INFORMS CONFERENCE ON BUSINESS ANALYTICS & OPERATIONS RESEARCH
April 12-14, 2015 | Huntington Beach, CA

GAMS

# The Role and Impact of Algebraic Modeling Languages in and on Industrial Optimization

Franz Nelissen: FNelissen@gams.com

# Company

- Roots: World Bank, 1976
- Went commercial in 1987
- Locations
  - GAMS Development Corporation (Washington)
  - GAMS Software GmbH (Germany)
- Product: The **G**eneral **A**lgebraic **M**odeling **S**ystem

# GAMS - System Highlights

Powerful algebraic modeling language with open architecture

Robust, scalable state-of-the-art modeling technology for complex, large-scale modeling applications

Uniform interface to all major commercial and academic solvers (30+ integrated)

GAMS

# Broad User Community and Network

11,500+ licenses

Users: 50% academic, 50% commercial

GAMS used in more than 120 countries

**25+ Years**
GAMS Development

GAMS

# but…

"… - asking yourself why you would do optimization in GAMS, software that looks as modern and friendly as Richard Nixon."

Customer review on Amazon.com for S. Zenios, S. Nielson, and A. Consiglio "Practical Financial Optimization: A Library of GAMS Models", Wiley, 2009

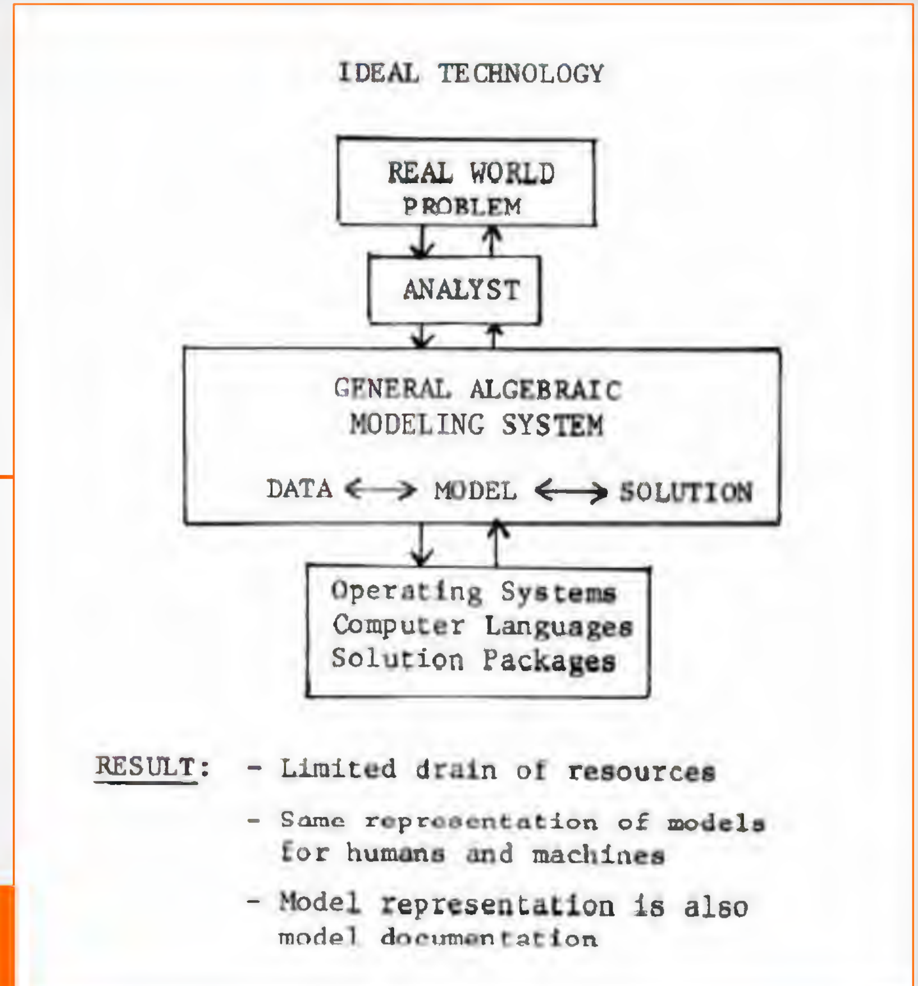
# Agenda

- GAMS – Elements, Enhancements, and Examples
- Enhancements around GAMS
- Some Case Studies
- Past – Presence – Future

GAMS

# 1976 - A World Bank Slide

The Vision




GAMS came into being!

# What did this vision give us?

Simplified model development, changes, and transfer

Made mathematical optimization available to a broader audience (domain experts)

Increased productivity tremendously

GAMS

# Foundation of GAMS

Powerful algebraic modeling language

Open architecture and interfaces to other systems, independent layers (platform, solver, data, interface)

# Simple Declarative Language

Similar to mathematical notation

Easy to learn - few basic language elements: sets, parameters, variables, equations, models

Model is executable description of the problem

# Similar to Mathematical Notation

The algebraic representation of this problem is usually presented in a format similar to the following.

Indices:
- $i$ = plants
- $j$ = markets

Given Data:
- $a_i$ = supply of commodity of plant $i$ (in cases)
- $b_j$ = demand for commodity at market $j$
- $c_{ij}$ = cost per unit shipment between plant $i$ and market $j$ (\$/case)

Decision Variables:
- $x_{ij}$ = amount of commodity to ship from plant $i$ to market $j$ (cases),
- where $x_{ij} \geq 0$, for all $i$, $j$

Constraints:
- Observe supply limit at plant $i$: $\sum_j x_{ij} \leq a_i$
- Satisfy demand at market $j$: $\sum_i x_{ij} \geq b_j$
- Objective Function: Minimize $\sum_i \sum_j c_{ij} x_{ij}$

```
Sets
     i   canning plants   / seattle, san-diego /
     j   markets          / new-york, chicago, topeka / ;
Parameters
     a(i)  capacity of plant i in cases
     b(j)  demand at market j in cases
     c(i,j)  transport cost in thousands of dollars per case ;
Variables
     x(i,j)  shipment quantities in cases
     z       total transportation costs in thousands of dollars ;
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/ ;
```

# Model2Tex

```
Sets
     i   canning plants    / seattle, san-diego /
     j   markets           / new-york, chicago, topeka
Parameters
     a(i)  capacity of plant i in cases
     b(j)  demand at market j in cases
     c(i,j)  transport cost in thousands of dollars pe
Variables
     x(i,j)  shipment quantities in cases
     z       total transportation costs in thousands o
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/ ;
```

## Symbols

### Sets

| Name | Domains | Description |
|---|---|---|
| i | * | canning plants |
| j | * | markets |

### Parameters

| Name | Domains | Description |
|---|---|---|
| a | i | capacity of plant i in cases |
| b | j | demand at market j in cases |
| c | i, j | transport cost in thousands of dollars per case |

### Variables

| Name | Domains | Description |
|---|---|---|
| x | i, j | shipment quantities in cases |
| z | | total transportation costs in thousands of dollars |

### Equations

| Name | Domains | Description |
|---|---|---|
| cost | | define objective function |
| supply | i | observe supply limit at plant i |
| demand | j | satisfy demand at market j |

## Equation Definitions

**cost**

$$z = \sum_{i,j}(c_{i,j} \cdot x_{i,j})$$

**supply$_i$**

$$\sum_{j}(x_{i,j}) \leq a_i \qquad \forall i$$

**demand$_j$**

$$\sum_{i}(x_{i,j}) \geq b_j \qquad \forall j$$

$$x_{i,j} \geq 0 \ \forall i, j$$

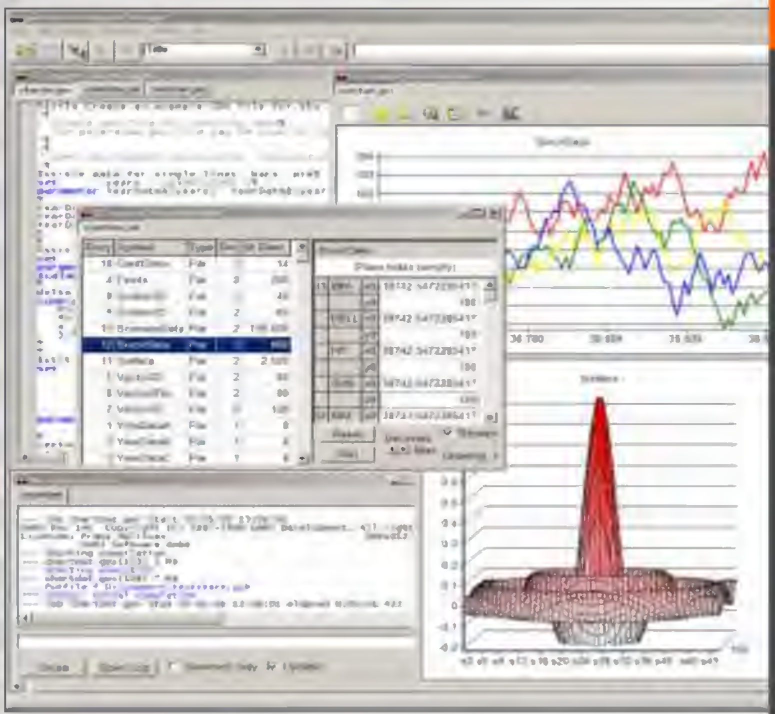
# Mix of Declarative and Imperative Elements

## Control Flow Statements (e.g. loops, for, if,...), macros and functions

1. Build complex problem algorithms within GAMS
2. Simplified interaction with other systems:
   - Data exchange
   - GAMS process control

GAMS

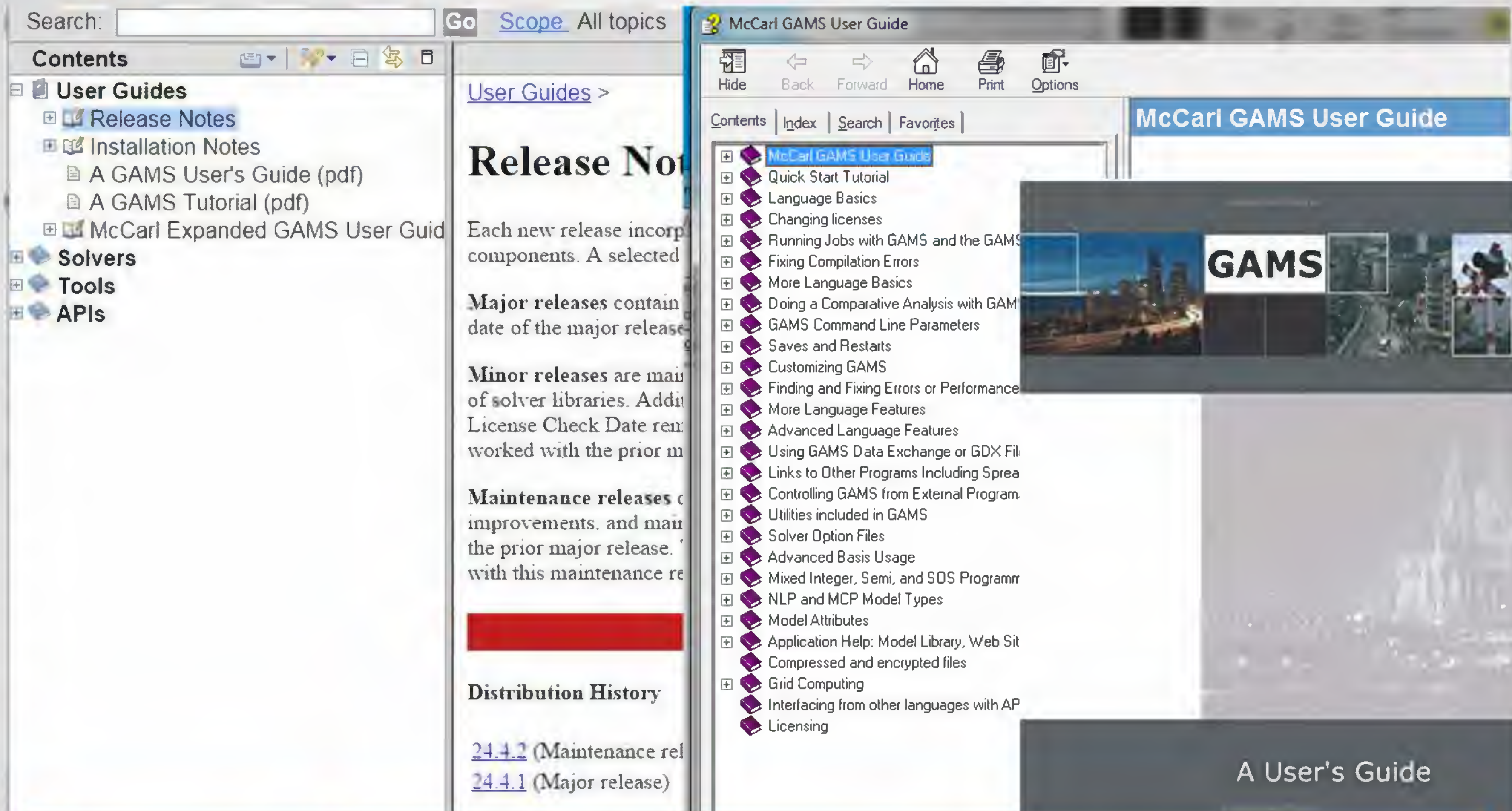
# Strong Development Environment



## GAMS IDE

- Project management
- Editor / Syntax coloring / Spell checks
- Tree view / Syntax-error navigation
- Model Debugging & Profiling
- Solver selection & setup
- Data viewer
  - Export
  - Charting
- GAMS Processes Control

# System Documentation




- Html, Windows Help, Pdf (printed)

GAMS

# Free Model Libraries


➤ **More than 1400 models!**

GAMS

# Foundation

Powerful algebraic modeling language

Open architecture and interfaces to other systems, independent layers (platform, solver, data, interface)

# Independence of Model and Platform

## Supported Platforms

Microsoft Windows | Linux | Welcome to Mac OS X | solaris | AIX

➢ **Move models between platforms with ease!**

Model

Platform | Solver | Data | Interface

GAMS

# Independence of Model and Platform

**Local and distributed / remote execution**

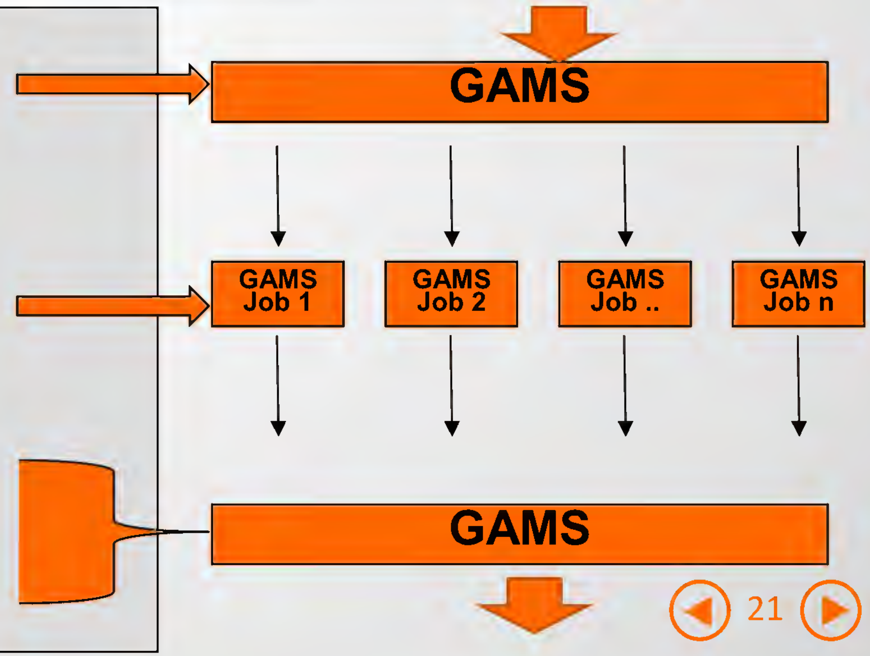
- Distributed MIP (CPLEX, GUROBI)
- Grid Computing Facility
- NEOS (Kestrel)

# GAMS Grid Computing Facility

GAMS jobs in a **distributed** environment

- Scalable: supports large grids, but also works on local machine
- Platform independent, works with all solvers/model types
- Only minor changes to model required

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



# Grid Computing Facility - Example

C:\Users\franz\Documents\gamsdir\projdir\trnsgrid.gms

trnsgrid.gms | trnsport.lst

```
              h(s) store the instance handle;

dem(s,j)= b(j)*uniform(.95,1.15); // create some random d

loop(s,
   b(j)  = dem(s,j)
   Solve transport using lp minimizing z;
   h(s)  = transport.handle );     // save instance handle

parameter repx(s,i,j) solution report
          repy        summary report;

repy(s,'solvestat') = na;
repy(s,'modelstat') = na;

* we use the handle parameter to indicate that the soluti
repeat
   loop(s$handlecollect(h(s)),
      repx(s,i,j) = x.l(i,j);
      repy(s,'solvestat') = transport.solvestat;
      repy(s,'modelstat') = transport.modelstat;
      repy(s,'resusd'   ) = transport.resusd;
      repy(s,'objval')    = transport.objval;
      display$handledelete(h(s)) 'trouble deleting handle
      h(s) = 0 ) ;    // indicate that we have loaded the
   display$sleep(card(h)*0.2) 'was sleeping for some time
until card(h) = 0 or timeelapsed > 10;  // wait until all

display repx, repy;

abort$sum(s$(repy(s,'solvestat')=na),1) 'Some jobs did no
```

No active process

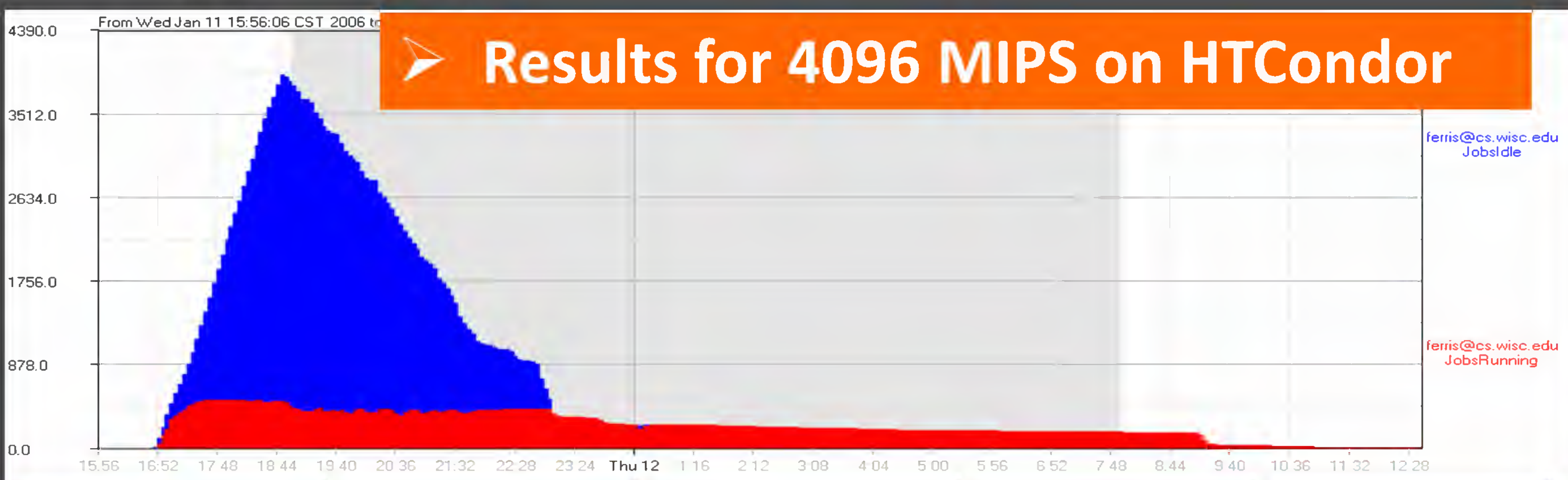
trnsgrid

```
--- Job trnsgrid.gms Start 04/08/15 19:03:10 24.4.3 r51699 
GAMS 24.4.3   Copyright (C) 1987-2015 GAMS Development. All
Licensee: Franz Nelissen                                S1
          GAMS Software GmbH / GAMS Development Corporation
--- Starting compilation
--- trnsgrid.gms(101) 3 Mb
--- Starting execution: elapsed 0:00:00.124
--- trnsgrid.gms(75) 4 Mb
--- Generating LP model transport
--- trnsgrid.gms(77) 4 Mb
--- LOOPS s = 1
---   6 rows  7 columns  19 non-zeroes
--- Submitting model transport with handle grid145000001
--- Executing after solve: elapsed 0:00:00.484
--- trnsgrid.gms(75) 4 Mb
--- Generating LP model transport
--- trnsgrid.gms(77) 4 Mb
--- LOOPS s = 2
---   6 rows  7 columns  19 non-zeroes
--- Submitting model transport with handle grid145000002
--- Executing after solve: elapsed 0:00:00.602
--- trnsgrid.gms(75) 4 Mb
--- Generating LP model transport
--- trnsgrid.gms(77) 4 Mb
--- LOOPS s = 3
---   6 rows  7 columns  19 non-zeroes
--- Submitting model transport with handle grid145000003
--- Executing after solve: elapsed 0:00:00.733
--- trnsgrid.gms(75) 4 Mb
--- Generating LP model transport
--- trnsgrid.gms(77) 4 Mb
--- LOOPS s = 4
---   6 rows  7 columns  19 non-zeroes
--- Submitting model transport with handle grid145000004
--- Executing after solve: elapsed 0:00:00.879
--- trnsgrid.gms(75) 4 Mb
```

➢ More Examples in the GAMS Model Library!

# Grid Computing Facility - HTCondor

- Submission started Jan 11,16:00
- All jobs submitted by Jan 11, 23:00
- All jobs returned by Jan 12, 12:40
  - 20 hours wall time, 5,000 CPU hours
  - Peak number of CPU's: 500




➢ **Results for 4096 MIPS on HTCondor**

# GAMS/Kestrel

- Remote Solver Execution on NEOS Servers
- Stay in your GAMS environment
- Results are being processed as with any local solver

**Local Machine** ⟷ **Remote Cluster**

```
Model transport /all/;
Option lp=kestrel;
transport.optfile=1;

$onecho > kestrel.opt
kestrel_solver xpress
$offecho

Solve transport using lp minimizing z;
```

```
--- Executing KESTREL: elapsed 0:00:00.006
Connecting to: http://neos-server.org:3332
NEOS Solver: xpress
NEOS job#=3631352, pass=iJLdAkhP

Check the following URL for progress report :
http://neos-server.org/neos/cgi-bin/nph-neos-
solver.cgi?admin=results&jobnumber=3631352&pass=i
JLdAkhP
Job 3631352 dispatched
password: iJLdAkhP
---------- Begin Solver Output -----------
Job submitted to NEOS HTCondor pool.

FICO-Xpress      24.3.3 r48116 Released Sep 19,
2014 LEG x86 64bit/Linux
```

# Independence of Model and Solver

**Solver/Model type availability - 24.4**

| | LP | MIP | NLP | MCP | MPEC | CNS | DNLP | MINLP | QCP | MIQCP | *Stoch.* | *Global* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ALPHAECP | | | | | | | | ✔ | | ✔ | | |
| ANTIGONE 1.1 | | | ✔ | | | ✔ | ✔ | ✔ | ✔ | ✔ | | ✔ * |
| BARON 14.4 | ✔ | ✔ | ✔ | | | ✔ | ✔ | ✔ | ✔ | ✔ | | ✔ * |
| BDMLP | ✔ | ✔ | | | | | | | | | | |
| BONMIN 1.7 | | | | | | | | ✔ | | ✔ | | |
| CBC 2.8 | ✔ | ✔ | | | | | | | | | | |
| CONOPT 3 | ✔ | | ✔ | | | ✔ | ✔ | | ✔ | | | |
| COUENNE 0.4 | | | ✔ | | | ✔ | ✔ | ✔ | ✔ | ✔ | | ✔ * |
| CPLEX 12.6 | ✔ | ✔ | | | | | | | ✔ | ✔ | | |
| DECIS | ✔ | | | | | | | | | | ✔ | |
| DICOPT | | | | | | | | ✔ | | ✔ | | |
| GLOMIQO 2.3 | | | | | | | | | ✔ | ✔ | | ✔ * |
| GUROBI 6.0 | ✔ | ✔ | | | | | | | ✔ | ✔ | | |
| GUSS | | | | | | | | | | | | |
| IPOPT 3.1 | | | | | | | | | | | | |
| KNITRO 9 | | | | | | | | | | | | |
| LGO | | | | | | | | | | | | |
| LINDO 9. | | | | | | | | | | | | |
| LINDOGL | | | | | | | | | | | | |
| LOCALS | | | | | | | | | | | | |
| MILES | | | | | | | | | | | | |
| MINOS | ✔ | | ✔ | | | ✔ | ✔ | | ✔ | | | |
| MOSEK 7 | ✔ | ✔ | ✔ | | | | ✔ | | ✔ | ✔ | | |
| MPSGE | | | | | | | | | | | | |
| MSNLP | | | ✔ | | | | ✔ | | ✔ | | | ✔ |
| NLPEC | | | | ✔ | ✔ | | | | | | | |
| OQNLP | | | ✔ | | | | ✔ | ✔ | ✔ | ✔ | | ✔ |
| PATH | | | | ✔ | | ✔ | | | | | | |
| SBB | | | | | | | | ✔ | | ✔ | | |
| SCIP 3.1 | | ✔ | ✔ | | | ✔ | ✔ | ✔ | ✔ | ✔ | | ✔ * |
| SNOPT | ✔ | | ✔ | | | ✔ | ✔ | | ✔ | | | |
| SOPLEX 2.0 | ✔ | | | | | | | | | | | |
| SULUM 4.0 | ✔ | ✔ | | | | | | | | | | |
| XA | ✔ | ✔ | | | | | | | | | | |
| XPRESS 27.01 | ✔ | ✔ | | | | | | | ✔ | ✔ | | |

* deterministic global solver

**One environment for a wide range of model types and solvers**

Model

Platform | Solver | Data | Interface

# Independence of Model and Solver

| Solver/Model type availability - 24.4 | LP | MIP | NLP | MCP | MPEC | CNS | DNLP | MINLP | QCP | MIQCP | *Stoch.* | *Global* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ALPHAECP | | | | | | | | ✔ | | ✔ | | |
| ANTIGONE 1.1 | | | ✔ | | | ✔ | ✔ | ✔ | ✔ | ✔ | | ✔* |
| BARON 14.4 | ✔ | ✔ | ✔ | | | ✔ | ✔ | ✔ | ✔ | ✔ | | ✔* |
| BDMLP | ✔ | ✔ | | | | | | | | | | |
| BONMIN 1.7 | | | | | | | | ✔ | | ✔ | | |
| CBC 2.8 | ✔ | ✔ | | | | | | | | | | |
| CONOPT 3 | ✔ | | ✔ | | | ✔ | ✔ | | ✔ | | | |
| COUENNE 0.4 | | | ✔ | | | ✔ | ✔ | ✔ | ✔ | ✔ | | ✔* |
| CPLEX 12.6 | ✔ | ✔ | | | | | | | ✔ | ✔ | | |
| DECIS | ✔ | | | | | | | | | | ✔ | |
| DICOPT | | | | | | | | ✔ | | ✔ | | |
| GLOMIQO 2.3 | | | | | | | | | ✔ | ✔ | | ✔* |
| GUROBI 6.0 | ✔ | ✔ | | | | | | | ✔ | ✔ | | |
| GUSS | | | | | | | | | | | | |
| IPOPT 3.1 | | | | | | | | | | | | |
| KNITRO | | | | | | | | | | | | |
| LGO | | | | | | | | | | | | |
| LINDO 9. | | | | | | | | | | | | |
| LINDOGL | | | | | | | | | | | | |
| LOCALSO | | | | | | | | | | | | |
| MILES | | | | | | | | | | | | |
| MINOS | | | | | | | | | | | | |
| MOSEK 7 | | | | | | | | | | | | |
| MPSGE | | | | | | | | | | | | |
| MSNLP | | | ✔ | | | | ✔ | | ✔ | | | ✔ |
| NLPEC | | | | ✔ | ✔ | | | | | | | |
| OQNLP | | | ✔ | | | | ✔ | ✔ | ✔ | ✔ | | ✔ |
| PATH | | | | ✔ | | ✔ | | | | | | |
| SBB | | | | | | | | ✔ | | ✔ | | |
| SCIP 3.1 | | ✔ | ✔ | | | ✔ | ✔ | ✔ | ✔ | ✔ | | ✔* |
| SNOPT | ✔ | | ✔ | | | ✔ | ✔ | | ✔ | | | |
| SOPLEX 2.0 | ✔ | | | | | | | | | | | |
| SULUM 4.0 | ✔ | ✔ | | | | | | | | | | |
| XA | ✔ | ✔ | | | | | | | | | | |
| XPRESS 27.01 | ✔ | ✔ | | | | | | | ✔ | ✔ | | |

* deterministic global solver

Average number of commercial solvers per license:
- Academic clients: 2.9
- Commercial clients: 2.2

# Independence of Model and Solver

**Uniform interface to all major solvers:**

- Switching between solvers with one line of code
- Documentation
- Licensing (GAMS as a „license broker“)

GAMS

# Independence of Model and Solver

**One** environment for a wide range of model types and solvers

**Commercial LP/MIP solver available in GAMS**

FICO · Gurobi Optimization · IBM · mosek · Sulum

➢ **Switching between solvers with one line of code**

| Model | | | |
|---|---|---|---|
| Platform | Solver | Data | Interface |

GAMS

# Independence of Model and Solver

## One environment for a wide range of model types and solvers

**Open Source Solver (COIN) available in GAMS**

COIN|OR
COMPUTATIONAL INFRASTRUCTURE FOR OPERATIONS RESEARCH

Bonmin

CBC

CUENNE

IPOPT

SCIP

Model

Platform | Solver | Data | Interface

# Independence of Model and Solver

## CyBio Scheduler

- Scheduling software for high throughput screening
- Used in the pharmaceutical industry (drug discovery)
- Model optimizes throughput of robotic screening systems
- Solver
  - COIN for smaller instances
  - Commercial MIP solver for large problems
- Developed by analytikjena

Model

| Platform | Solver | Data | Interface |
|---|---|---|---|

GAMS

# Independence of Model and Solver

**One** environment for a wide range of model types and solvers

**Commercial NLP Solvers available in GAMS**

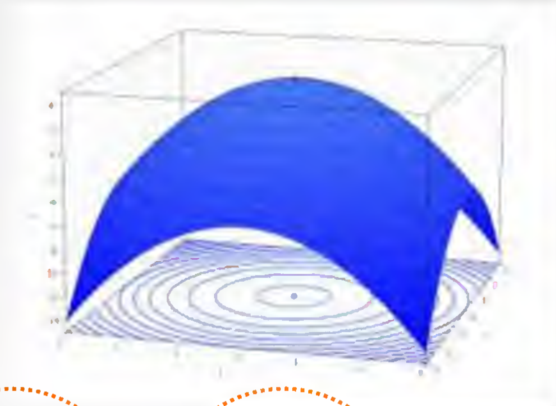
CONOPT

KNITRO

MINOS

PATH

SNOPT

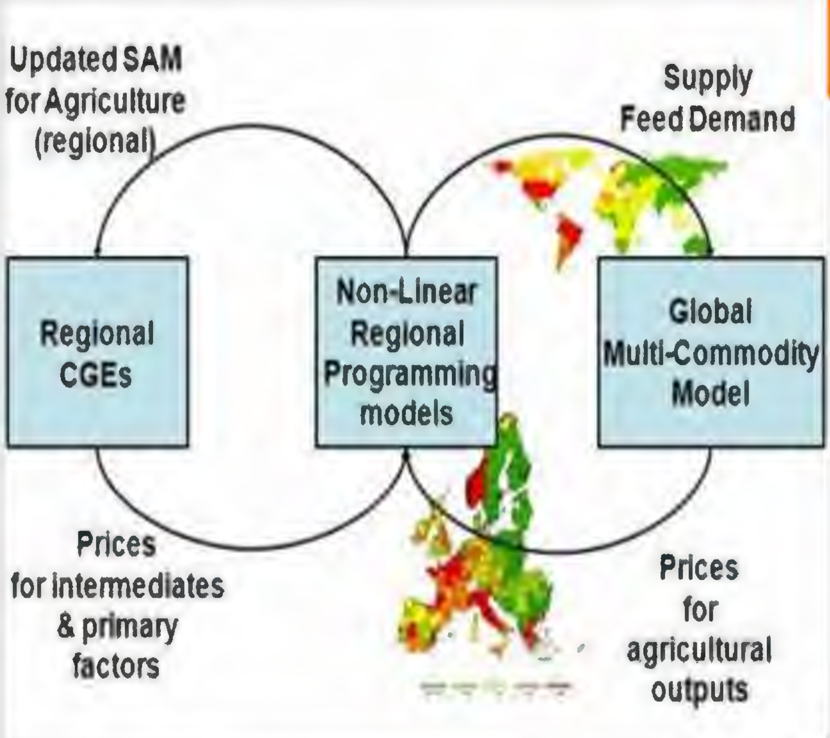


➢ **Switching between solvers with one line of code**

Model

Platform | Solver | Data | Interface

# Independence of Model and Solver




## CAPRI

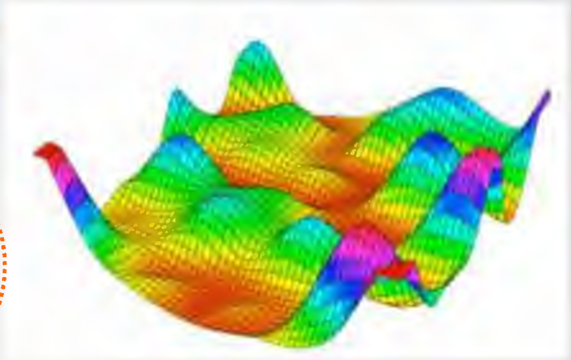
- Global agricultural sector models with focus on EU27 members
- Evaluates impacts of agricultural and trade policies on production income, markets, trade, and the environment
- Different NLP solvers
- Open source approach with an active network of developers and users coordinated by University of Bonn

GAMS

# Independence of Model and Solver

## One environment for a wide range of model types and solvers

**Commercial MINLP or Global Solver available in GAMS**



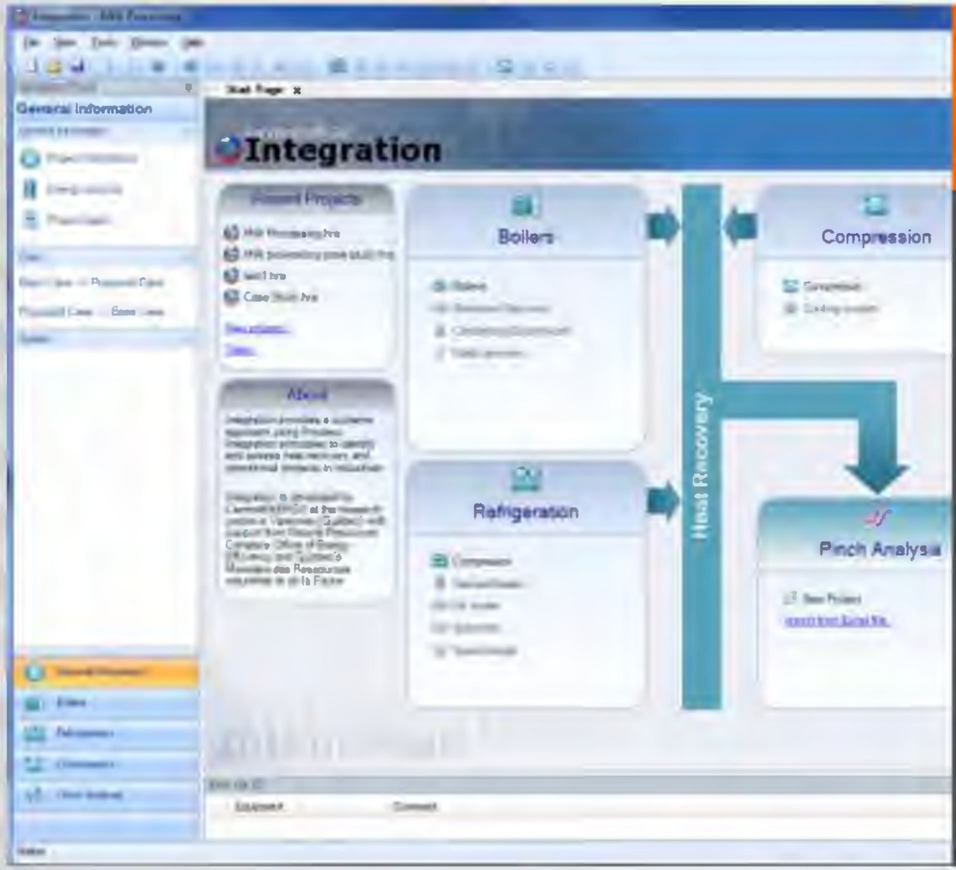
- AlphaECP
- *new* ANTIGONE
- BARON
- DICOPT
- LGO
- *new* Local Solver
- KNITRO
- MSNLP
- OQNLP
- SBB

➢ **Switching between solvers with one line of code**

| Model | | | |
|---|---|---|---|
| Platform | Solver | Data | Interface |

GAMS

# Independence of Model and Solver




## INTEGRATION

- Identifies, evaluates and selects energy efficiency projects in complex industrial facilities
- Solver:
  - BARON: MINLP
  - COIN: MIP
  - CONOPT: NLP
- Developed by Natural Resources Canada's CanmetENERGY research center

Model

Platform | Solver | Data | Interface

# Independence of Model and Solver

## One environment for a wide range of model types and solvers

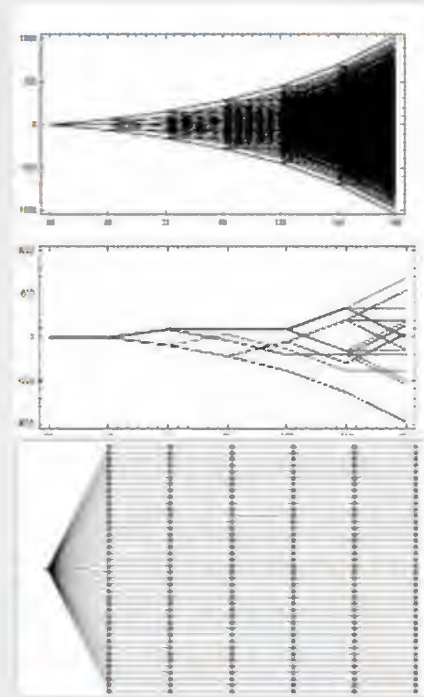
**Stochastic Optimization in GAMS**

DE

DECIS

LINDO

*Scenred*



➢ **Switching between solvers with one line of code**

Model

Platform | Solver | Data | Interface

GAMS

# Independence of Model and Data

gamside: C:\Users\franz\Documents\gamsdir\projdir\gmsproj.gpr

File Edit Search Windows Utilities Model Libraries Help

W( {a} a=c

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

trnsport.gms trnsport.lst

```
Sets
       i   canning plants,
       j   markets;
Parameters
      a(i)  capacity of plant i in cases
      b(j)  demand at market j in cases
      d(i,j)
      f  freight in dollars per case per thousand miles
      c(i,j)  transport cost in thousands of dollars per case ;
Variables
       x(i,j)  shipment quantities in cases
       z       total transportation costs in thousands of dollars
Positive Variable x ;
Equations
      cost         define objective function
      supply(i)    observe supply limit at plant i
      demand(j)    satisfy demand at market j ;
cost ..        z  =e=  sum((i,j), c(i,j)*x(i,j)) ;
supply(i) ..   sum(j, x(i,j))  =l=  a(i) ;
demand(j) ..   sum(i, x(i,j))  =g=  b(j) ;
Model transport /all/ ;
```

No active process

trnsport

```
--- Job trnsport.gms Start 03/28/15 12:31:1
GAMS 24.4.1   Copyright (C) 1987-2014 GAMS
Licensee: Franz Nelissen
          GAMS Software GmbH / GAMS Develop
--- Starting compilation
--- trnsport.gms(21) 2 Mb
*** Status: Normal completion
--- Job trnsport.gms Stop 03/28/15 12:31:15
```

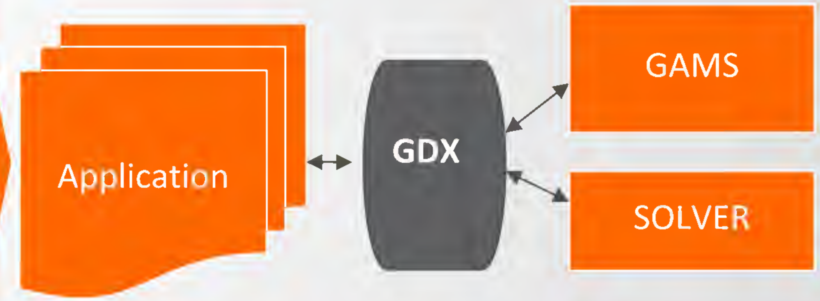
➢ Declarative Modeling

Model

Platform | Solver | Data | Interface

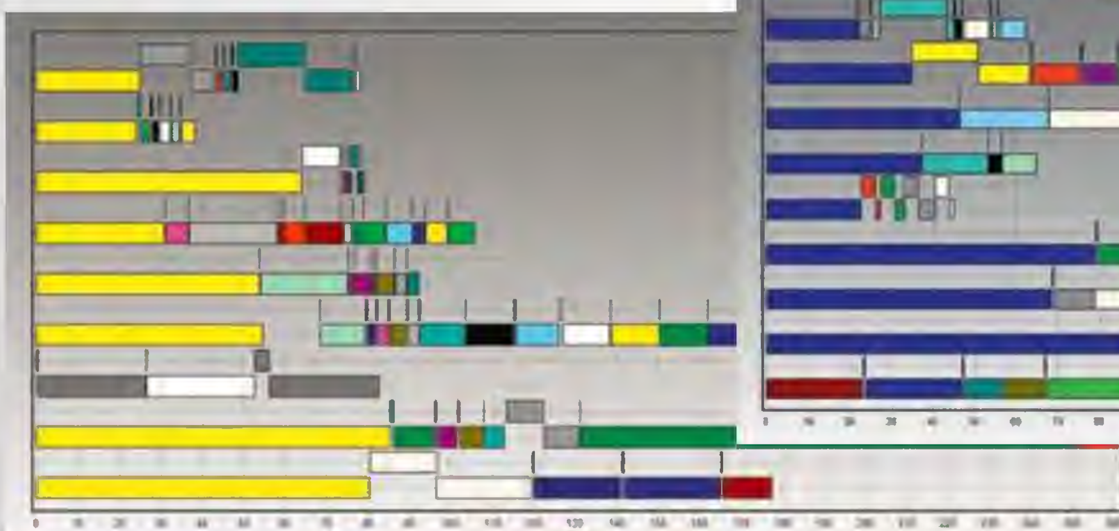
# Independence of Model and Data

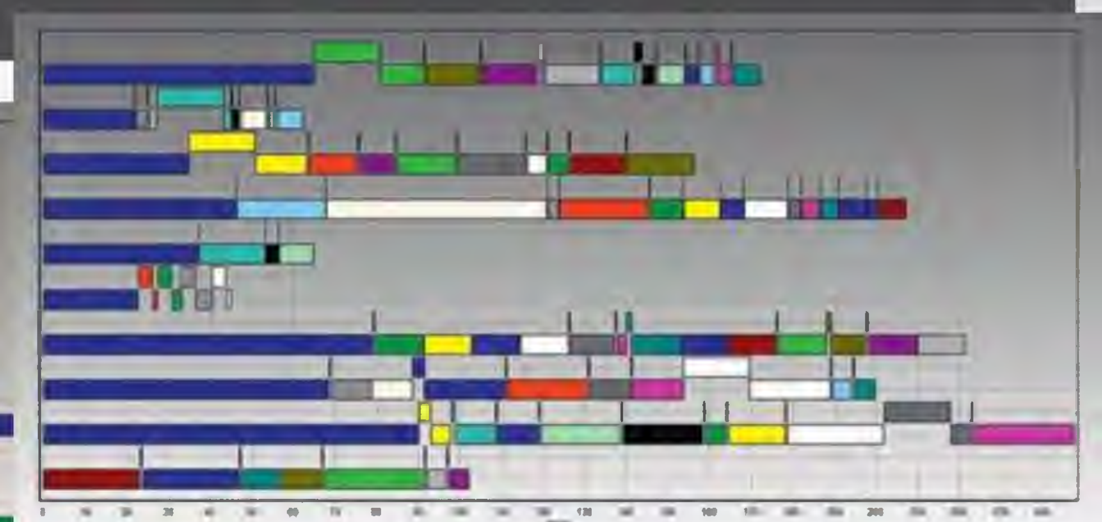
- ASCII: Initial model development
- GDX: Binary Data layer ("contract") between GAMS and applications
  - Platform independent
  - Direct GDX interfaces and general API



# Scheduling and Planning at BASF

- Project Partners: BASF, Princeton University, University of Omsk, SAP, Mathesis GmbH
- Optimization of the operation of batch and continuous plants
- Used on a daily basis to improve planning and scheduling
- Hybrid methods and decomposition schemes to handle large instances of MIP problems
- **New interfacing technology and integration approaches to connect to SAP-APO**





# Independence of Model and User Interface

1 Open architecture and interfaces to other systems
→ No preference for a particular user interface

2 (OO) Application Programming Interfaces

3 Smart Links to popular environments: Excel, MATLAB, R, ...

Model

| Platform | Solver | Data | Interface |
|---|---|---|---|

GAMS

# Independence of Model and User Interface

## API's

- *Low Level*
- **Object Oriented**: .Net, Java, Python
- No modeling capability: Model is written in GAMS
- Wrapper class that encapsulates a GAMS model

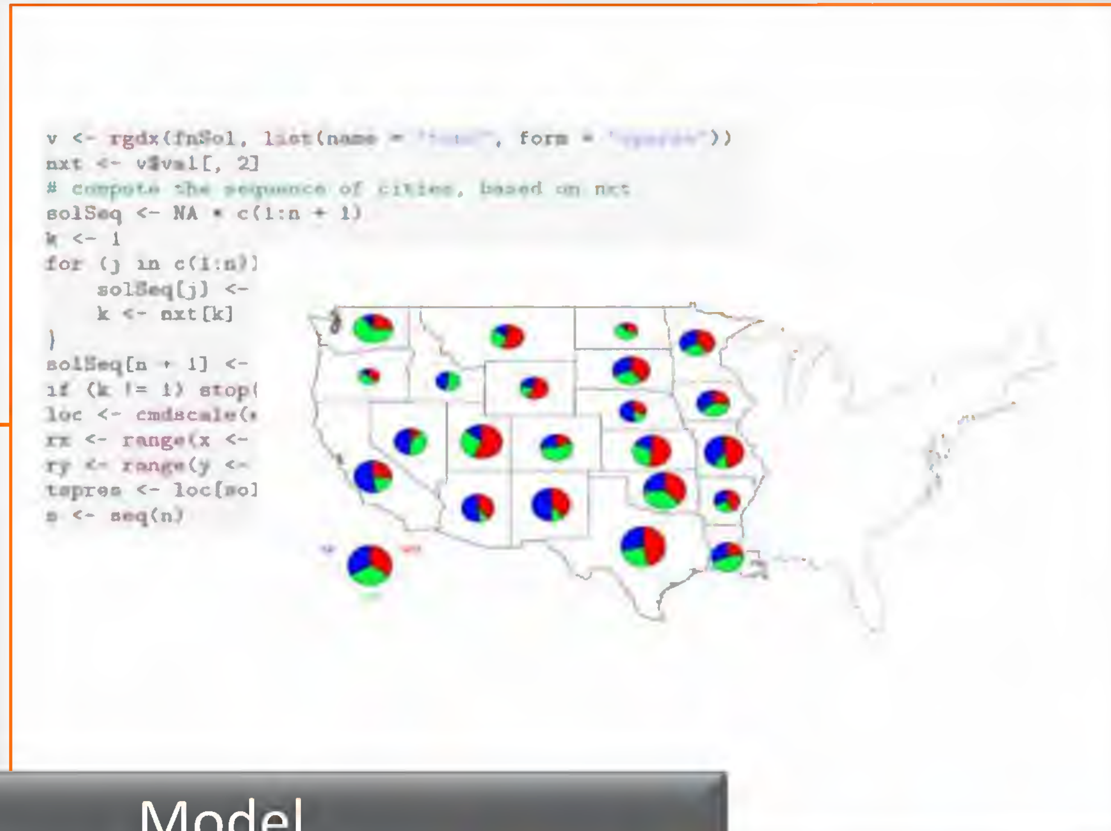
# Simple Encapsulation of a GAMS Model

## Very simple interface

- Properties to **communicate input data and results**
- Properties to **change options** like the solver to use
- Run() method to **run the model**

# Smart Links to other Applications

- User keeps working in his productive tool environment
- Application accesses all optimization capabilities of GAMS through API
- Visualization and analysis of model data and results in the application



GAMS

# Agenda

GAMS – Elements, Enhancements, and Examples

**Enhancements around GAMS**

Some Case Studies

Past – Presence – Future

# Quality Assurance at GAMS

| Solver/Platform availability - 24.4 | | | | | | | |
|---|---|---|---|---|---|---|---|
| | x86 32bit MS Windows | x86 64bit MS Windows | x86 64bit Linux | x86 64bit MacOS X | x86 64bit SOLARIS | Sparc 64bit SOLARIS | IBM Power 64bit AIX |
| ALPHAECP | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| ANTIGONE 1.1 | ✓ | ✓ | ✓ | ✓ | | | |
| BARON 14.4 | ✓ | ✓ | ✓ | | | | |
| BDMLP | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| BONMIN 1.7 | ✓ | ✓ | ✓ | ✓ | ✓ | | |
| CBC 2.8 | ✓ | ✓ | ✓ | ✓ | ✓ | | |
| COUENNE 0.4 | ✓ | ✓ | ✓ | ✓ | ✓ | | |
| CONOPT 3 | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| CPLEX 12.6 | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| DECIS | ✓ | ✓ | ✓ | | | ✓ | |
| DICOPT | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| GLOMIQO 2.3 | ✓ | ✓ | ✓ | ✓ | | | |
| GUROBI 6.0 | ✓ | ✓ | ✓ | ✓ | | | ✓ |
| [illegible] | | | | | ✓ | | |
| [illegible] | | | | | | | |
| [illegible] | | | | | 8.0 | | |
| [illegible] | | | | | 8.0 | | |
| [illegible] | | | | | ✓ | ✓ | |
| MILES | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| MINOS | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| SULUM 4.0 | ✓ | ✓ | ✓ | | | | |
| XA | ✓ | ✓ | ✓ | | | | |
| XPRESS 27.01 | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |

- 7 supported Platforms
- 30+ Integrated Solvers

- What are the impacts of
  - new features
  - updated or new solvers?
- Is the new distribution backward compatible?

GAMS

# Quality Assurance - Motivation

Quality Assurance
- Essential component in most industries
- Important in most software engineering sectors

Mathematical Programming
- Less attention to quality assurance (small community)
- Specific QA issues for modeling systems (initially expensive)
- Different focus for industry and academia

**Industry** ⟷ **Academia**

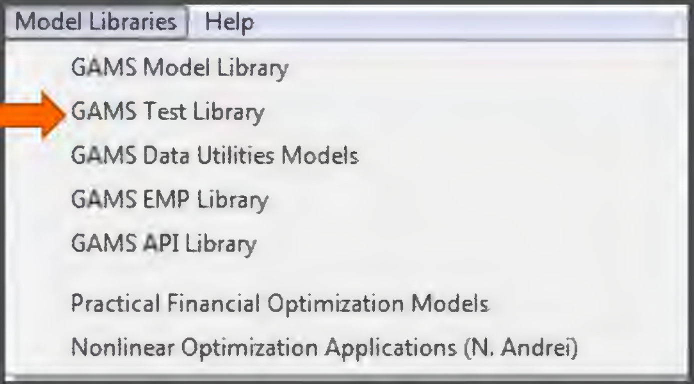
Focus on reliability

Focus on performance

GAMS

# Quality Test Model Library

- Tests to verify proper behavior of the system
- More than 680 quality test models, each containing numerous pass/fail tests
- Assurance about the basic functionality of the software!
- Give the tools in the hand of the user: Included in any distribution!




- Automatically executed every night for all solver combinations:
  - 13,000+ runs / platform (all tests)
  - Test summaries with different level of information

GAMS

# Nightly Quality Tests: Results

## Latest GAMS System Builds and Test Results

Sunday 12Apr15 15:22 (UTC)

[ Latest Builds | Alpha Builds | Beta Builds | Nightly Builds | α Help System | Glossary ]

Comments?

**NOTE:** The (nightly) alpha builds are internal development versions of the GAMS system. They may have known bugs, unfinished features, beta versions of third-party software, or may not function at all! Not for production use!

| nightly α | System | Libraries | Build | Rev | Status and Time (UTC) | | Initial Tests | | Full Tests | |
|---|---|---|---|---|---|---|---|---|---|---|
| Saturday | aix | Download | 24.5.0 | 51758 | Test done | 11Apr2015 09:29:07 | 385 runs 0 failures (q=0,s=0) | Report | 3569 runs 1 failures (q=0,s=1) | Report |
| Saturday | deg | Download | 24.5.0 | 51758 | Test started | 11Apr2015 01:47:52 | 619 runs 1 failures (q=1,s=0) | Report | results pending | |
| Saturday | leg | Download | 24.5.0 | 51758 | Test started | 11Apr2015 02:01:21 | 647 runs 0 failures (q=0,s=0) | Report | results pending | |
| Saturday | legONdrcooper | Download | 24.5.0 | 51758 | Test done | 11Apr2015 09:05:50 | 629 runs 0 failures (q=0,s=0) | Report | 10832 runs 0 failures (q=0,s=0) | Report |
| Saturday | sig | Download | 24.5.0 | 51758S | Test done | 12Apr2015 04:24:15 | 493 runs 0 failures (q=0,s=0) | Report | 7110 runs 0 failures (q=0,s=0) | Report |
| Saturday | vs8 | Download | 24.5.0 | 51758 | Test started | 11Apr2015 02:45:42 | 654 runs 0 failures (q=0,s=0) | Report | results pending | |
| Saturday | wei | Download | 24.5.0 | 51758 | Test started | 11Apr2015 05:06:52 | 652 runs 0 failures (q=0,s=0) | Report | results pending | |

| nightly β | System | Libraries | Build | Rev | Status and Time (UTC) | | Initial Tests | | Full Tests | |
|---|---|---|---|---|---|---|---|---|---|---|
| Thursday | aix | Download | 24.4.4 | 51738 | Test done | 09Apr2015 17:39:11 | 394 runs 2 failures (q=0,s=2) | Report | 3615 runs 3 failures (q=0,s=3) | Report |
| Monday | deg | Download | 24.4.4 | 51709 | Test done | 08Apr2015 19:01:03 | 602 runs 0 failures (q=0,s=0) | Report | 13030 runs 0 failures (q=0,s=0) | Report |

GAMS

# Nightly Quality Tests: Reports

## GAMS System Builds and Test Results Archive

Sunday 12Apr15 15:26 (UTC)

[ Latest Builds | Alpha Builds | Beta Builds | Nightly Builds | Glossary ]

```
Total:          3569 runs          1 failures
Quality:        1117 runs          0 failures
Slvtest:        2339 runs          1 failures
EMP:              99 runs          0 failures
Data:             14 runs          0 failures

**** SLVTEST FAILURES (failures_slv.gms)
$call  =gams slvtest lo=2 --prefix=aix --fail=failures_slvI.gms --test=bchtlbas u1="ord(s)=286" --runall=no --c1=sbb --ftr

**** SLVTEST FAILURES DETAIL (slvtest.sum?)
 25020  04/11/15 05:45:16 bchtlbas        MINLP   SBB         Bad ModelSolveStat[13,13] minlp=sbb
```

# GAMS/CONVERT

- Transforms a GAMS model instance into a scalar model into different formats: Models can then be passed on to others for investigation without confidentiality being lost
- A way of sharing GAMS test problems for use with other modeling systems or solvers
- More than 25 target formats

| Option | Description | |
|---|---|---|
| All | Generates all supported file formats | |
| AlphaECP | Generates AlphaECP input file | |
| Ampl | Generates Ampl input file | |
| AmplNLC | Generate Ampl NLC compatible file | |
| Analyze | Generates three text files for rows columns and matrix | |
| AnalyzeS | Generates short form of Analyze | |
| Baron | Generates Baron input file | |
| CplexLP | Generate CPLEX LP format input file | |
| CplexMPS | Generate CPLEX MPS format input file | |
| Dict | Generate Convert to GAMS Dictionary | |
| DictMap | Generate Convert to GAMS Dictionary Map | |
| FileList | Generate file list of file formats generated | |
| FixedMPS | Generate fixed format MPS file | fixed.mps |
| Gams | Generate GAMS scalar model. This is the default conversion format used. | gams.gms |
| Lgo | Generate an LGO Fortran file | lgomain.for |
| LindoMPI | Generate Lindo MPI file | lindo.mpi |
| Lingo | Generate Lingo input file | lingo.lng |
| LocalSolver | Generate LocalSolver input file (only with ConvertD) | localsolver.lsp |
| LSPSol | Generate Output function in LocalSolver input file (only with ConvertD) | lspsol.gms |
| Memo | Generate a memo file containing model statistics and files created. | memo.txt |
| Minopt | Generate Minopt input file | minopt.dat |
| NLP2dual | Generate the Wolfe dual of a smooth optimization model | gamsdual.gms |
| NLP2MCP | Generates GAMS scalar MCP model | gamsmcp.gms |
| OSiL | Generates Optimization Services instance Language (OSil) file | osil.xml |
| Pyomo | Generates Pyomo Concrete scalar model | gams.py |
| SFS | Generates Solver Foundation Services OML file | sfs.oml |
| ViennaDag | Generate Vienna Dag input file | vienna.dag |

GAMS

# GAMS/CONVERT - Example

## GAMS Code

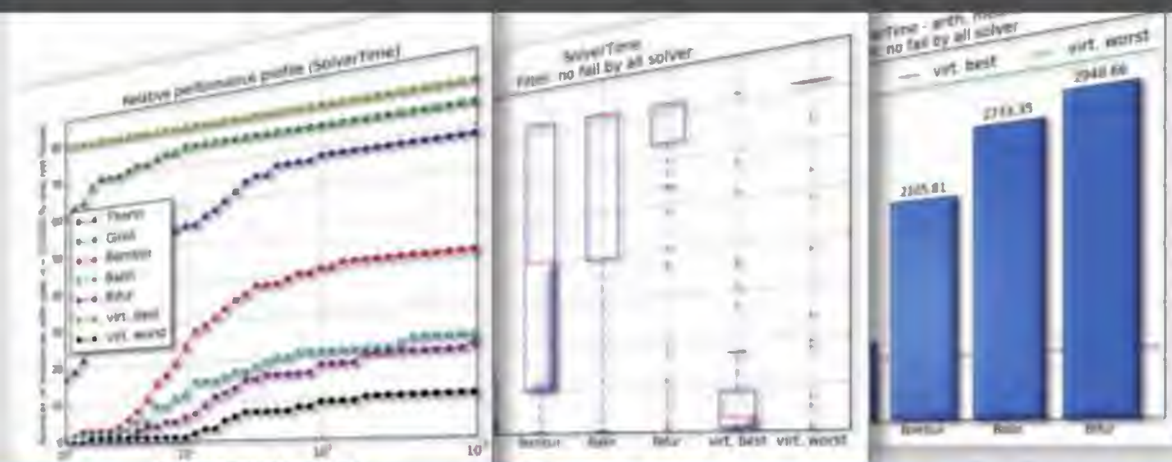
```
Variables
     x(i,j)   shipment quantities in cases
     z        total transportation costs in thousands
Positive Variable x ;
Equations
     cost         define objective function
     supply(i)    observe supply limit at plant i
     demand(j)    satisfy demand at market j ;
cost ..        z  =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/ ;
Solve transport using lp minimizing z ;
```

## Scalar Model

```
Variables  x1,x2,x3,x4,x5,x6,x7;
Positive Variables  x1,x2,x3,x4,x5,x6;
Equations  e1,e2,e3,e4,e5,e6;
e1..  - 0.225*x1 - 0.153*x2 - 0.162*x3 -
0.225*x4 - 0.162*x5 - 0.126*x6 + x7=E= 0;
e2..    x1 + x2 + x3 =L= 350;
e3..    x4 + x5 + x6 =L= 600;
e4..    x1 + x4 =G= 325;
e5..    x2 + x5 =G= 300;
e6..    x3 + x6 =G= 275;
Model m / all /;
m.limrow=0; m.limcol=0;
Solve m using LP minimizing x7;
```

# Paver 2 – GAMS Performance Tools

- Automates the analysis and comparison of solver performance data
- Easy customization of performance metrics
- Computation and visualization of performance statistics
- Platform independent, simple use, high performance, and flexibility, open source
- Give the tools in the hand of the user: Make your own benchmarks!



➢ http://www.gamsworld.org/performance/paver2/

# What else is new?

## GAMS Distribution 24.4

**Distribution History**

24.4.2 (Maintenance release) March 15 , 2015
24.4.1 (Major release) December 20 , 2014

### GAMS Major Release 24.4.1 - December 20 , 2014

**Table of Contents**



www.gams.com/docs/release/release.htm#gams-24.4

# Agenda

GAMS – Elements, Enhancements, and Examples

Enhancements around GAMS

**Some Case Studies**

Past – Presence – Future

GAMS

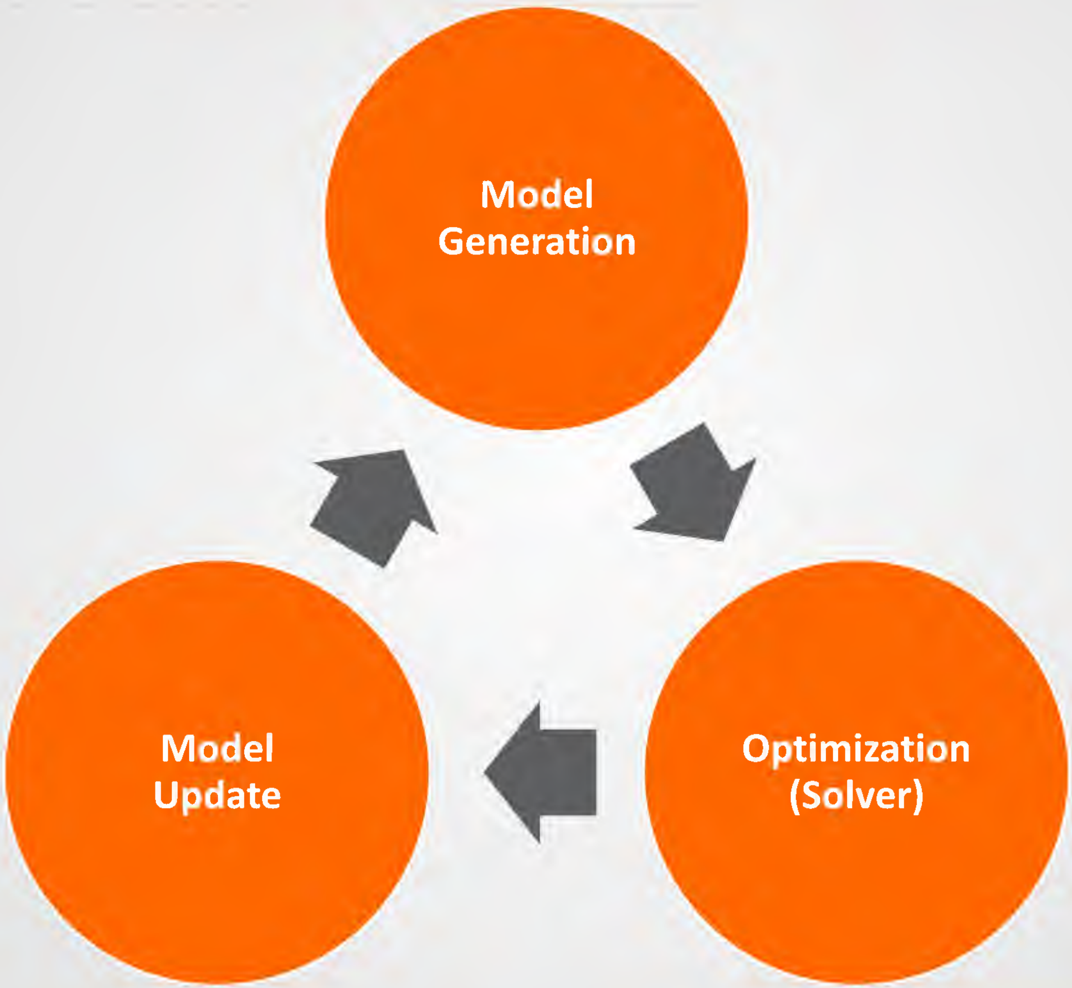
# Three Case Studies

1 General Dynamics – efficient frontiers of multi-objective design optimization problems

2 xyz Energy Company – solving many difficult MIP models in parallel on the Amazon cloud

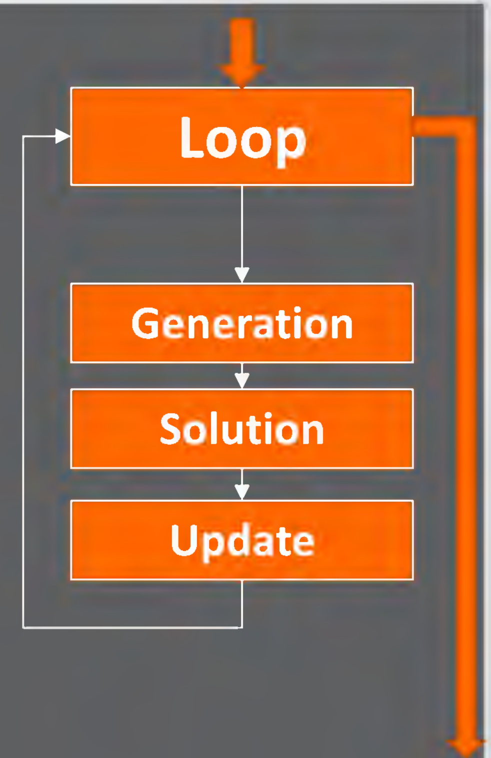
3 EMS-EDM Prophet – an Energy and Energy Data Management System

# Scenario Solving



# Simple Serial Solve Loop

```
Set s /s*s10/;
Parameter
 A_s(s,i,j) “scenario data”,
 xlo_s(s,i,j) ”scenario lower bound for x.l”,
 em_s(s,i) “scenario solution for e.m;
Loop(s,
     A(i,j) = A_s(s,i,j);
     x.lo(j)=xlo_s(s,j);
     solver mymodel min z using lp;
     xl_s(s,j) = x.l(j);
     em_s(s,i) = e.m(i);
    );
```



GAMS

# Solving Scenarios

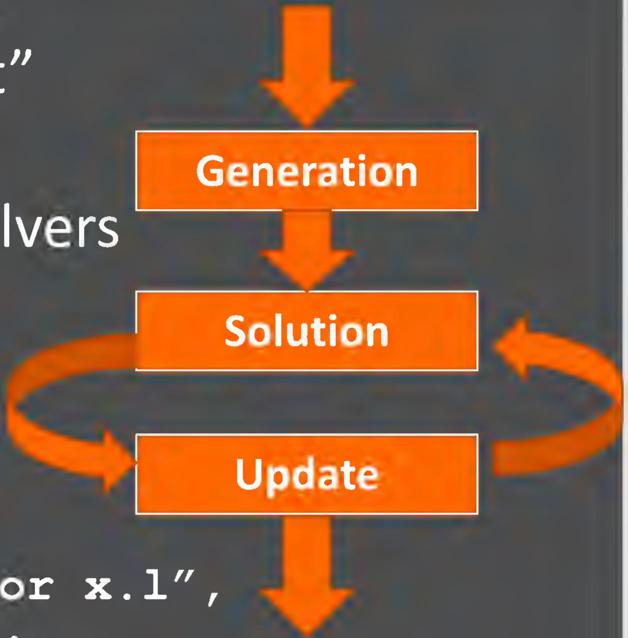
trnsport.gms (LP) solved 500 times with CPLEX:

```
Loop(s,
     d(i,j) = dd(s,i,j);
     f = ff(s);
     solve transport using lp minimizing z;
     rep(s) = transport.objval;
);
```

| Setting | Solve time (secs) |
|---|---|
| Solvelink=%Solvelink.ChainScript% | 52.221 |
| Solvelink=%Solvelink.CallModule% | 37.366 |
| Solvelink=%Solvelink.LoadLibrary% | 03.252 |

# Scenario Solver

- Generates model once and updates the algebraic model keeping the model "hot" inside the solver
- Platform independent, works with all solvers
- Performance close to native solver API




```
Set s /s*s10/;
Parameter
  A_s(s,i,j) "scenario data",
  xlo_s(s,i,j) "scenario lower bound for x.l",
  em_s(s,i) "scenario solution for e.m;
Set dict / s. scenario. '',
           A. param.    A_s,
           x. lower.    xlo_s,
           x. level.    xl_s,
           e. marginal. em_s /;
solve mymodel min z using lp scenario dict;
```

GAMS

# Performance

Example: Stochastic model with 66,320 linear problems

| Setting | Solve time (secs) |
|---|---|
| Loop: Solvelink=%Solvelink.Chainscript (default) | 7,204 |
| Loop: Solvelink=%Solvelink.LoadLibrary% | 2,481 |
| GAMS Scenario Solver | 392 |
| Cplex Concert Technology | 210 |

Factor

18.3

1.86

GAMS

# Solving Independent Models

1. Small Ratio of solver time / GAMS time → Scenario Solver
2. Large ratio i.e. only solver time is relevant (pre/post processing not critical) → Grid Computing Facility, Cplex Remote Object or Gurobi Compute Server
3. If entire model run including pre processing/MP solve/post processing is costly → Parallel execution of entire model in the cloud

# ACSOM

- **A**dvanced **C**ollaborative **S**ystem **O**ptimization **M**odeler
- Configuration of (expensive) military vehicles
- Project partners:
  - General Dynamics Land Systems (GDLS)
  - Industrial & Systems Engineering, Wayne State University
  - GAMS Development Corp
  - Amsterdam Optimization Group

# Considers All to Make the Whole

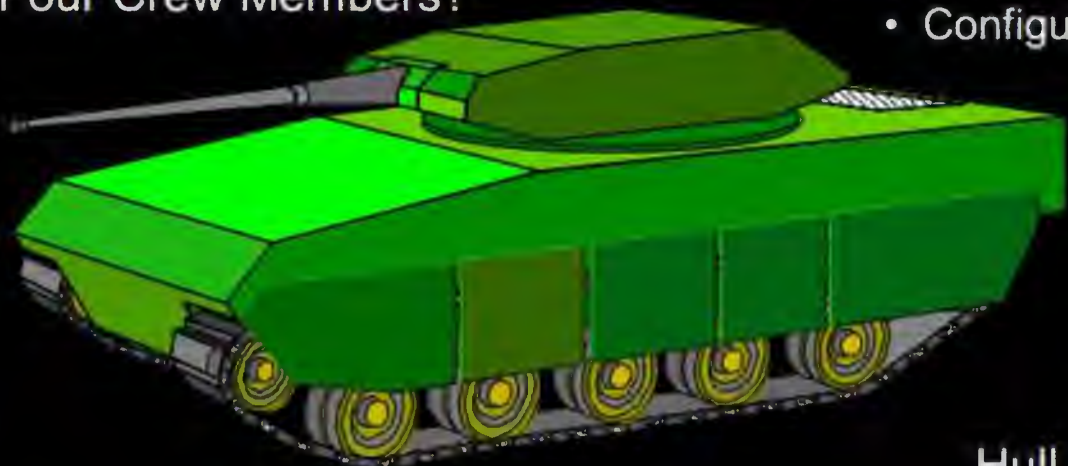
## Full Spectrum

**Numerous Subsystems with a multitude of options for each**

Force Protection Approach?

Two, Three, Four Crew Members?

Auto loader ?
- Configuration/Approach?



Hull Material?
- Aluminum?
- Steel?
- Titanium?

Which Core Data Network?

Hull Design?

Power ?
- What Type of Engine?
- What Type Transmission?

What Type of Suspension System?
- Torsion bars?
- HSUs?

Passive?
Fully Active?

Track?

Which Servo Motor Controller Architecture?

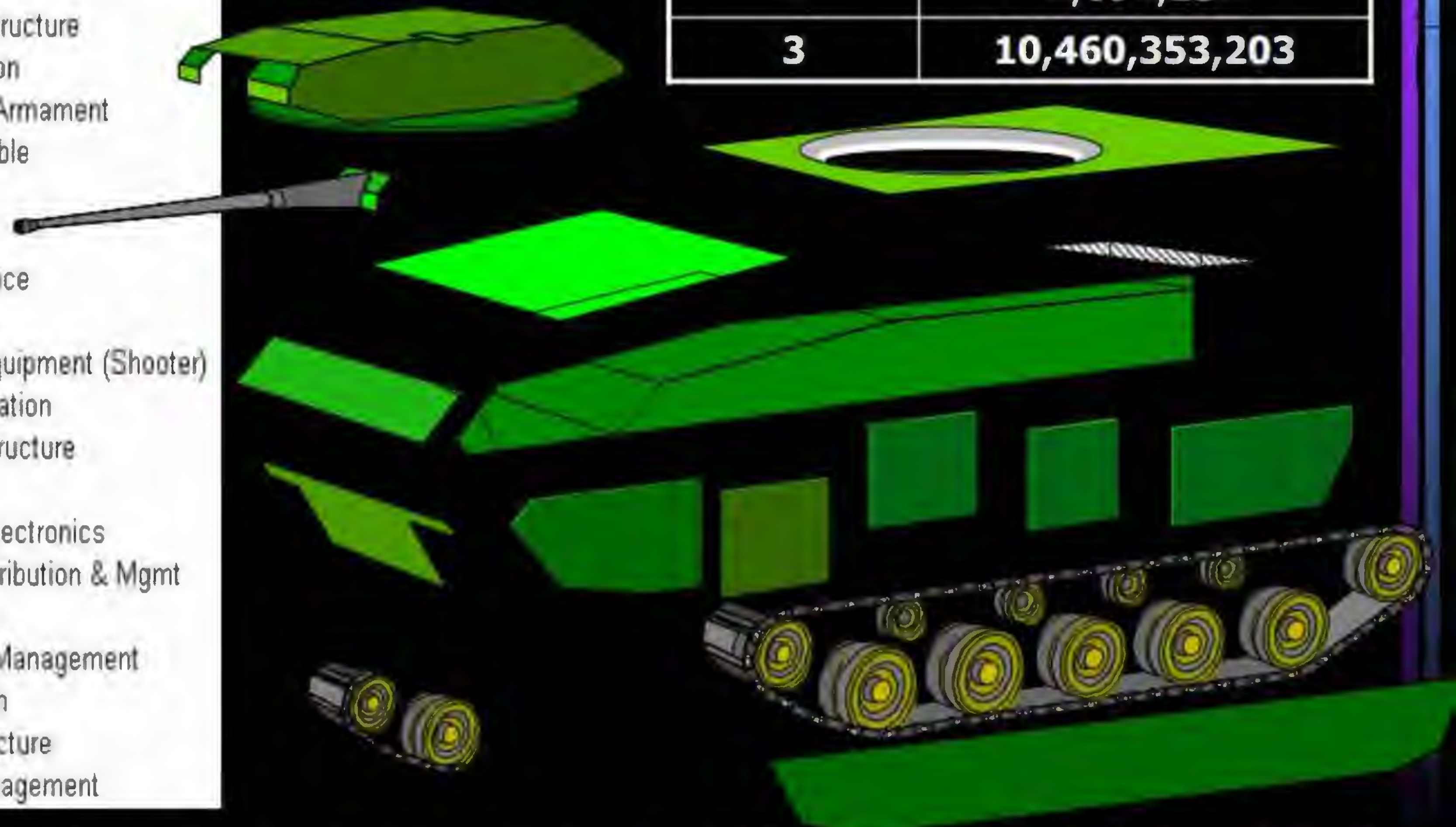
 

# The Whole-system Design Problem

**21 SUBSYSTEMS**

- AFES
- Armor
- Chassis Structure
- Crew Station
- Defensive Armament
- Dismountable
- ECS
- Fuel
- Hit Avoidance
- Lighting
- Mission Equipment (Shooter)
- Mission Station
- Mission Structure
- NBC
- Platform Electronics
- Power Distribution & Mgmt
- Propulsion
- Signature Management
- Suspension
- Turret Structure
- Water Management

| Options per subsystem | Theoretically Possible Subsystem Combinations |
|---|---|
| 2 | 2,092,152 |
| 3 | 10,460,353,203 |



GAMS

# Project Scope

Generation of Efficient Frontiers

Significant performance improvements

- Use multiple cores:
  - For current setup (laptops)
  - For high-performance machines
- Prepare for advancing technologies (distributed)

# Scenario Solver and Parallel Combined

| Implementation | Number of MIP models | Solve time | Rest of algorithm | Total time |
|---|---|---|---|---|
| Traditional GAMS loop | 100,000 | 1068 sec | 169 sec | 1237 sec |
| Scenario Solver | 100,000 | 293 sec | 166 sec | 459 sec |

| Implementation | Number of MIP models | Worker Threads | Parallel sub-problem time | Rest of algorithm (serial) | Total time |
|---|---|---|---|---|---|
| Parallel + Scenario Solver | 100,000 | 4 | 116 sec | 67 sec | 183 sec |

http://yetanothermathprogrammingconsultant.blogspot.de/2012/04/parallel-gams-jobs-2.html

GAMS

# Retooling of an Application

## Old System

- VB.Net
- MPL (single point)
- CPLEX
- SQL throughout

## New System

- GAMS (complete algorithm; streamlined design)
- GAMS .NET API for ACE algorithm
- CPLEX
- Bulk SQL just once

## Performance Improvements

On the same hardware:

- From hours and even days for large problems
- To minutes, up to an hour

GAMS

# xyz Energy Company

## Massive Parallel for Large Scale MIP

- Failures with Stochastic and Robust Optimization
- Scenario Analysis worked!
- Task: Solve 1,000 scenarios (MIPs, ~1 hour per scenario) every week overnight in parallel
- Post processing of results outside GAMS
- Issues:
  - Automation
  - Licensing
  - Security in the cloud

GAMS

# Protecting IP and Sensitive Data

- Obfuscate or hide sensitive information
  - Extrinsic function libraries
  - External Equations
  - Secure work files
  - Encrypted source files
  - Obfuscated files: change all the names and other documentation related to a specific model run

GAMS

# Obfuscated Save/Restart File

## Solver Log

### Normal

```
Reduced LP has 5 rows, 6 columns, and 12 nonzeros.
Presolve time = 0.00 sec. (0.00 ticks)

Iteration      Dual Objective            In Variable           Out Variable
     1              73.125000    x(seattle.new-york) demand(new-york) slack
     2             119.025000     x(seattle.chicago)  demand(chicago) slack
     3             153.675000    x(san-diego.topeka)   demand(topeka) slack
     4             153.675000  x(san-diego.new-york)  supply(seattle) slack
LP status(1): optimal
```

### Obfuscated

```
Reduced LP has 5 rows, 6 columns, and 12 nonzeros.
Presolve time = 0.00 sec. (0.00 ticks)

Iteration      Dual Objective            In Variable           Out Variable
     1              73.125000H('"!!!!!!'.'"!!!!!!!')A00002('"!!!!!!!' slack
     2             119.025000 H('"!!!!!!'.'#!!!!!!')A00002('#!!!!!!') slack
     3             153.675000H('"!!!!!!!!'.'"!!!!!') A00002('"!!!!!') slack
     4             153.675000H('"!!!!!!!!'.'"!!!!!!!A00001('"!!!!!!') slack
LP status(1): optimal
```

GAMS

# Obfuscated Save/Restart File

## Looking at Results

### Normal

| | | | | |
|---|---|---|---|---|
| 12 | demand | Equ | 1 | 3 |
| 6 | f | Par | 0 | 1 |
| 1 | i | Set | 1 | 2 |
| 2 | j | Set | 1 | 3 |
| 11 | supply | Equ | 1 | 2 |
| 8 | x | Var | 2 | 6 |
| 9 | z | Var | 0 | 1 |

| | | Level | Marginal |
|---|---|---|---|
| seattle | new-york | 50 | |
| | chicago | 300 | |
| | topeka | | 0.036 |
| san-diego | new-york | 275 | |
| | chicago | | 0.0090000000000001 |
| | topeka | 275 | |

### Obfuscated

| | | | | |
|---|---|---|---|---|
| 3 | C | Par | 1 | 2 |
| 4 | D | Par | 1 | 3 |
| 5 | E | Par | 2 | 6 |
| 6 | F | Par | 0 | 1 |
| 7 | G | Par | 2 | 6 |
| 8 | H | Var | 2 | 6 |
| 9 | I | Var | 0 | 1 |

| | | Level | Marginal |
|---|---|---|---|
| "!!!!!! | "!!!!!!! | 50 | |
| | #!!!!!! | 300 | |
| | "!!!!! | | 0.036 |
| "!!!!!!!! | "!!!!!!! | 275 | |
| | #!!!!!! | | 0.0090000000000001 |
| | "!!!!! | 275 | |

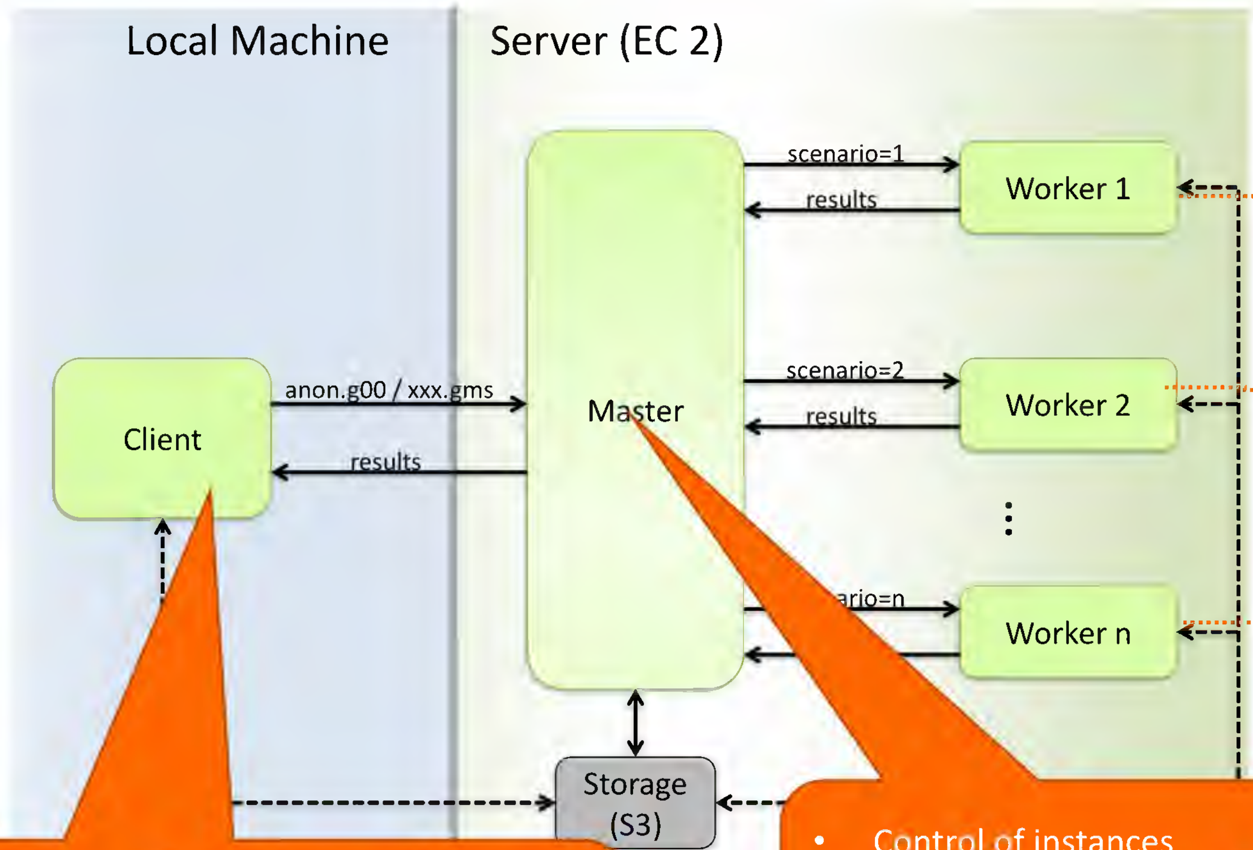
# Massive Parallel in the Cloud

- Deployment environment: „Cloud“ (Amazon EC2)
- Up to 1,000 parallel instances (workers)
- Automated setup, including
  - Start instances
  - Prepare & Submit GAMS jobs
  - Collect results
  - Stop instances
- Python
  - Boto: Python interface to Amazon webservices
  - Setup and control of instances (Workers)
  - GAMS OO API (Python): Control of GAMS jobs

Model

Platform | Solver | Data | Interface

# AWS Cloud Setup at xyz Company




- Preparation of obfuscated binary model file
- Preparation of data for every worker
- Mapping of results into original namespace

- Control of instances
- Submission of model and scenario data to workers
- Collection and merge of results

Configured AWS Instances
- Python
- GAMS

GAMS

# Energy Systems

EMS-EDM PROPHET

Energy and Energy Data Management

Fraunhofer

IOSB

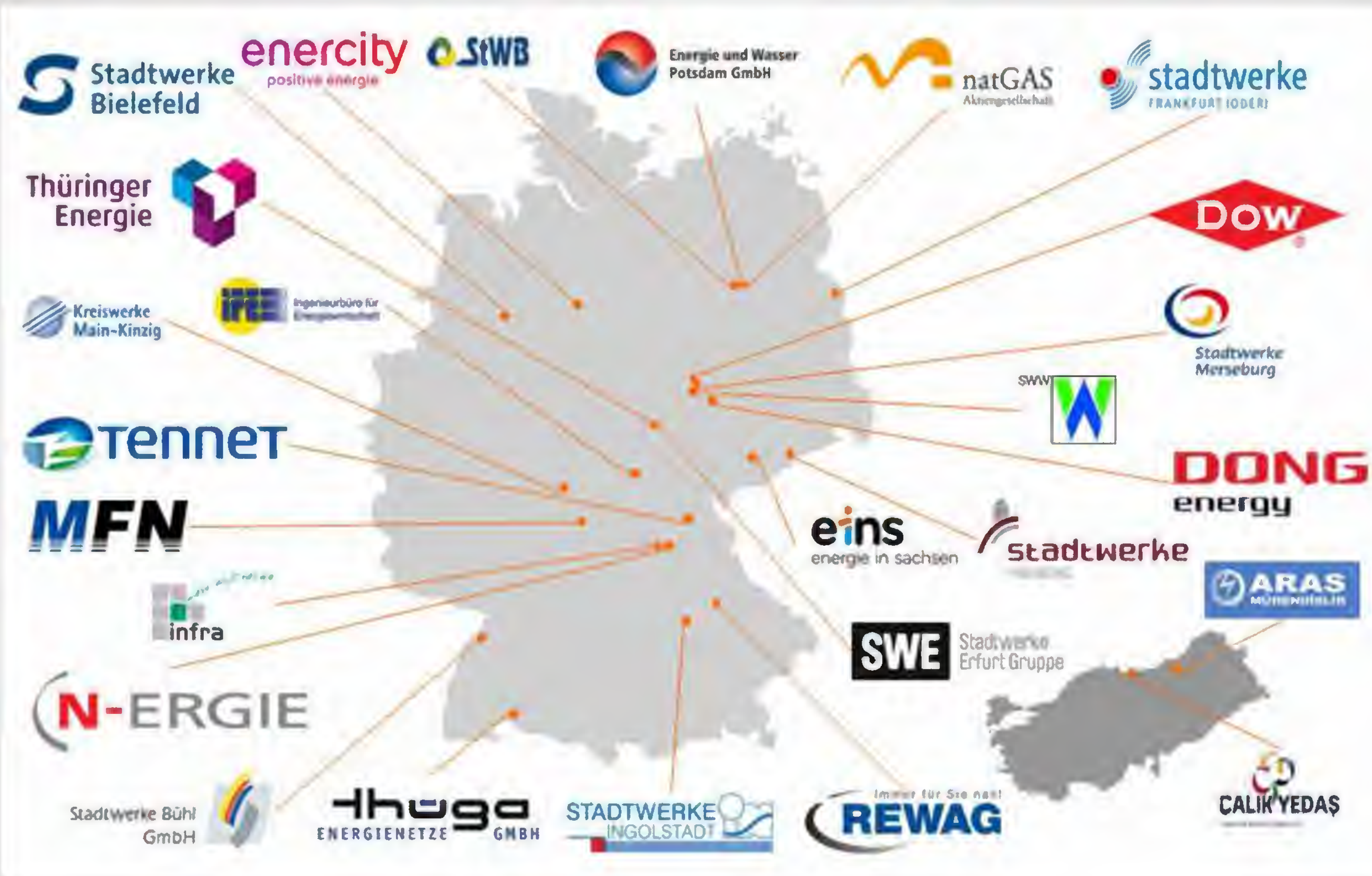
Institutsteil Angewandte Systemtechnik AST

# EMS-EDM PROPHET® – Modules 2015

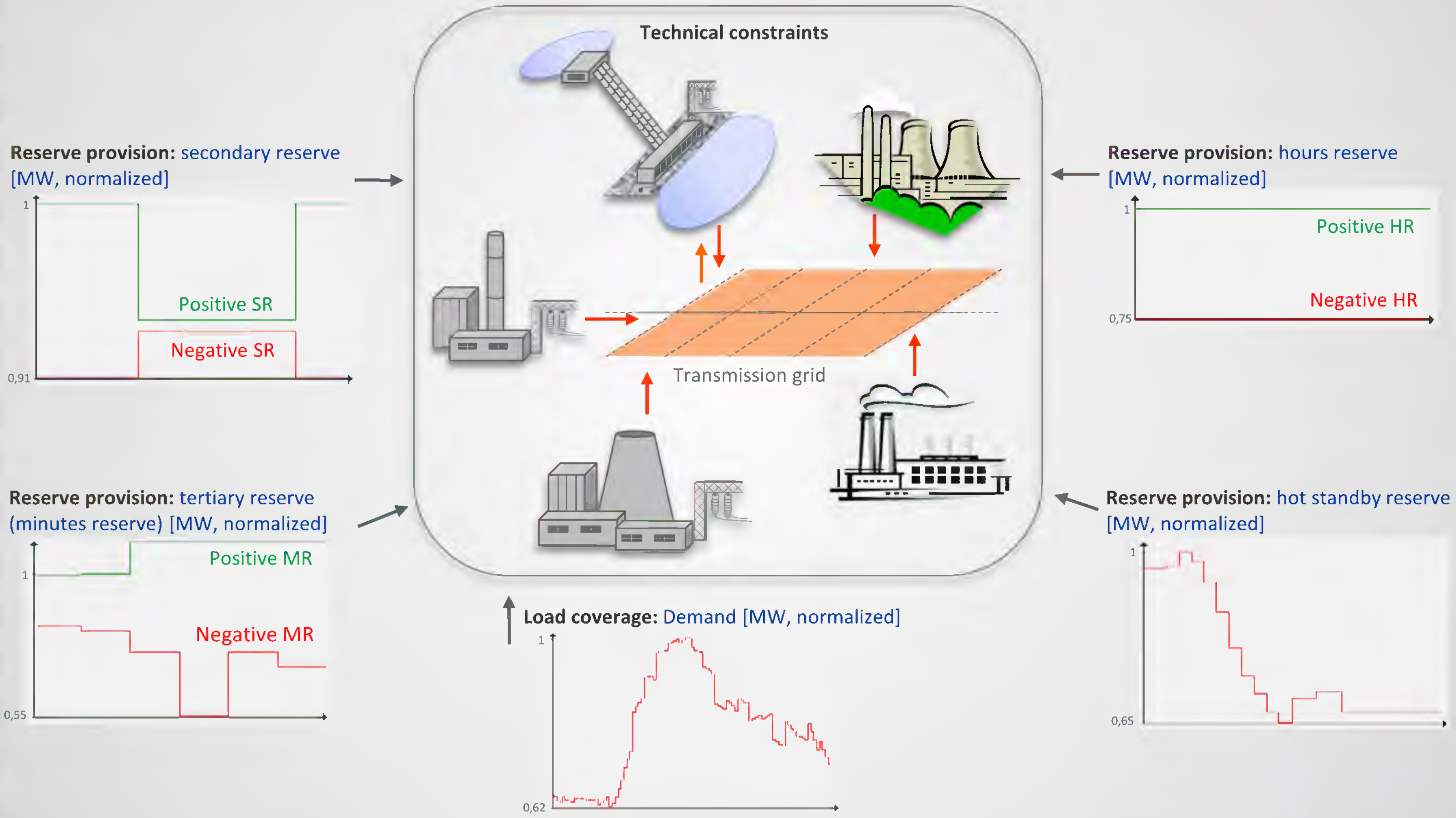

**Resource Planning System – RPS**

- LP & MIP optimization
- Deterministic & Stochastic
- High Performance Solver
- Short, medium & long term
- **Archiving (Oracle)**

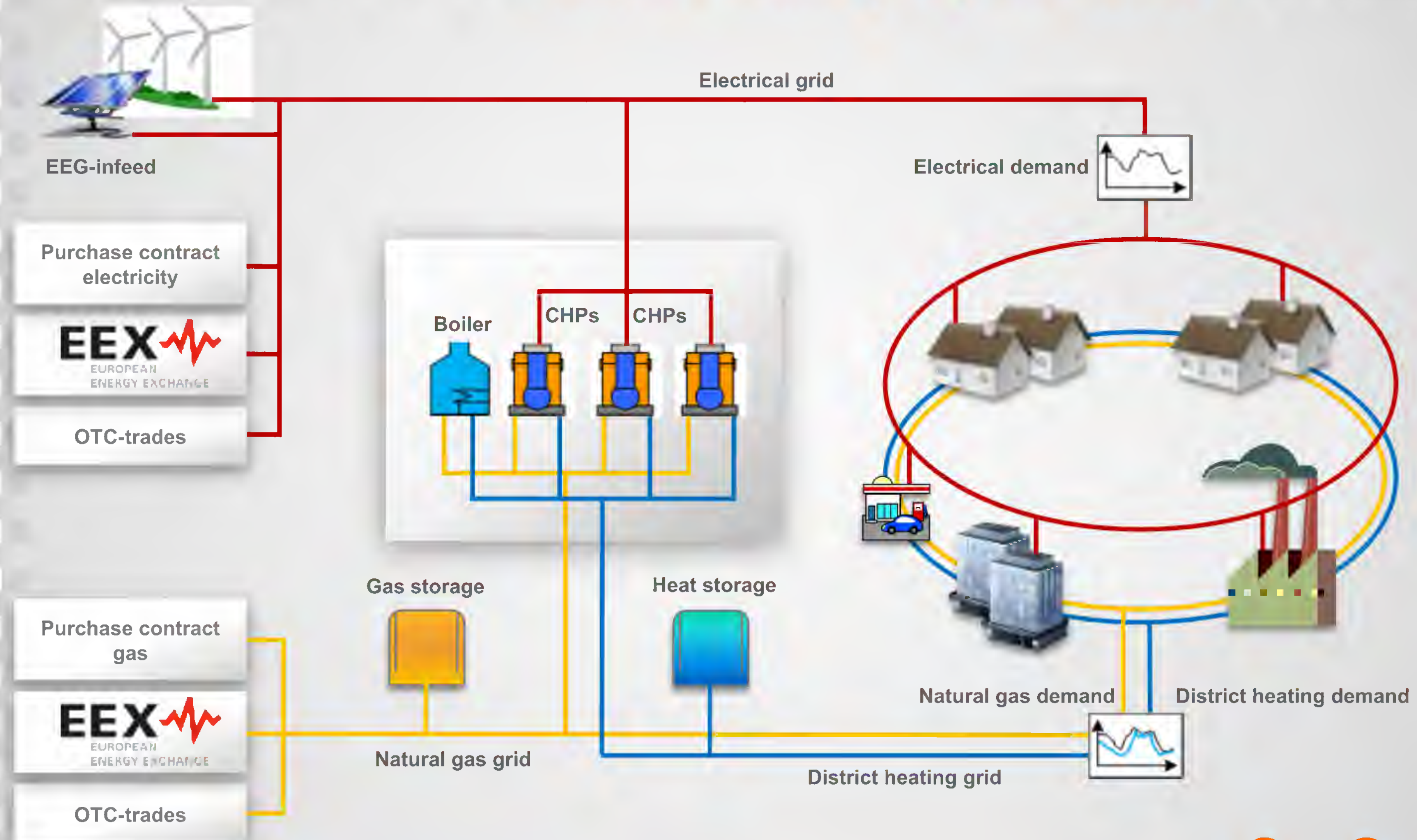
# EMS-EDM PROPHET® – Customers



# Optimization of power plant utilization



# Optimization of multi-utility operation

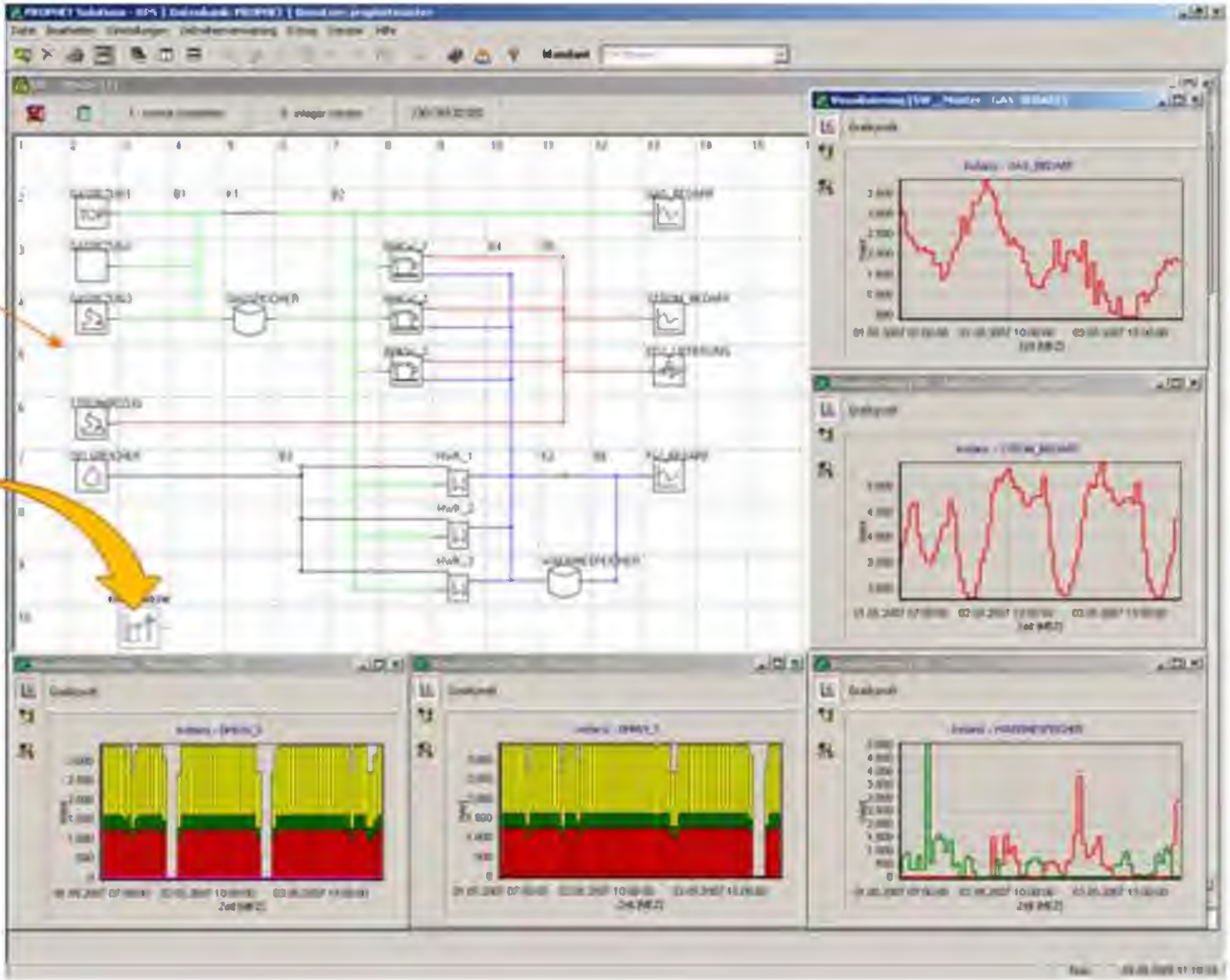


# RPS – Graphical Modeling

Graphical modeling of optimization problems

Drag ´n Drop

Power plant



# RPS – Interaction with GAMS

Lade Optimierungs-DLL
Operation abgeschlossen 00:00
Lade Zeitbasis
Operation abgeschlossen: 00:00
Erzeuge Porjektverzeichnis und entferne temporäre Dateien
Operation abgeschlossen: 00:00
Erzeuge GAMS-Datei ...
schreibe Komponentendeklarationen
schreibe GDX-Daten
schreibe Instanzwerte
schreibe Set-Datenwerte
schreibe Set-Datenwerte für die Startbedingungen
schreibe Tabellen
schreibe Tabelle "Startzustandstabelle [NW_BK_034] "
...
Zeitbedarf GDX-Datei-Erzeugung [hh:mm:ss]: 00:00:09
schreibe Modelldaten
schreibe Instanzgleichungen
schreibe Bilanzgleichungen
schreibe Untermodellgleichungen
schreibe Objektfunktion
Schreiben der Deklarationsdatenwerte
Schreiben der Deklarationswerte abgeschlossen
Erzeuge Optionsdatei (OptFile)
Zeitbedarf GAMS-Datei-Erzeugung [hh:mm:ss]: 00:02:34
..
Durchführung der Optimierung ... [19.03.2014 01:00 - 23.03.201 00:00]
Datei: "C:\GAMS\win64\24.3\gams.exe"
Parameter: "C:\EMS-EDM PROPHET\system\Rps-

Data Exchange with GAMS (GDX)

Dynamic Model Generation (Source)

Solver Options

Optimization

GAMS

# Some Lessons Learned

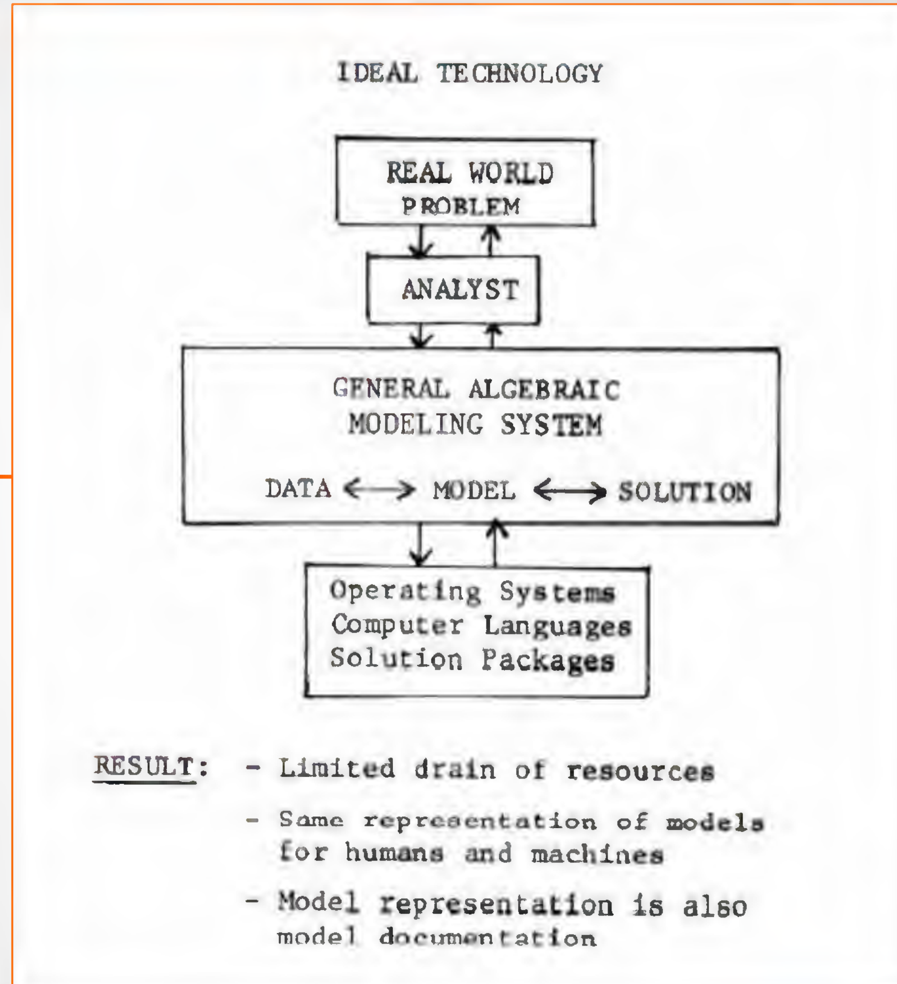
- For successful applications know more than math/modeling or work with domain specific experts
- Applications (may) evolve over time: Appetite comes with eating..
- Be aware of non-technical constraints, e.g. legal requirements

# Agenda

- GAMS – Elements, Enhancements, and Examples
- Enhancements around GAMS
- Some Case Studies
- **Past – Presence – Future**

# 1976 - A World Bank Slide

The Vision



GAMS

# 2012 INFORMS Impact Prize

**36 Years later**

Originators of Algebraic Modeling Languages

AIMMS 3

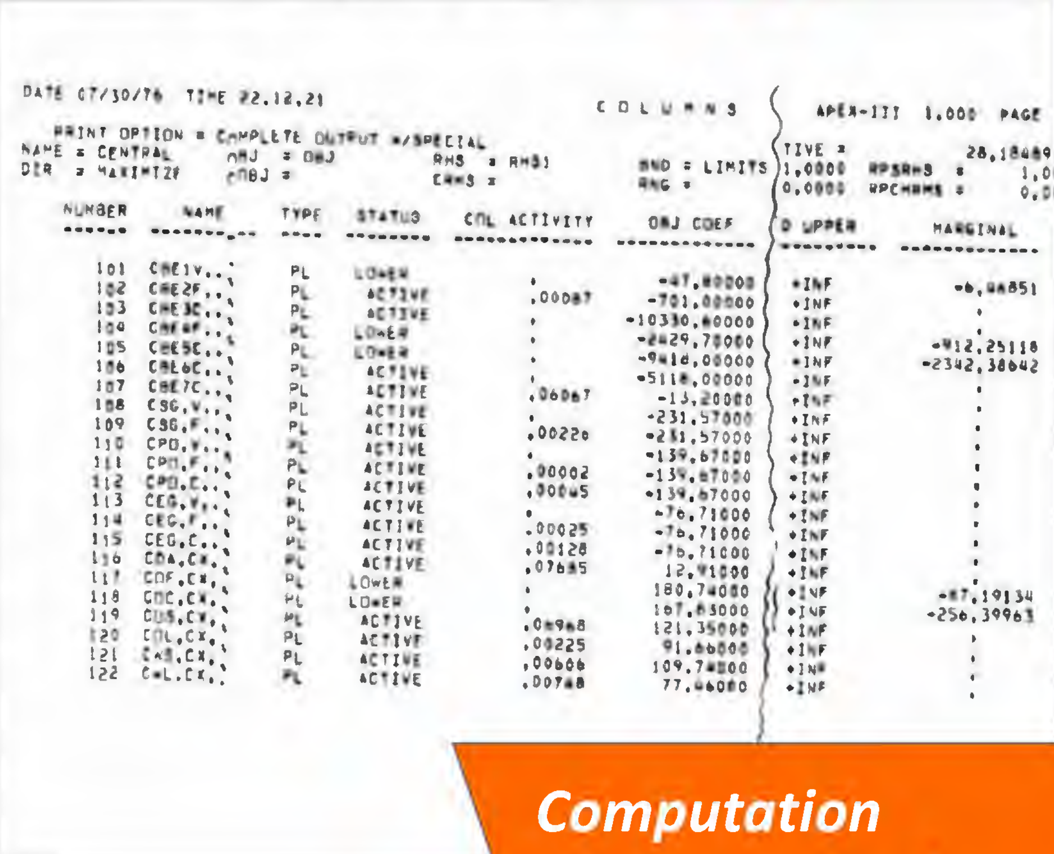
AMPL

MAXIMAL

GAMS

LINDO SYSTEMS

# Change in Focus: Past



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 = 1.00
0.0000 RPCHRHS = 0.00

| NUMBER | NAME | TYPE | STATUS | COL ACTIVITY | OBJ COEF | D UPPER | MARGINAL |
|---|---|---|---|---|---|---|---|
| 101 | CRE1V.. | PL | LOWER | . | -47.80000 | +INF | -6.44851 |
| 102 | CRE2F.. | PL | ACTIVE | .00087 | -701.00000 | +INF | . |
| 103 | CRE3C.. | PL | ACTIVE | . | -10330.80000 | +INF | . |
| 104 | CRE4F.. | PL | LOWER | . | -2429.70000 | +INF | -412.25118 |
| 105 | CRE5C.. | PL | LOWER | . | -9418.00000 | +INF | -2342.38642 |
| 106 | CRE6C.. | PL | ACTIVE | . | -5118.00000 | +INF | . |
| 107 | CRE7C.. | PL | ACTIVE | .06067 | -13.20000 | +INF | . |
| 108 | CSG.V.. | PL | ACTIVE | . | -231.57000 | +INF | . |
| 109 | CSG.F.. | PL | ACTIVE | .00220 | -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 | .07635 | 12.91000 | +INF | . |
| 117 | CDF.CX. | PL | LOWER | . | 180.74000 | +INF | -87.19134 |
| 118 | CDC.CX. | PL | LOWER | . | 167.63000 | +INF | -256.39963 |
| 119 | CDS.CX. | PL | ACTIVE | .04968 | 121.35000 | +INF | . |
| 120 | CDL.CX. | PL | ACTIVE | .00225 | 91.66000 | +INF | . |
| 121 | CXS.CX. | PL | ACTIVE | .00606 | 109.74800 | +INF | . |
| 122 | CWL.CX. | PL | ACTIVE | .00748 | 77.46000 | +INF | . |

***Computation***
*→Hardware / Algorithm limits application*
*→ Users left out*

# Change in Focus: Now

C:\Users\franz\Documents\gamsdir\projdir\epscmmip.gms

epscmmip.gms

```
posg(km1) = 0; iter=0; infeas=0; start=jnow;

repeat
  rhs(km1) = sum(grid(km1,g)$(numg(g)=posg(km1)), gridrhs(km1,g));
  solve mod_epsmethod maximizing a_objval using mip;
  iter=iter+1;
  if (mod_epsmethod.modelstat<>%ModelStat.Optimal% and
      mod_epsmethod.modelstat<>%ModelStat.Integer Solution%,
    infeas=infeas+1;  // not optimal is in this case infeasible
    put iter:5:0, '  infeasible' /;
    lastZero = 0; loop(km1$(posg(km1)>0 and lastZero=0), lastZero=numk(km1));
    posg(km1)$(numk(km1)<=lastZero) = maxg(km1); // skip all solves for more demanding
  else
    put iter:5:0;
    loop(k, put z.l(k):12:2);
    jump(km1)=1;
*   find the first off max (obj function that hasn't reach the final grid point).
*   If this obj.fun is k then assign jump for the 1..k-th objective functions
*   The jump is calculated for the innermost objective function (km=1)
    jump(km1)$(numk(km1)=1)=1+floor(sl.L(km1)/step(km1));
    loop(km1$(jump(km1)>1), put '   jump');
    put /;
    );
* Proceed forward in the grid
  firstOffMax = 0;
  loop(km1$(posg(km1)<maxg(km1) and firstOffMax=0),
     posg(km1)=min((posg(km1)+jump(km1)),maxg(km1)); firstOffMax=numk(km1));
  posg(km1)$(numk(km1)<firstOffMax) = 0;
until sum

finish=jno
```

***Computation***

*→Hardware / Algorithm limits application*

*→ Users left out*

***Model***

*→ Modeling skill limits applications*

*→ Users involved*

GAMS

# Solver Technology - Now

## Progress in LP: 1988—2004

(Operations Research, Jan 2002, pp. 3—15, updated in 2004)

- Algorithms (*machine independent*):

  Primal *versus* best of Primal/Dual/Barrier 3,300x

- Machines (workstations →PCs): 1,600x
- NET: Algorithm × Machine 5,300,000x

(2 months/5300000 ~= 1 second)

Robert E. Bixby

Gurobi Optimization & Rice University

# Change in Focus: Now

| Mathematical Optimization | Business Analytics |
|---|---|
| **Computation** | **Application** |
| Well defined (narrow) application area | Broad application area |
| Small set of methods (LP, MIP, NLP,…) | Wide range of methods |
| Small amounts of (structured) data | Huge amounts of data |
| Visualization? | Visualization crucial |
| Niche market | Big market |

*Computation* → *Model* → ***Application***

*→ Embedded Models*

*→ User hardly aware of model*

# Change in Focus: Future

Powerful algebraic modeling language

Open architecture and interfaces to other systems, independent layers

*"I never predict. I just look out the window and see what is visible – but not yet seen"*
(Peter Drucker)

# Algebraic Problem Representation

## Model as a communication device

- Helps defining the problem
- Gives structure for efficient (inter-team) communication
- Provides (data) contract between different parts of the application
- Executable description of the problem

**Effort for model development is often small compared to the effort required for the rest of application**

GAMS

# Evolving Solver-Links

**GAMS provides uniform interface to all major solvers**

Often new and interesting algorithmic features driven by implementation choices

**But:** Using solver specific features prevents easy exchange of solvers

GAMS

# Evolving Solver-Links

Challenge: Find a concept that combines the essentials of new features independent of the particular implementation choices. Examples:

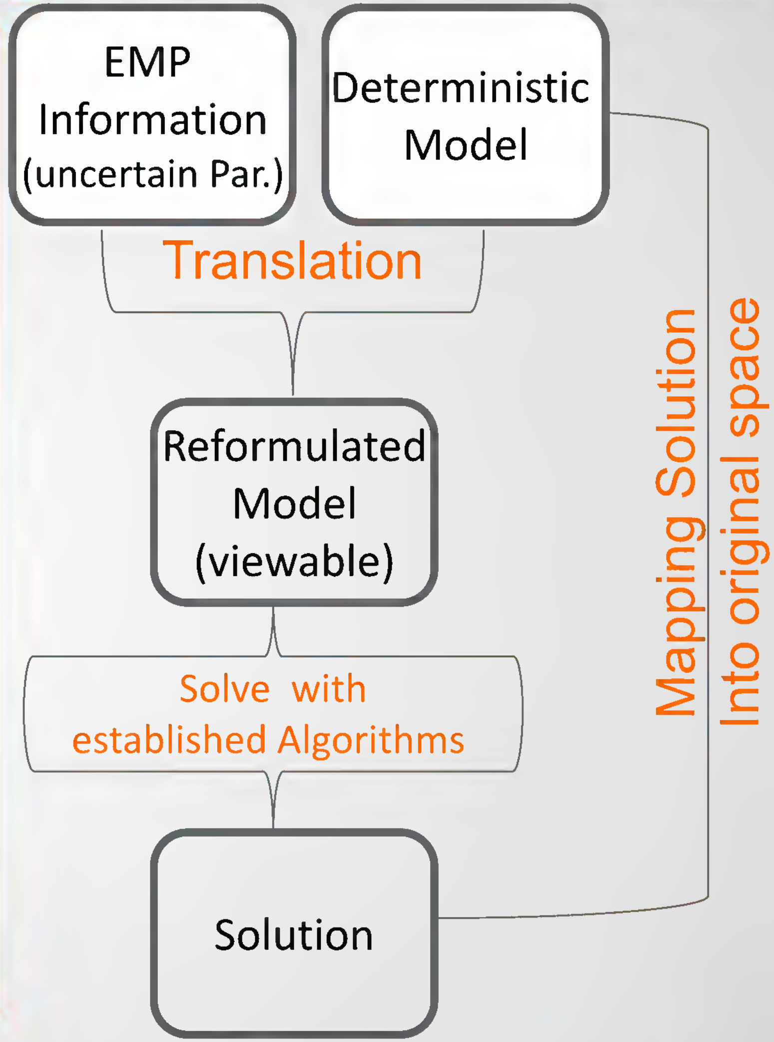
- **Logical Constraints**: `If y=1 => x1 + x2 + x3=L= 0;`
  - BigM-Formulation
    `constr01.. x1 + x2 + x3 =L= M*(1-y); y ∊ {0,1};`
  - Indicator Constraints (CPLEX, XPRESS, SCIP):
    `constr01.. x1 + x2 + x3 =L= 0; indic constr01$y 1`
  - Alternative: SOS1 (GUROBI):
    `constr01.. x1 + x2 + x3 =L= M; SOS1:(y, M);`
  - (Generalized) Disjunctive Programming (Grossmann)

- **Stochastic Programming** - supported solvers through EMP/SP

GAMS

# Stochastic Programming EMP/SP

- Simple interface to add uncertainty to existing deterministic models
- (EMP) Keywords to describe uncertainty include: discrete and parametric random variables, stages, chance constraints, Value at Risk, ...
- Available solution methods:
  - Automatic generation of **D**eterministic **E**quivalent (can be solved with any solver)
  - Specialized commercial algorithms (DECIS, LINDO)



# Open architecture and interfaces

Frequently optimization models only (important) element of larger system

GAMS provides environment to build robust and fail safe systems, because optimization

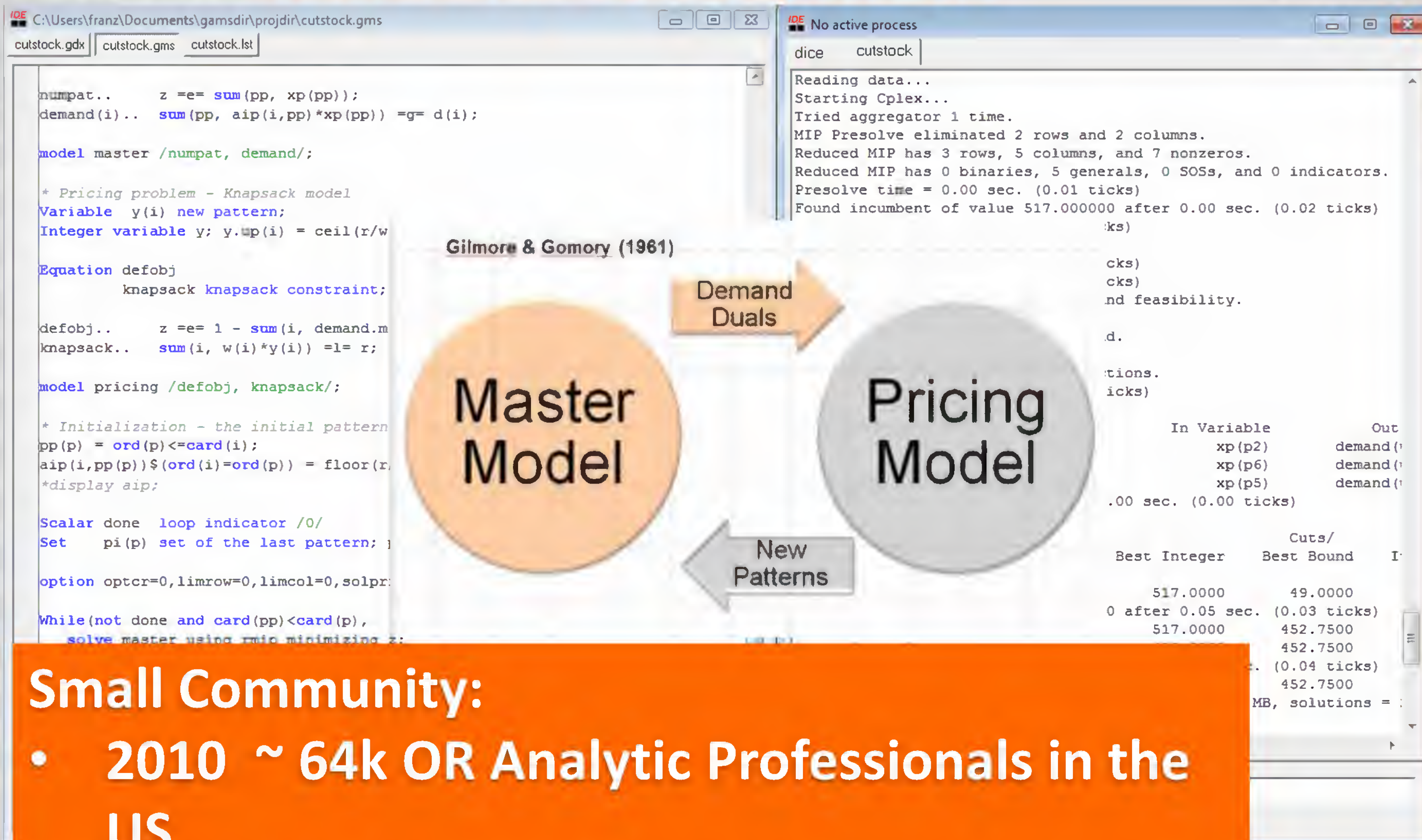
- May take longer than one is willing to wait
- Will eventually fail

# Open architecture and interfaces

**Don’t lock developers and users into a certain environment. Adjust for:**

- Advancing hardware and computer paradigms (e.g. cloud computing)
- New solver technology and solution methods
- New graphical user interfaces and deployment environments

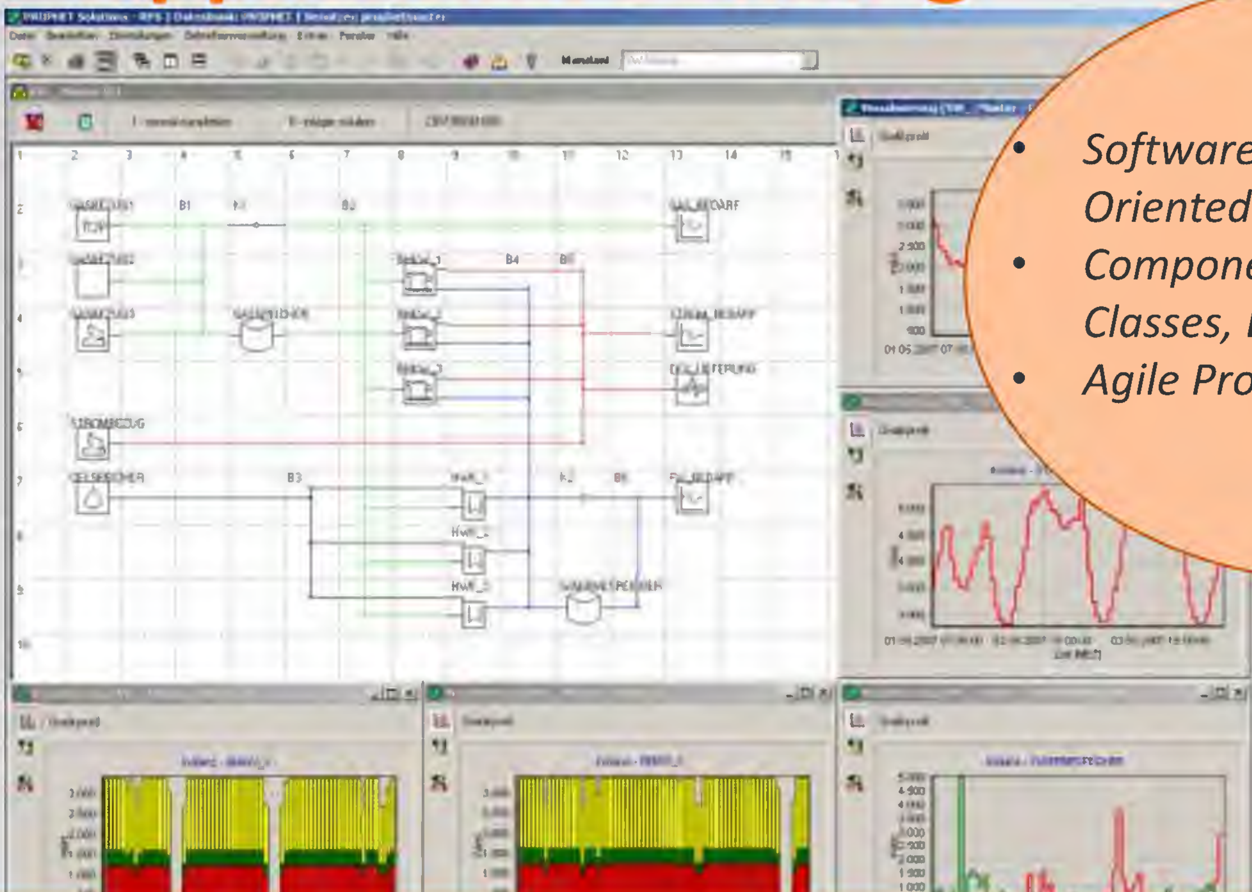
# From Model Development




**Small Community:**

- 2010 ~ 64k OR Analytic Professionals in the US
- INFORMS 10-12k members

# to Application Building



- *Software Architecture, Object Oriented Design*
- *Components, Encapsulation, Classes, Data Acess Layer,..*
- *Agile Programming, Mesh, …*

**Huge Community:**

- **2006 ~ 3.3 Mill. IT Professionals in the US**
- **Rapidly changing IT environments**

# (Some of the) Issues

**Role of Optimization within** Application

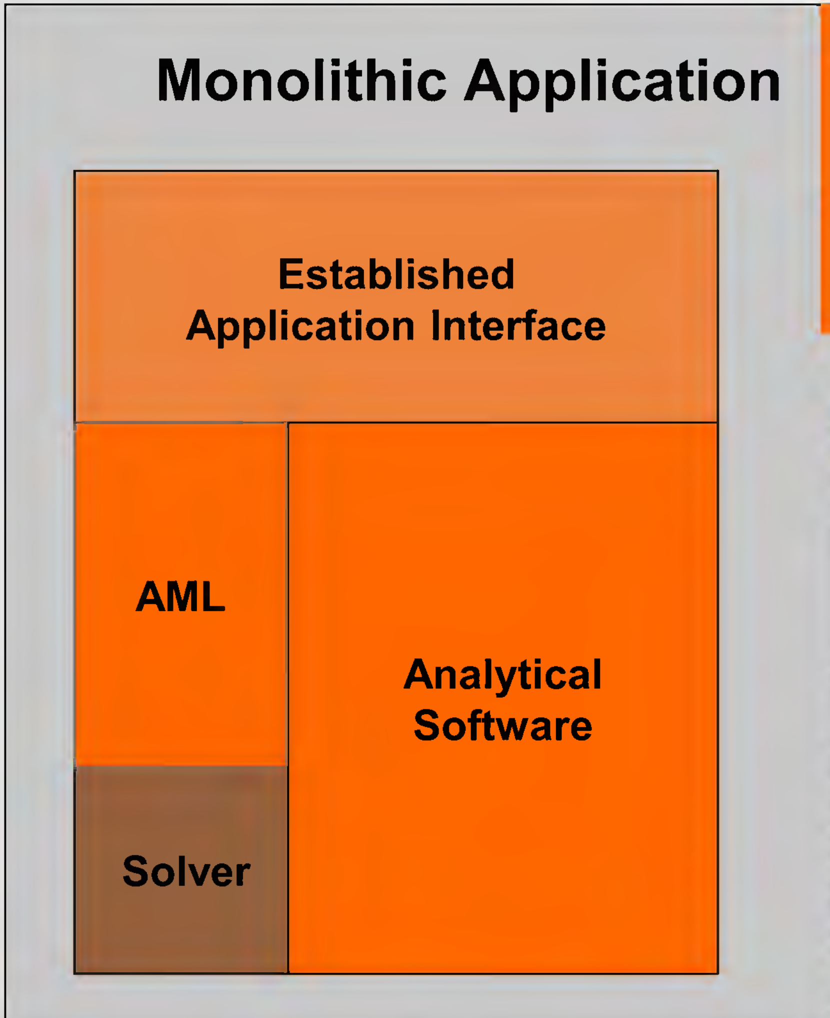
**Generalist** (domain expert and modeling expert and IT expert) versus **Team of Specialists**

Quality of Data

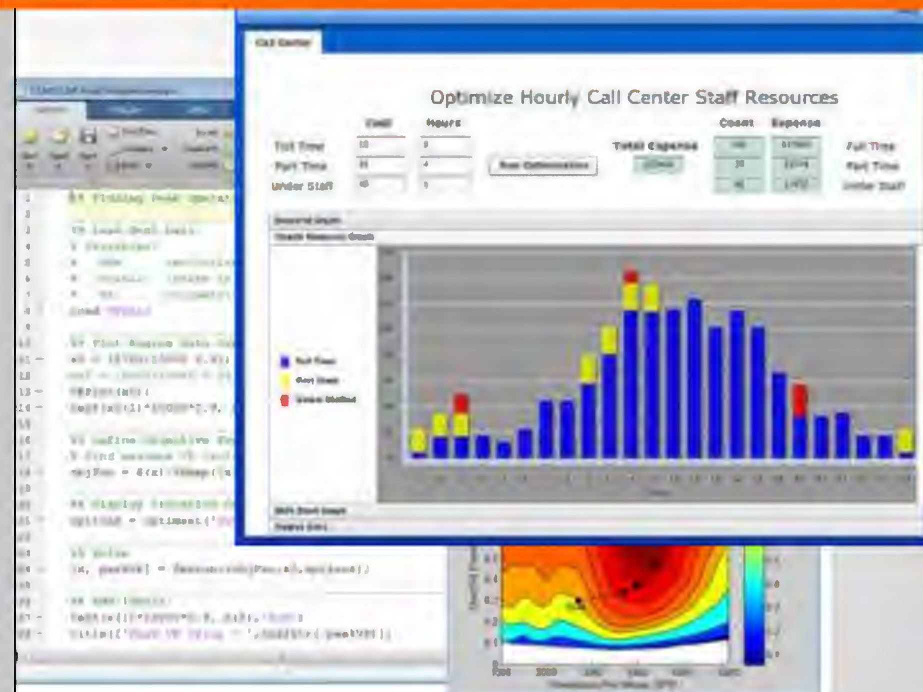
**Standalone** Application or **Integration**

**Lifecycle of Application**

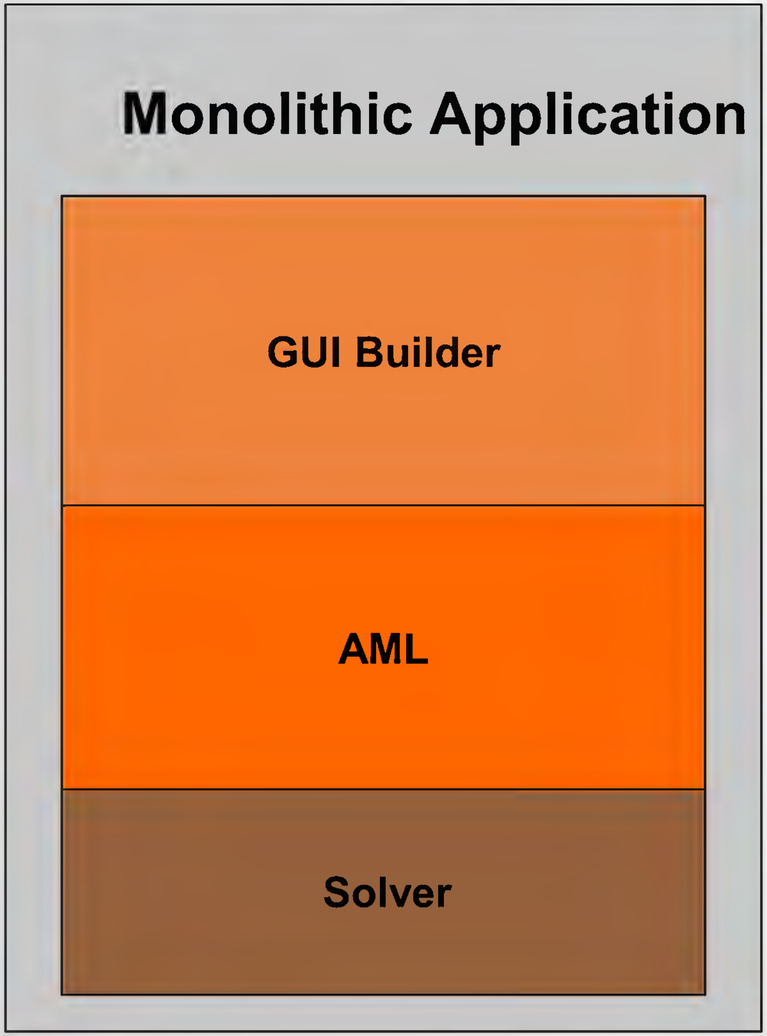
# Example: All in One – Top Down



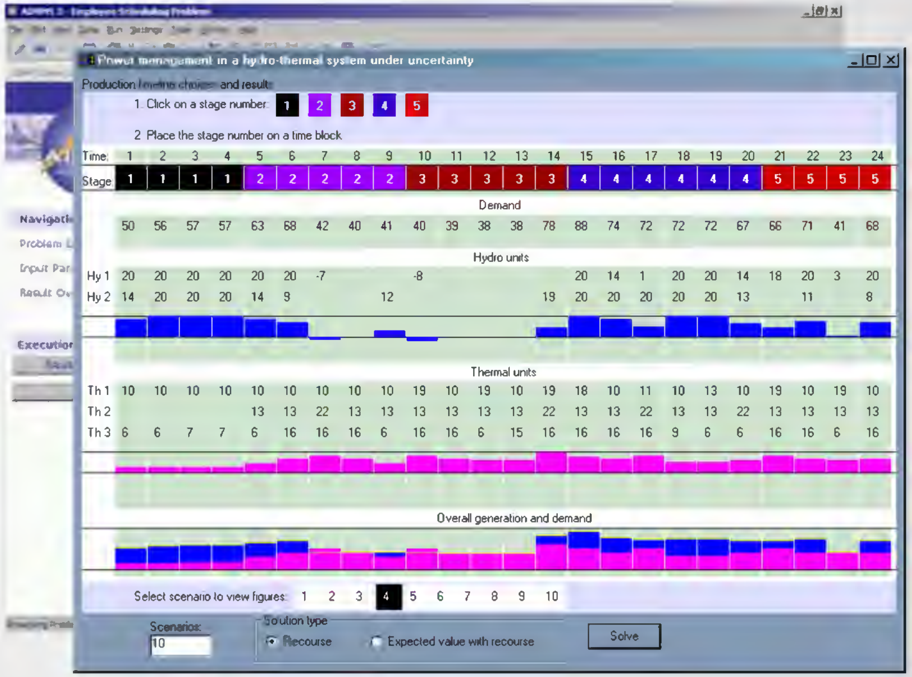

- Add "AML" to existing analytical software system
- "large" user base, e.g. MATLAB, or SAS



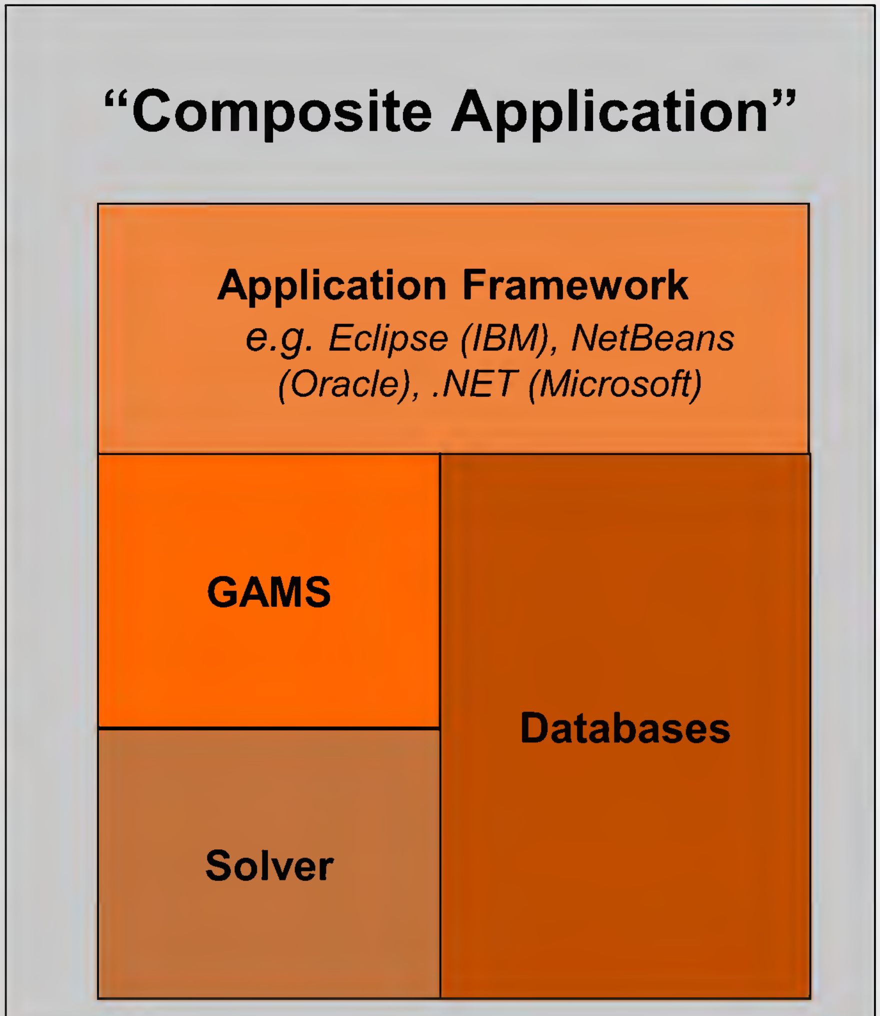
# Example: All in One – Bottom Up




- Integrate GUI-builder into AML
- “small” user base, e.g. AIMMS (Pro) or FICO Xpress-Insight



# Example: Composite Application




- "Construction Kit" with different connected elements
- Use existing frameworks to build applications, e.g. Oracle Application Express, MS .NET, IBM ODME, ….
- OO API to connect to framework

GAMS

# Summary

## GAMS – Elements, Enhancements, and Examples

- **Simple, but powerful language**
- **Designed to interact**
- **Evolution** through more than 25 years of R&D and user feedback
- **Maturity** through experience and rigorous testing

## Striving for Innovation and Compatibility

- **Increase productivity**
- Provide **cutting edge technology**
- Don't **lock** developers and users into a certain environment
- **Protect** investments of users

# GAMS – Software Demo

- Steve Dirkse, GAMS Development
- An Introduction to Model Development with GAMS
- Monday, 1:50-2:40 pm
- Room: Goldenwest

INFORMS CONFERENCE ON BUSINESS ANALYTICS & OPERATIONS RESEARCH
April 12-14, 2015 | Huntington Beach, CA

GAMS

# Thank You


USA
GAMS Development Corp. 1217 Potomac Street, NW Washington, DC 20007
USA
Phone: +1 202 342 0180
Fax: +1 202 342 0181
sales@gams.com

Europe
GAMS Software GmbH
P.O. Box 40 59
50216 Frechen, Germany
Phone: +49 221 949 9170
Fax: +49 221 949 9171
info@gams.de