-2006 GAMS Development. All rights reserved
Licensee: EURO 2006 GAMS Workshop                          G060626/0001CB-LNX
          GAMS Software GmbH                                           DC5946
--- Starting compilation
--- indus89.gms(3622) 4 Mb
--- Starting execution
--- indus89.gms(3618) 5 Mb
--- Generating LP model wsisn
--- indus89.gms(3621) 7 Mb
---   2,726 rows  6,570 columns  39,489 non-zeroes
--- Executing CPLEX

GAMS/Cplex    Apr 21, 2006 LNX.CP.CP 22.2 031.034.041.LX3 For Cplex 10.0
Cplex 10.0.1, GAMS Link 31
Cplex licensed for 1 use of lp, qp, mip and barrier, with 4 parallel threads.

Reading data...
Starting Cplex...
Tried aggregator 1 time.
LP Presolve eliminated 280 rows and 805 columns.
Aggregator did 652 substitutions.
Reduced LP has 1794 rows, 5113 columns, and 33006 nonzeros.
Presolve time =    0.04 sec.
Initializing dual steep norms . . .

Iteration log . . .
Iteration:     1   Scaled dual infeas =       2955667.467575
```

A few Words about GAMS Syntax



Minimize	Transportation cost
subject to	Demand satisfaction at markets
	Supply constraints

GAMS Syntax – Mathematical Algebra

$$\sum_{\substack{c,p:\\(c,p)\in\mathcal{N}}} tcost \cdot dist(c,p) \cdot x_p^c \quad \rightarrow \quad \min$$

$$\sum_{\substack{c,p:\\(c,p)\in\mathcal{N}}} x_p^c \quad \leq \quad sup(c) \qquad \forall c$$

$$\sum_{\substack{c,p:\\(c,p)\in\mathcal{N}}} x_p^c \quad \geq \quad dem(p) \qquad \forall p$$

$$x_p^c \quad \geq \quad 0 \qquad \forall c,p:\ (c,p)\in\mathcal{N}$$

GAMS Syntax – GAMS Algebra

gamside: C:\Documents and Settings\bussieck\My Documents\gamsdir\project.gpr - [c:\documents an...

File Edit Search Windows Utilities Help

call

trnsport.gms

```
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: 1 Insert

GAMS Syntax – cont.

- Symbols:
  - Sets
  - Parameters
  - Variables
  - Equations
  - Models
  - ASCII Output Files

```
Set I some stuff /cat,dog,ding1*ding10/

Parameter life(I) life count / cat 7 /

Integer Variable x(I) number to purchase;

Equation e(I) relate something;

Model animallife /e, some, more/;

File fx some file / 'c:\t\text.txt' /
```

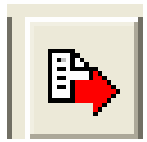
- Statements
  - Declaration+Data statement
  - Data Assignments
  - Equation Definition
  - Programming Flow Control
  - Option statement

```
Set I /cat,dog/;

life('dog')=life('cat')-1; x.lo(I)=1;

e(I).. Sqr(x(I)) =l= log(life(I));

loop(I, put fx I.tl);

Option reslim=10;
```

Hands-On! Inspect trnsport.gms

- IDE:

File→Model Library
trnsport

Hit F9 or Click 

- Unix:

```
$ gamslib trnsport
$ vi trnsport.gms
$ gams trnsport
$ vi trnsport.lst
```

Hands-on! IDE - A Guided Tour

- IDE Project Management
- Documentation
  - User's Guide/McCarl UG, Solver Manual
- Model Library
- Editor
- Solver Selection
- Option Selection
- Listing file/Tree view/Error navigation
- GDX Viewer
  - Data cube
  - Export to Excel
  - Graphs

Solver Option Files

- Pass solver specific options
  - E.g. tolerances, limits, algorithm selection

- Solver option file ***solver*.opt** e.g. **cplex.opt** with solver specific options (one per line)

- Activate solver option file
  - **optfile=1** on command line/parameter window
  - **<modelname>.optfile=1;** before solve

- Multiple option files:
  - ***solver*.opt** **optfile=1**
  - ***solver*.op2** **optfile=2**
  - …
  - ***solver*.999** **optfile=999**

Special Solvers

- *Solvers* that do not *solve* the problem:
  - **CONVERT**
    - Converts the model into different formats
  - **AMPL/LINGO**
    - Converts model into AMPL/LINGO syntax and calls the other system to solve the problem
  - **EXAMINER**
    - Checks the quality of a solution found by a different solver
  - **BENCH**
    - Benchmarking solver

Model Translation

Instructions

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

```
Subject: GAMS
```

At the moment we support the following *languages*:

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

Model Translation – Cont.

- Translation of MP Model into *Scalar Model*
  - List of Variables/Equations
- Advantages:
  - Syntax for Scalar Models almost identical for different Modeling Languages (easy Translation)
  - Hides proprietary Information
- Seamless Modeling System Connection
  - For example: GAMS/AMPL with Kestrel (NEOS)

```
Set I Products         /P1*P2/
    J Cutting Patterns /C1*C2/;

Parameter c(J)    cost of raw material                  /C1 1, C2 1/
          cc(J)   cost of change-over of knives         /C1 0.1, C2 0.2/
          b(I)    width of product roll-type I          /P1 460, P2 570/
          nord(I) number of orders of product type I    /P1 8, P2 7/
          Bmax    width of raw paper roll               /1900/
          Delta   tolerance for width                   / 200/
          Nmax    max number of products in cut         /   5/
          bigM    max number of repeats of any pattern  /  15/;

Variable  y(J)    cutting pattern
          m(J)    number of repeats of pattern j
          n(I,J)  number of products I produced in cut J
          obj     objective variable;

Binary Variable y; Integer Variable m, n;

Equation defobj, max_width(J), min_width(J), max_n_sum(J),
                 min_order(I), cut_exist(J), no_cut(J);

defobj..          sum(j, c[j]*m[j] + cc[j]*y[j]) =e= obj;
max_width(j)..    sum(i, b[i]*n[i,j])            =l= Bmax;
min_width(j)..    sum(i, b[i]*n[i,j]) + Delta    =g= Bmax;
max_n_sum(j)..    sum(i, n[i,j])                 =l= Nmax;
min_order(i)..    sum(j, m[j]*n[i,j])            =g= nord[i];
cut_exist(j)..    y[j]                           =l= m[j];
no_cut(j)..       m[j]                           =l= bigM*y[j];

m.up[j] =  bigM; n.up[i,j] = nmax;

model trimloss /all/;
solve trimloss minimize obj using minlp;
```

```
*  MINLP written by GAMS Convert
Variables  b1,b2,i3,i4,i5,i6,i7,i8,x9;
Binary Variables b1,b2;
Integer Variables i3,i4,i5,i6,i7,i8;
Equations  e1,e2,e3,e4,e5,e6,e7,e8,e9,e10,
           e11,e12,e13;

e1..  0.1*b1 + 0.2*b2 + i3 + i4 - x9 =E= 0;
e2..  460*i5 + 570*i7 =L= 1900;
e3..  460*i6 + 570*i8 =L= 1900;
e4..  460*i5 + 570*i7 =G= 1700;
e5..  460*i6 + 570*i8 =G= 1700;
e6..  i5 + i7 =L= 5;
e7..  i6 + i8 =L= 5;
e8..  i3*i5 + i4*i6 =G= 8;
e9..  i3*i7 + i4*i8 =G= 7;
e10.. b1 - i3 =L= 0;
e11.. b2 - i4 =L= 0;
e12.. - 15*b1 + i3 =L= 0;
e13.. - 15*b2 + i4 =L= 0;

* set non default bounds
i3.up = 15; i4.up = 15; i5.up = 5;
i6.up = 5;  i7.up = 5;  i8.up = 5;

Model m / all /;
Solve m using MINLP minimizing x9;
```

```
#  MINLP written by GAMS Convert
var b1 binary;
var b2 binary;
var i3 integer >= 0, <= 15;
var i4 integer >= 0, <= 15;
var i5 integer >= 0, <= 5;
var i6 integer >= 0, <= 5;
var i7 integer >= 0, <= 5;
var i8 integer >= 0, <= 5;

minimize obj:
     0.1*b1 + 0.2*b2 + i3 + i4;

subject to

e2:  460*i5 + 570*i7 <= 1900;
e3:  460*i6 + 570*i8 <= 1900;
e4:  460*i5 + 570*i7 >= 1700;
e5:  460*i6 + 570*i8 >= 1700;
e6:  i5 + i7 <= 5;
e7:  i6 + i8 <= 5;
e8:  i3*i5 + i4*i6 >= 8;
e9:  i3*i7 + i4*i8 >= 7;
e10: b1 - i3 <= 0;
e11: b2 - i4 <= 0;
e12: - 15*b1 + i3 <= 0;
e13: - 15*b2 + i4 <= 0;
```

Sudoku

Address http://www.dailysudoku.com/sudoku/index.shtml

Daily SuDoku

- Home
- Today's SuDoku
- SuDoku Archive
- SuDoku for Kids
- Draw/Play
- Discussion
- FAQ
- Books
- Syndication
- Links
- Email and News
- Contact

Welcome to the Daily SuDoku!

Today's SuDoku is shown on the right. Click the grid to download a printable version of the puzzle. Visit **the archive** for previous daily puzzles and solutions. Play online, print a Sudoku, solve and get hints using the new improved **Draw/Play** function.

But how do I do it?

The object is to insert the numbers in the boxes to satisfy only one condition: each row, column and 3x3 box must contain the digits 1 through 9 exactly once. What could be simpler?

The rules of the new **Monster Sudokus** are exactly the same, but more numbers and letters are needed.

Classic | Monster | Kids | Squiggly

						6		1
			7	3	1			4
5					9			
6			2				1	
		8				4		
	1				5			8
			9					3
7			8	6	3			
9		2						

Daily SuDoku: Thu 2-Nov-2006 very hard

Christmas tree Sudoku

Address http://www.dailysudoku.com/sudoku/archive.shtml?year=2005&month=12&day=23&type=seasonal

Daily SuDoku

- Home
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- FAQ
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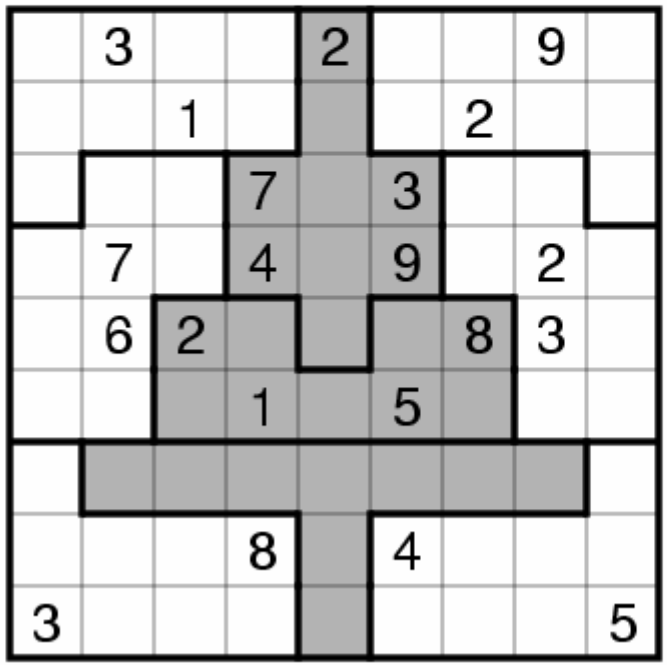
Daily Seasonal Sudoku: Fri 23-Dec-2005 [instructions]



Christmas tree Sudoku: Fri 23-Dec-2005 very hard

Agenda

- GAMS Development / GAMS Software
- Working with GAMS – A Guided Tour
- Model Development
- Model Deployment and Maintenance

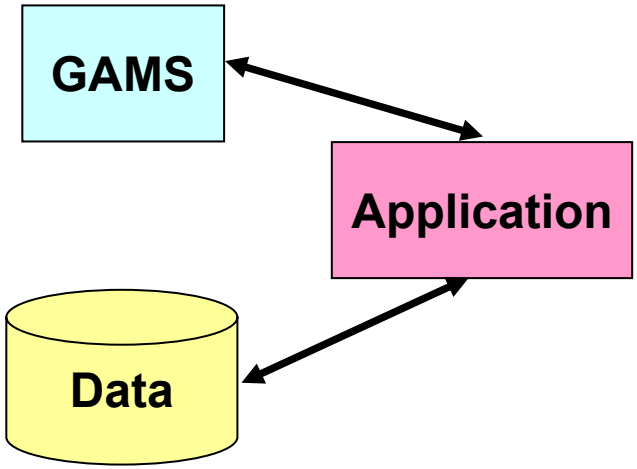
Important Principles

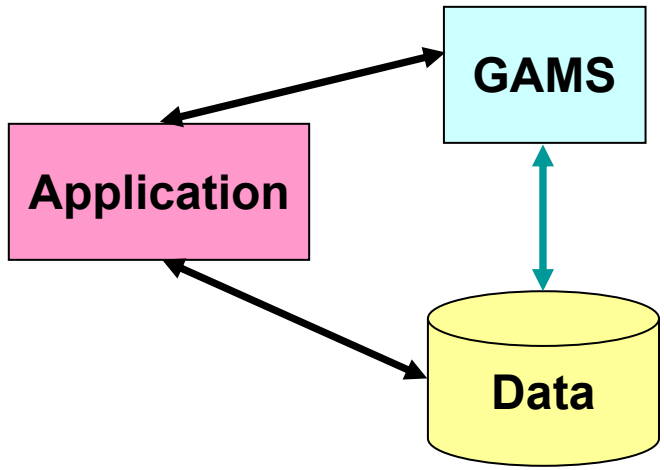
- Deployed models have often 15+ years lifecycle
  - Changing environment:
    - hardware, operating system, interface (GUI/data)

- Backward compatibility
- Platform/Solver/Interface Independence
  - Model benefits from
    - Advanced hardware
    - Advanced solver technology

- Reduced Total Cost of Ownership (TCO)

Flow of Data





Data Model I

- Application in control of data processing
- No direct data access

Data Model II

- Large Scale/Raw data exchange GAMS↔DB
- Control Data GAMS↔Application

Input/Output through ASCII Files

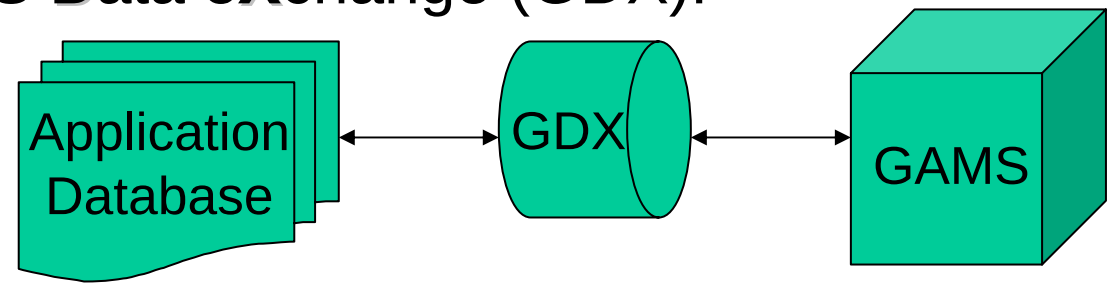
- ASCII Input Data
  - Part of model input (**`$include file.txt`**)
  - Posix Utilities are part of GAMS Windows System
    - Platform independent data file preparation
    - sed, awk, grep, cut, …

```
$call cut -d, -f1,3- file.txt > filenew.txt
```

- ASCII File Output
  - GAMS Put Facilities

GAMS Data eXchange

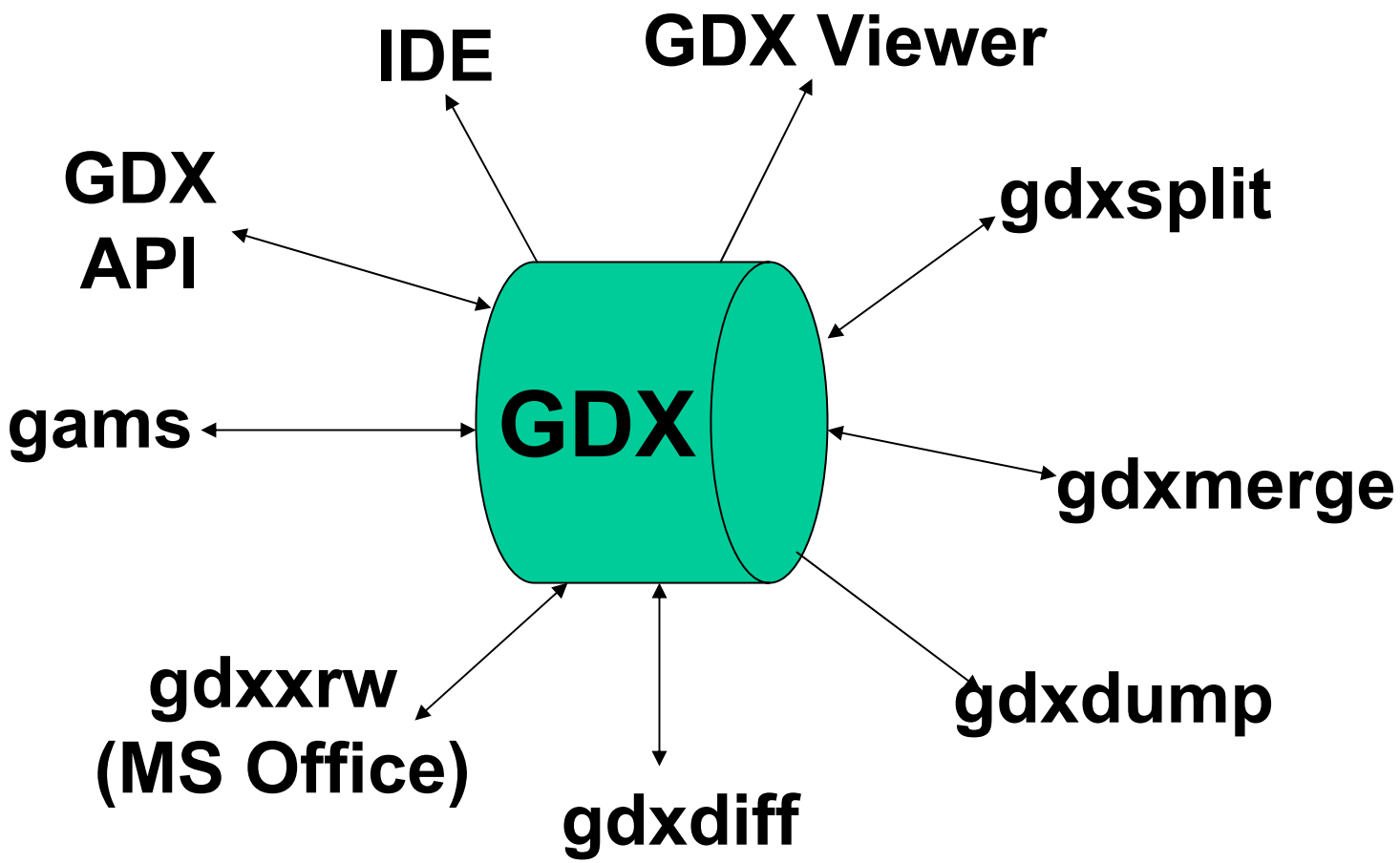
- **G**AMS **D**ata e**X**change (GDX):



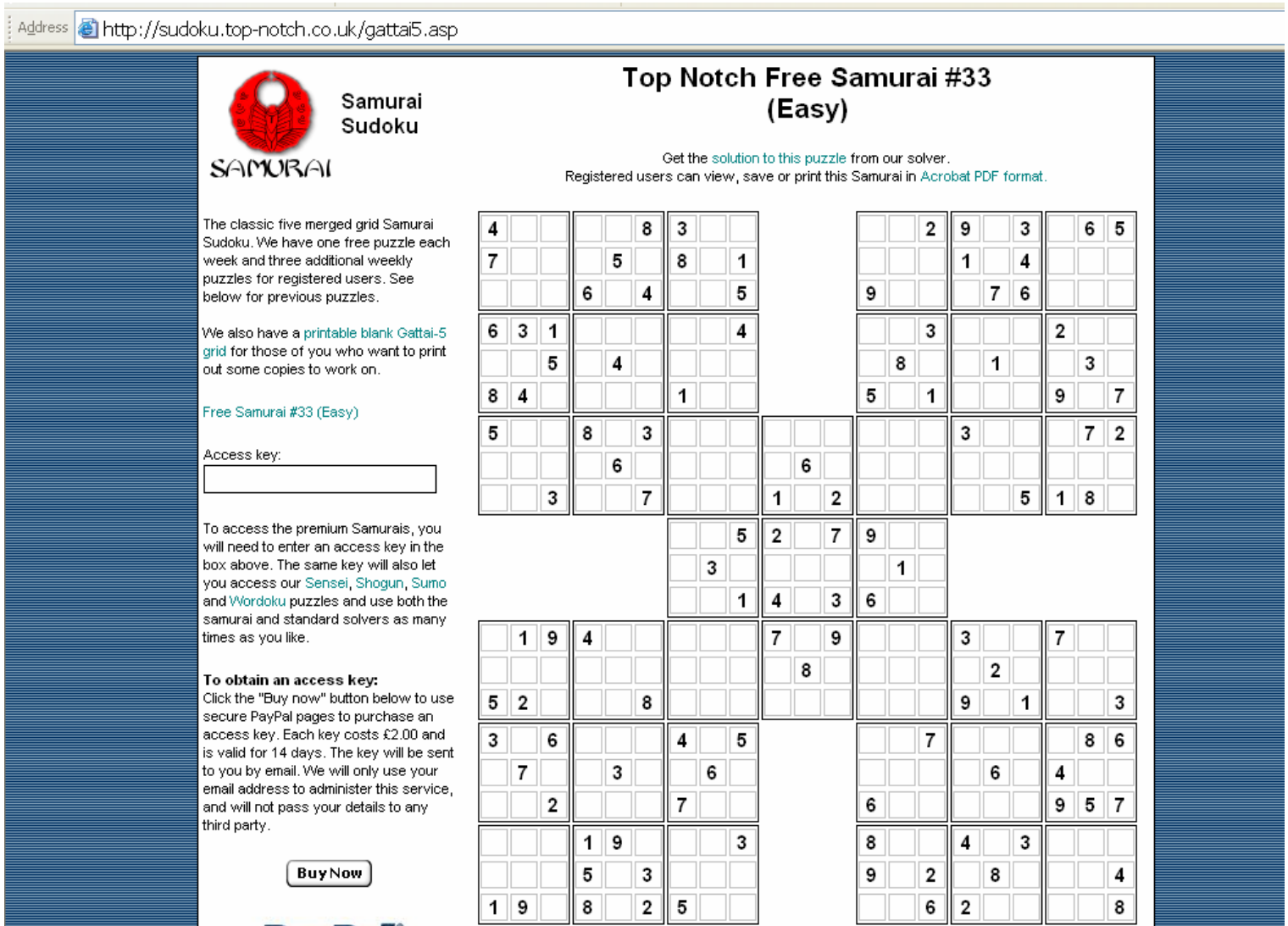
- Complements the ASCII text data input
- Advantages:
  - Fast exchange of data (factor >20)
  - Syntactical check on data before model starts
  - Compile-time and Run-time Data Exchange
  - Platform Independent

- Hands-on! IDE GDX browser

GDX Tools


IDE
GDX Viewer
GDX
API
gdxsplit
gams
GDX
gdxmerge
gdxxrw
(MS Office)
gdxdiff
gdxdump

Samurai Sudoku



Data in Excel and GAMS in Control

- GAMS is the driving program
- Data is stored in Excel (database)
- Use gdxxrw to import data from Excel
- Use gdxxrw to export data to Excel

- Hands-on: samurai_mrb, samurai_xls

Calling GAMS from an Application

Creating Input for GAMS Model
Callout to a GAMS Process/Executable
Reading Output from GAMS Model

- Works from basically every environment
  - Web application (server side)
  - Application Builder
    - Oracle, Eclipse, .NET, …
    - Regular Programming language C++, Java, VB, …
  - MS Office Application / VBA

- Hands-on! samurai_vb.xls

A few Words about Maintenance

Optimization
- Takes Longer than one is willing to wait
- It will eventually fail

Application
- Real Time
- Always need a *Solution* to Problem

- Key for support/maintenance
  - Catch problems before a model is solved
    - Implement Data Error checks
  - Reproduce the problem offline
    - Get hold of Instance (`dumpopt=11`)
  - Solver related problems in confidential models
    - Get scalar Model using solver **CONVERT**

Summary

- 30+ Years Experience in Modeling
  - Strong views on modeling process (*The GAMS Way*)
    - Development
    - Deployment
    - Maintenance
  - Less than 5% of modeling/optimization projects do not fit the GAMS way
  - Use of GAMS and its productivity tools (after potentially steep learning curve)
    - Increases productivity of model building
    - Reduces total cost of ownership for model client
    - Opens doors to a large network of GAMS developers and clients with modeling needs

Contacting GAMS

Europe:

GAMS Software GmbH
Eupener Str. 135-137
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