



# Rapid Application Prototyping with GAMS

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# Welcome/Agenda

GAMS Development / GAMS Software

Working with GAMS – A Guided Tour

Model Development

Model Deployment and Maintenance



# Agenda

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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
-



# Network of Application Partners

**ETSAP**

**TELEGYR<sup>®</sup>**  
SYSTEMS

**COWI**

**OPTIENCE**



**BARKAWI**

**COPENHAGEN ECONOMICS**



**VA TECH SAT**



**SAT**  
AUTOMATION



**profitpoint**



**CGR**

**Verbund**



**EcoMod<sup>®</sup>Net**

**NeqUIT**



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# GAMS at a Glance

The screenshot displays the GAMS software interface with several windows open:

- Code Editor:** Shows GAMS code for creating a GDX file for charting, including parameters for years and data sets.
- Data Table:** A table listing model entries with columns for Entry, Symbol, Type, Dim, and Nr Elem. The selected entry is '12 StockData' with 800 elements.
- StockData Chart:** A line chart showing data for four companies: IBM (red), DELL (green), HP (yellow), and SUN (blue) over time.
- Surface Plot:** A 3D plot of a surface, likely representing a solution space or optimization results.
- Log Window:** Shows the execution log, including job start and stop times, and the status 'Normal completion'.

## General Algebraic Modeling System:

Algebraic Modeling Language,  
Integrated Solver, Model  
Libraries, Connectivity- &  
Productivity Tools

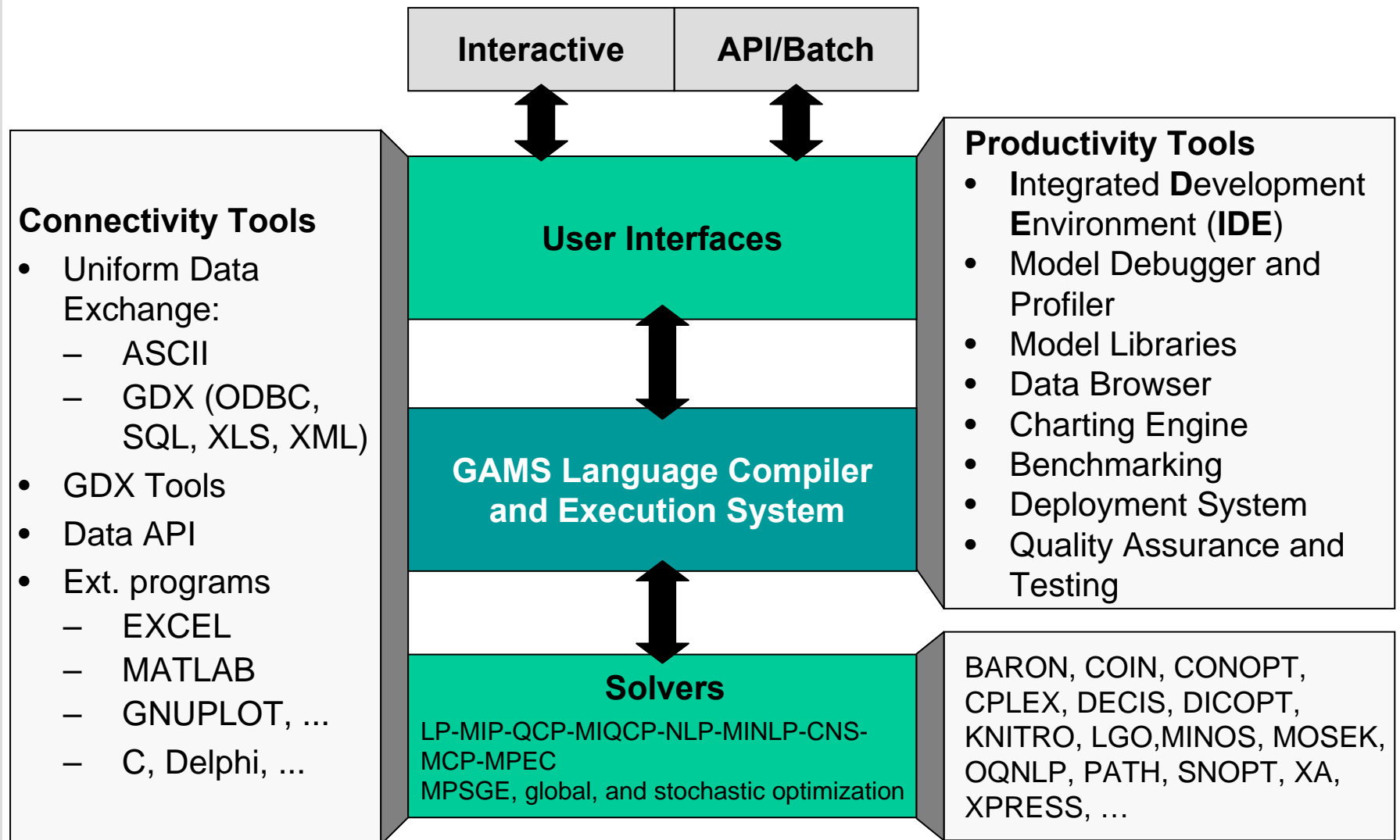
## Design Principles:

- 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



## Connectivity Tools

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

## Productivity Tools

- Integrated Development Environment (IDE)
- Model Debugger and Profiler
- Model Libraries
- Data Browser
- Charting Engine
- Benchmarking
- Deployment System
- Quality Assurance and Testing

## Solvers

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

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



# Hands-on! Installing GAMS

**Setup - GAMS 22.2**

Welcome to the GAMS 22.2 Setup Wizard

**Setup - GAMS 22.2**

Select Components

Which components should be installed?

Select the components you want to install; clear the components you do not want to install. Click Next when you are ready to continue.

Full installation

McCarl User Guide 13.5 MB

**Copy license file**

Look in: tmp

oe	currstate.txt
Office-Bibliothek	d.txt
prill	dc5557.txt
rui	dict.txt
server-4.0	dictorg.txt
spec	distd.txt
sungrid	eins.txt
wizardry	env.txt
100x2_2005_12-13_NEXC.txt	Ergeb.txt
album.txt	file2.txt
allruns.txt	gamslice.txt
bestbnd.txt	gamslog.txt
ccgroup.txt	glow.txt

File name: gamslice.txt

Files of type: license file

Open Cancel

**lewis.gams.com - PuTTY**

```
$ls
euro06lnx.zip
$unzip euro06lnx.zip
Archive:  euro06lnx.zip
  inflating:  lx3gams_sfx.exe
  inflating:  gamslice.txt
$./lx3gams_sfx.exe
UnZipSFX 5.41 of 16 April 2000, by Info-ZIP (Zip-Bugs@lists.wku.edu) .
  extracting:  gams.zip
  inflating:  gamsinst
  inflating:  gamsunpack
  inflating:  gmsunzip
$rm euro06lnx.zip lx3gams_sfx.exe
$./gamsinst -a

gamsinst version 034
=====
Installation of GAMS distribution 22.2

Unpacking GAMS ...
  estimated disk blocks needed : 20480, available : 92
3181
  executing--> ./gamsunpack

$export PATH=/home/susanne/euro2006/:$PATH
```



# Hands-on! Testing the installation

**GAMS Model Library Version 24.0**

Search:

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 surface

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

File Edit Search Windows Utilities Help

Call

**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
growthcy(c, z)(growthcy(c, z) at 3) = 3.0 ;
    
```

**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 GO60626/0001CB-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

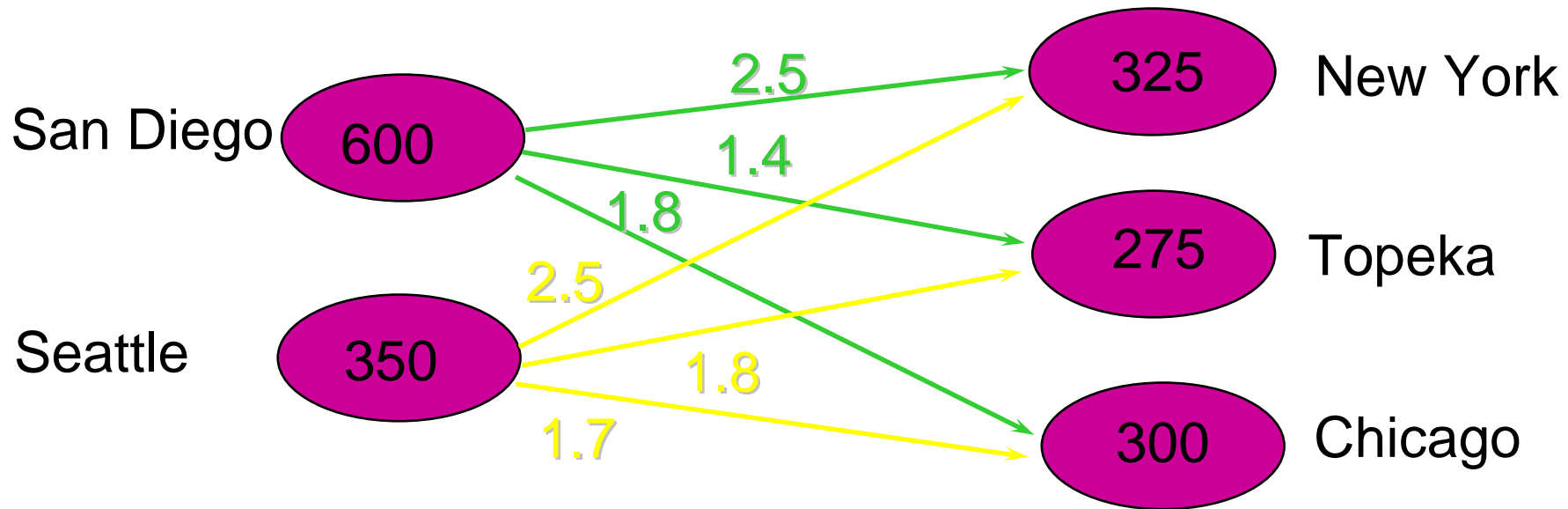
GAMS/Cplex Apr 21, 2006 LNX.CP.CP 22.2 031.034.041.LX3 For Cplex 10.0
Cplex 10.0.1, GAMS Link 31
Cplex licensed for 1 use of lp, qp, mip and barrier, with 4 parallel threads.

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

$$\sum_{\substack{c,p: \\ (c,p) \in \mathcal{N}}} tcost \cdot dist(c,p) \cdot x_p^c \rightarrow \min$$
$$\sum_{\substack{c,p: \\ (c,p) \in \mathcal{N}}} x_p^c \leq sup(c) \quad \forall c$$
$$\sum_{\substack{c,p: \\ (c,p) \in \mathcal{N}}} x_p^c \geq dem(p) \quad \forall p$$
$$x_p^c \geq 0 \quad \forall c, p : (c, p) \in \mathcal{N}$$



# GAMS Syntax – GAMS Algebra

```
IDE gamside: C:\Documents and Settings\bussieck\My Documents\gamsdir\project.gpr - [c:\documents an...
IDE File Edit Search Windows Utilities Help
call
transport.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/ ;
```



# GAMS Syntax – cont.

- Symbols:
  - Sets `Set I some stuff /cat,dog,ding1*ding10/`
  - Parameters `Parameter life(I) life count / cat 7 /`
  - Variables `Integer Variable x(I) number to purchase;`
  - Equations `Equation e(I) relate something;`
  - Models `Model animallife /e, some, more/;`
  - ASCII Output Files `File fx some file / 'c:\t\text.txt' /`
  
- Statements
  - Declaration+Data statement `Set I /cat,dog/;`
  - Data Assignments `life('dog')=life('cat')-1; x.lo(I)=1;`
  - Equation Definition `e(I).. Sqr(x(I)) =l= log(life(I));`
  - Programming Flow Control `loop(I, put fx I.t1);`
  - Option statement `Option reslim=10;`



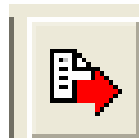


## Hands-On! Inspect trnsport.gms

- 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



# 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				

(c) Daily Sudoku Ltd 2006. All rights reserved.

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
Today's SuDoku
<b>SuDoku Archive</b>
SuDoku for Kids
Draw/Play
Discussion
FAQ
Books
Syndication
Links
Email and News
Contact

Daily Seasonal Sudoku: Fri 23-Dec-2005 [[instructions](#)]

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

© Daily Sudoku Ltd 2005. All rights reserved.

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



## Hands-on! Basic Sudoku (*su1* -> *su2*)

- Basic model *su1* computes solution to Sudoku
- Is the solution unique?
- If not, how many solutions exist?
- Edits for *su1* -> *su2*:
  - Implement binary cuts to exclude known solutions
  - To cut off *xb*:  $\sum(i, \text{abs}(xb(i)-x(i)) = g = 1$ ;
  - Use loop to find and store solutions
  - Use GDX to view model data and solution



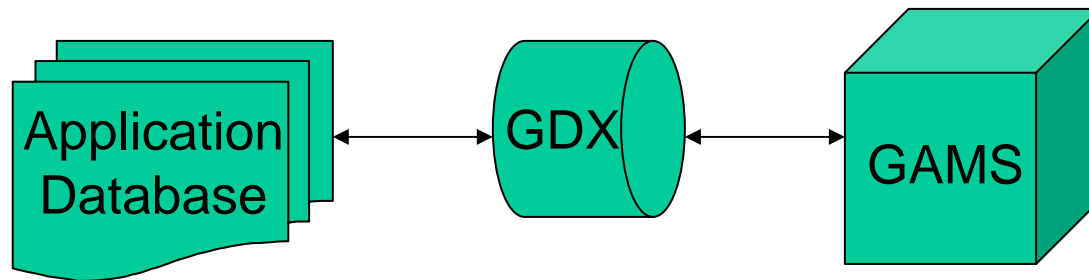
# Input/Output through ASCII Files

- 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

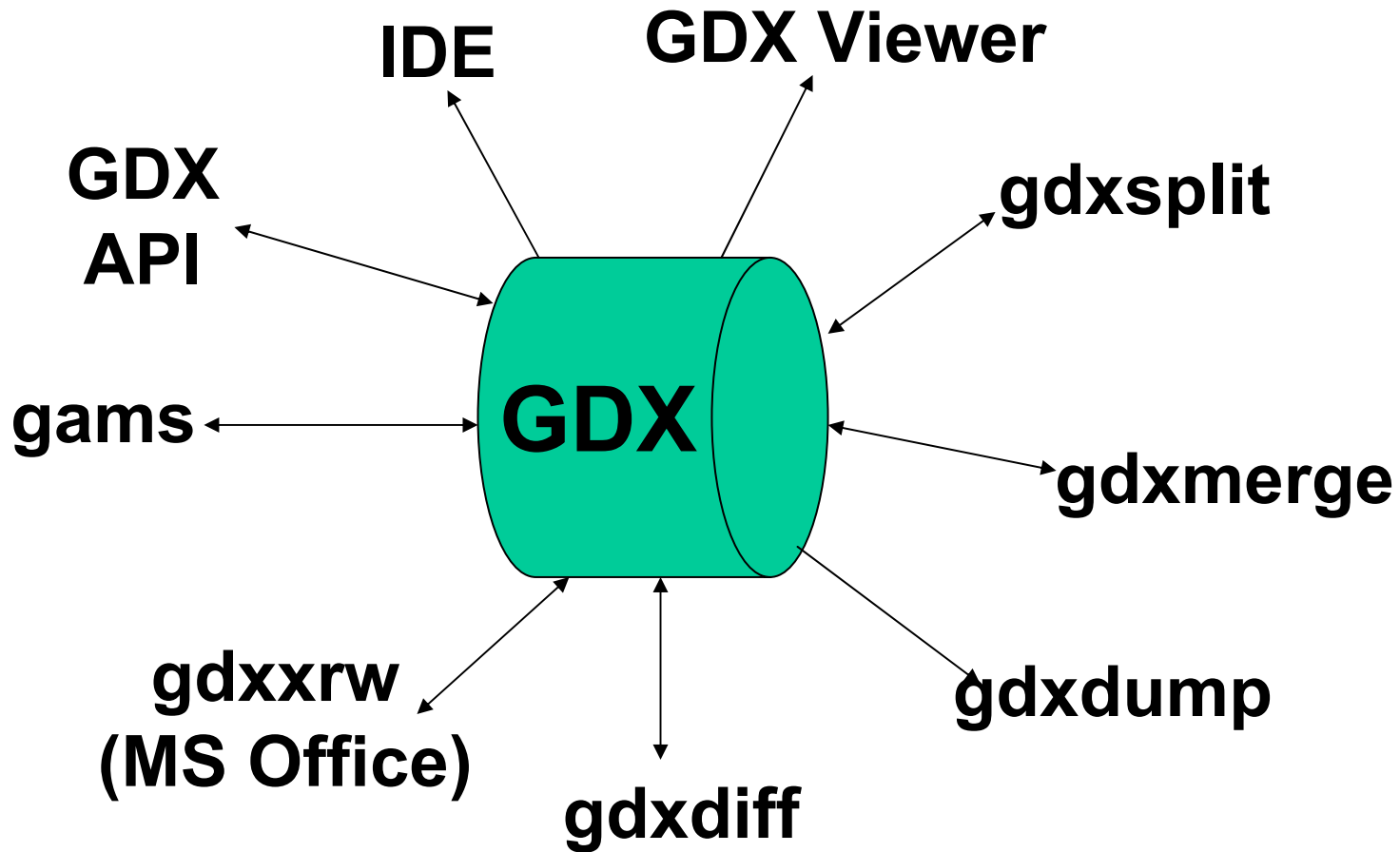
- **GAMS Data eXchange (GDX):**



- 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



# GDX Tools







## Hands-on! Report on all solutions (su3)

- Find a “good” cell to fix
  - A good fix is one that leaves few (one?) solutions
  - Compute result of any fix using saved GDX data



## Hands-on! Force Uniqueness ( $su2 \rightarrow su4$ )

- Set cell r7.c4 to the value 4 (c.f.  $su3$ )
- Verify that the resulting solution is unique



# Hands-on! Text output (*rep0* - *rep3*)

```
+-----+-----+-----+
|  4      |    5    |      |
|         |    3    |      |
|         |    5    |      |
+-----+-----+-----+
|    7    |    1    |  6    | |
|    7    |    5 1  |      |
|    5    |    7    |  2    |  8    |
+-----+-----+-----+
|  2    2  |  4 5 5  |    4  |
|         |    6    |      |
|         |  2    5  |    7  |
+-----+-----+-----+
```



## Hands-on! Infeasible Sudoku (*su1* -> *su5*)

- What should we do with an infeasible Sudoku?
  - Not enough to just report the infeasibility
  - Here, repair the data to make the model feasible
- Edits for going from *su1* -> *su5*
  - Add binary variable `undo` (relaxes fixed cells)
  - Remove `x.fx` for fixed cells
  - Use random generation to get bogus data



# Samurai Sudoku

Address <http://sudoku.top-notch.co.uk/gattai5.asp>



Samurai  
Sudoku

SAMURAI

## Top Notch Free Samurai #33 (Easy)

Get the [solution to this puzzle](#) from our solver.

Registered users can view, save or print this Samurai in [Acrobat PDF format](#).

The classic five merged grid Samurai Sudoku. We have one free puzzle each week and three additional weekly puzzles for registered users. See below for previous puzzles.

We also have a [printable blank Gattai-5 grid](#) for those of you who want to print out some copies to work on.

[Free Samurai #33 \(Easy\)](#)

Access key:

To access the premium Samurais, you will need to enter an access key in the box above. The same key will also let you access our [Sensei](#), [Shogun](#), [Sumo](#) and [Wordoku](#) puzzles and use both the samurai and standard solvers as many times as you like.

### To obtain an access key:

Click the "Buy now" button below to use secure PayPal pages to purchase an access key. Each key costs £2.00 and is valid for 14 days. The key will be sent to you by email. We will only use your email address to administer this service, and will not pass your details to any third party.

[Buy Now](#)

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



## Hands-on! Mapping data (map1)

- We solve the Samurai as 5 basic puzzles, with linking constraints for the overlapping cells
- Requires mapping 21x21 Samurai puzzle into separate 9x9 puzzles



## Hands-on! Samurai model (su5 -> su6)

- Add puzzle index  $p$  to all variables/equations
- Add linking constraints
- Use random data to test
- Fix undo variables initially to 0
  - If the model is feasible, it will solve quickly
  - If infeasible, we unfix undo and resolve



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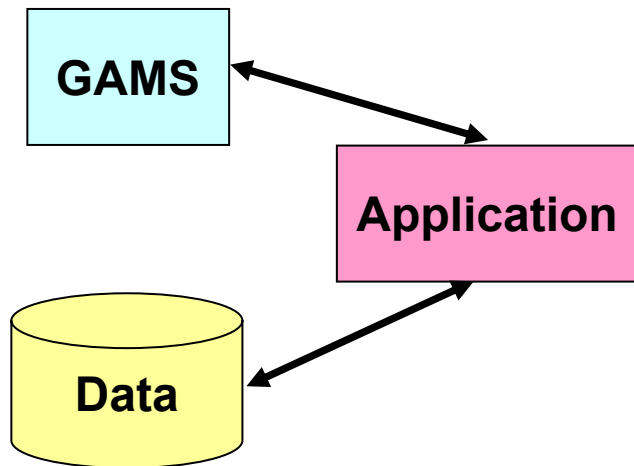


# Important Principles

- 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)

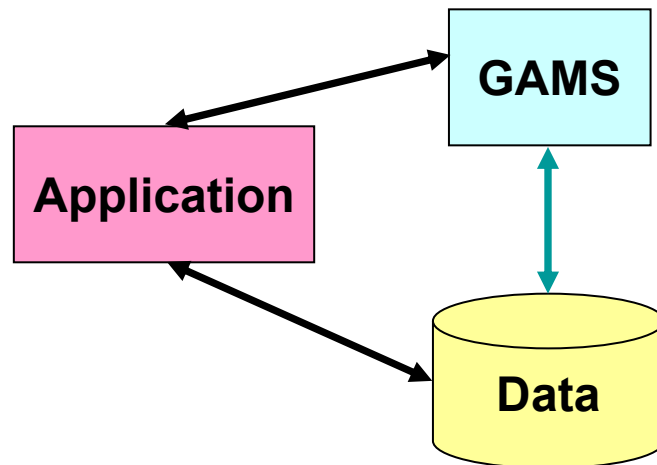


# Flow of Data



## Data Model I

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



## Data Model II

- Large Scale/Raw data exchange  $\text{GAMS} \leftrightarrow \text{DB}$
- Control Data  $\text{GAMS} \leftrightarrow \text{Application}$



## Hands-on! Excel in charge (samurai\_vb)

- Existing Samurai model with Excel GUI
- Look at data communication between model and GUI



## Hands-on! Samurai data input (su6 -> su7)

- Prepare our Samurai model su6 to plug in to spreadsheet
- Import/export 21x21 data from GUI (via GDX)
- Use mappings from map1 to map 21x21 -> 5x9x9
- Validate solution produced via GDXDIFF
  - Compare to solution from old application



## Hands-on! Clean up (su7 -> su8)

- Create text file for display in GUI



# 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:

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<http://www.gams.com>