GAMS – Striving for Innovation and Compatibility

Michael R Bussieck mbussieck@gams.com

GAMS Development Corp.

www.gams.com

GAMS Software GmbH

www.gams.de

Åbo Akademi

December 1, 2011

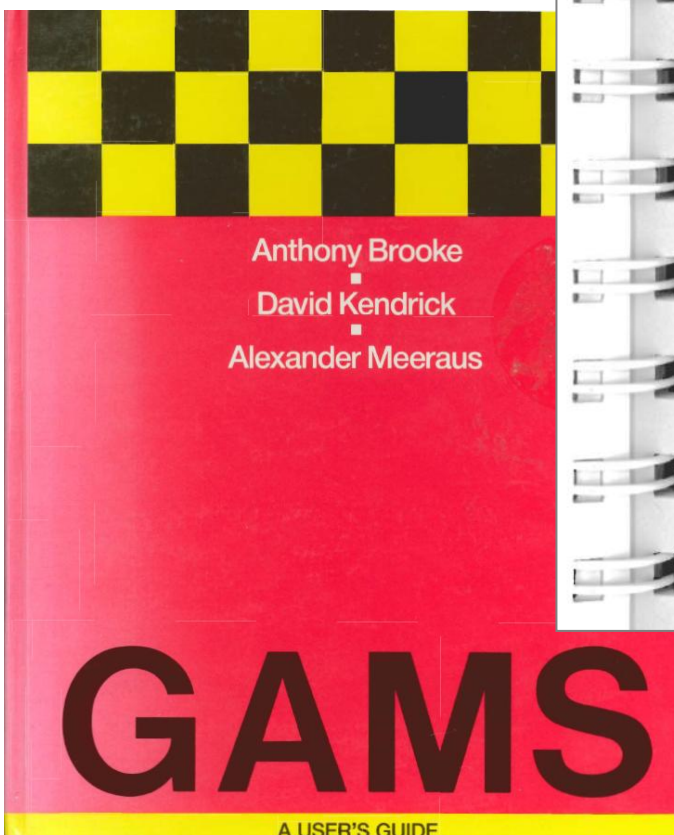
Then …

In Table 17.1 we list sizes and attributes of representative models that are "large" in the sense that they are near the limit of what is practical on a personal computer, along with the model generation time (GAMS) and solution time (solver), both in minutes. These examples were run on an 8 MHz AT with an 80287 coprocessor and 640K of RAM. The times shown are to give you a rough idea of what is possible: these are not precisely controlled benchmarks, and we have a host of performance improvements in mind for the near future.

Table 17.1: Problem Characteristics

Name	*Number of Rows*	*Number of Columns*	*Number of Nonzeroes*	*Generation Time*[a]	*Solution Time*[a]	*Iterations*	*Solver*
DINAMICO	318	425	4156	3.0	30.1	628	MINOS
SARF	532	542	3949	37.7	115.8	2775	MINOS
FERTD[b]	458	2968	7252	11.4	28.3	1368	ZOOM
CAMCGE[c]	243	280	1356	0.8	7.0	189	MINOS
GANGES[d]	274	357	1405	1.8	7.3	187	MINOS
YEMCEM[e]	168	258	953	0.9	7.6	600	ZOOM
EGYPT[f]	281	618	3168	4.0	25.3	1551	ZOOM

[a]Measured in minutes.
[b]The problem is too big for MINOS. ZOOM was used instead.
[c]A nonlinear problem. 63% of the non-zeroes are nonlinear.
[d]A nonlinear problem. 58% of the non-zeroes are nonlinear.
[e]A mixed binary problem, with 55 binary variables (solved with a relative termination criterion of 10%).
[f]A linear problem, solved using XMP which is contained within ZOOM.



GAMS Users Guide (1988)

… and now

	Type	s in 1988	s in 2008	Improvement Factor
camcge	NLP	468	0.031	15097
dinamico	LP	1986	0.125	15888
egypt*	MIP	1758	0.015	117200
fertd*	MIP	2382	0.062	38419
ganges	NLP	546	0.109	5009
sarf	LP	9210	0.139	66259
yemcem*	MIP	510	0.140	3643

* MIP 1988 solver ZOOM, 2008 solver CPLEX

Agenda

- **G**eneral **A**lgebraic **M**odeling **S**ystem
- Impact, Compatibility, and Innovation
- Example

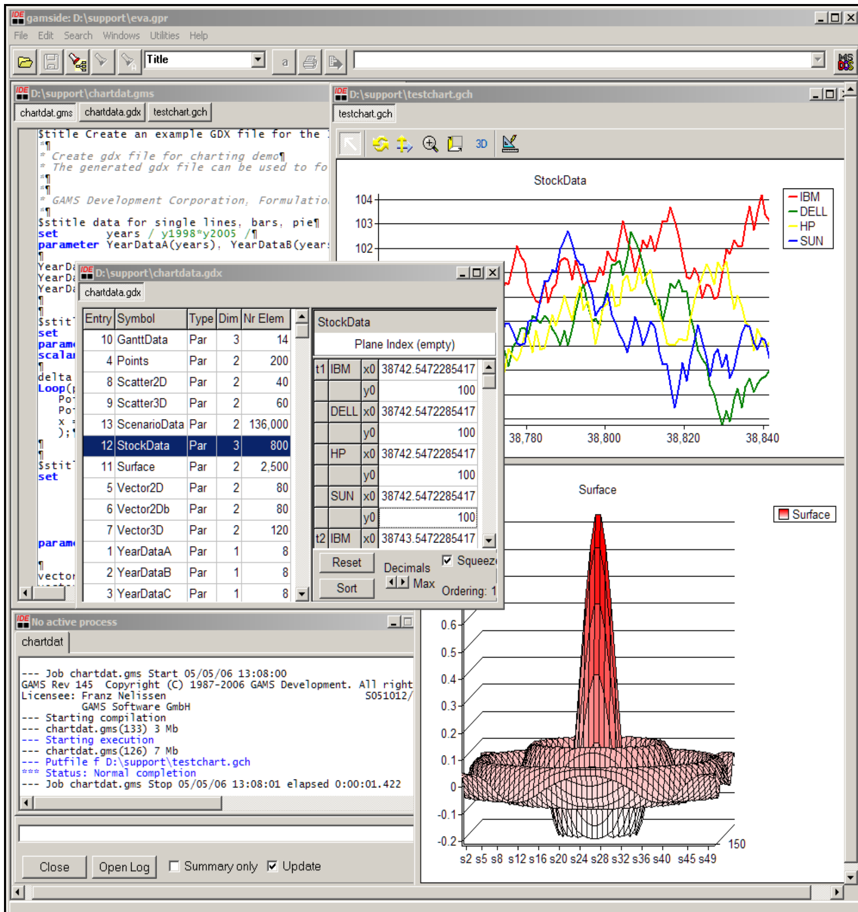
Agenda

General **A**lgebraic **M**odeling **S**ystem

Impact, Compatibility, and Innovation

Example

GAMS at a Glance

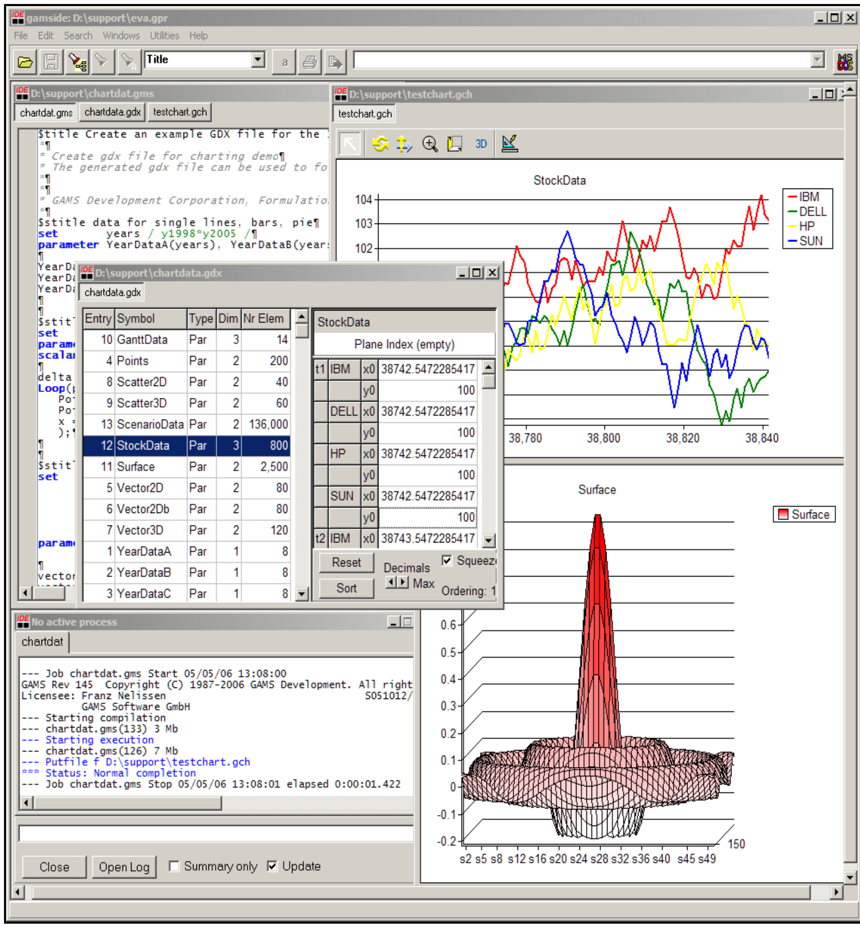


General **A**lgebraic **M**odeling **S**ystem

- Roots: World Bank, 1976
- Went commercial in 1987
- GAMS Development Corp.
- GAMS Software GmbH
- GOR Company Award 2010

- Broad academic & commercial user community and network

GAMS at a Glance



General **A**lgebraic **M**odeling **S**ystem

- Algebraic Modeling Language
- 25+ Integrated Solvers
- 10+ Supported MP classes
- 10+ Supported Platforms
- Connectivity- & Productivity Tools
    - IDE
    - Model Libraries
    - GDX, Interfaces & Tools
    - Grid Computing
    - Benchmarking
    - Compression & Encryption
    - Deployment System
    - …

System Overview

Interactive | **API / Batch**

User Interfaces

GAMS Language Compiler and Execution System

Solvers

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

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

Connectivity Tools

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

Productivity Tools

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

Supported Model Types

Solver/Model type availability - 22.7 May 1, 2008	LP	MIP	NLP	MCP	MPEC	CNS	DNLP	MINLP	QCP	MIQCP	*Stoch.*	*Global*
ALPHAECP								✔		✔		
BARON 8.1	✔	✔	✔				✔	✔	✔	✔		✔
BDMLP	✔	✔										
COIN	✔	✔										
CONOPT 3	✔		✔			✔	✔		✔			
CPLEX 11.0	✔	✔							✔	✔		
DECIS	✔										✔	
DICOPT								✔		✔		
KNITRO 5.1	✔		✔				✔		✔			
LINDOGLOBAL 5.0	✔	✔	✔				✔	✔	✔	✔		✔
LGO	✔		✔				✔		✔			✔
MILES				✔								
MINOS	✔		✔				✔		✔			
MOSEK 5	✔	✔	✔				✔		✔	✔		
MPSGE												
MSNLP			✔				✔		✔			✔
NLPEC				✔	✔							
OQNLP			✔				✔	✔	✔	✔		✔
OSL V3	✔	✔										
OSLSE	✔										✔	
PATH				✔		✔						
SBB								✔		✔		
SNOPT	✔		✔				✔		✔			
XA	✔	✔										
XPRESS 18.00	✔	✔							✔			
Contributed Plug&Play solvers												
AMPLwrap	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
DEA	✔	✔										
Kestrel	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔

GAMS

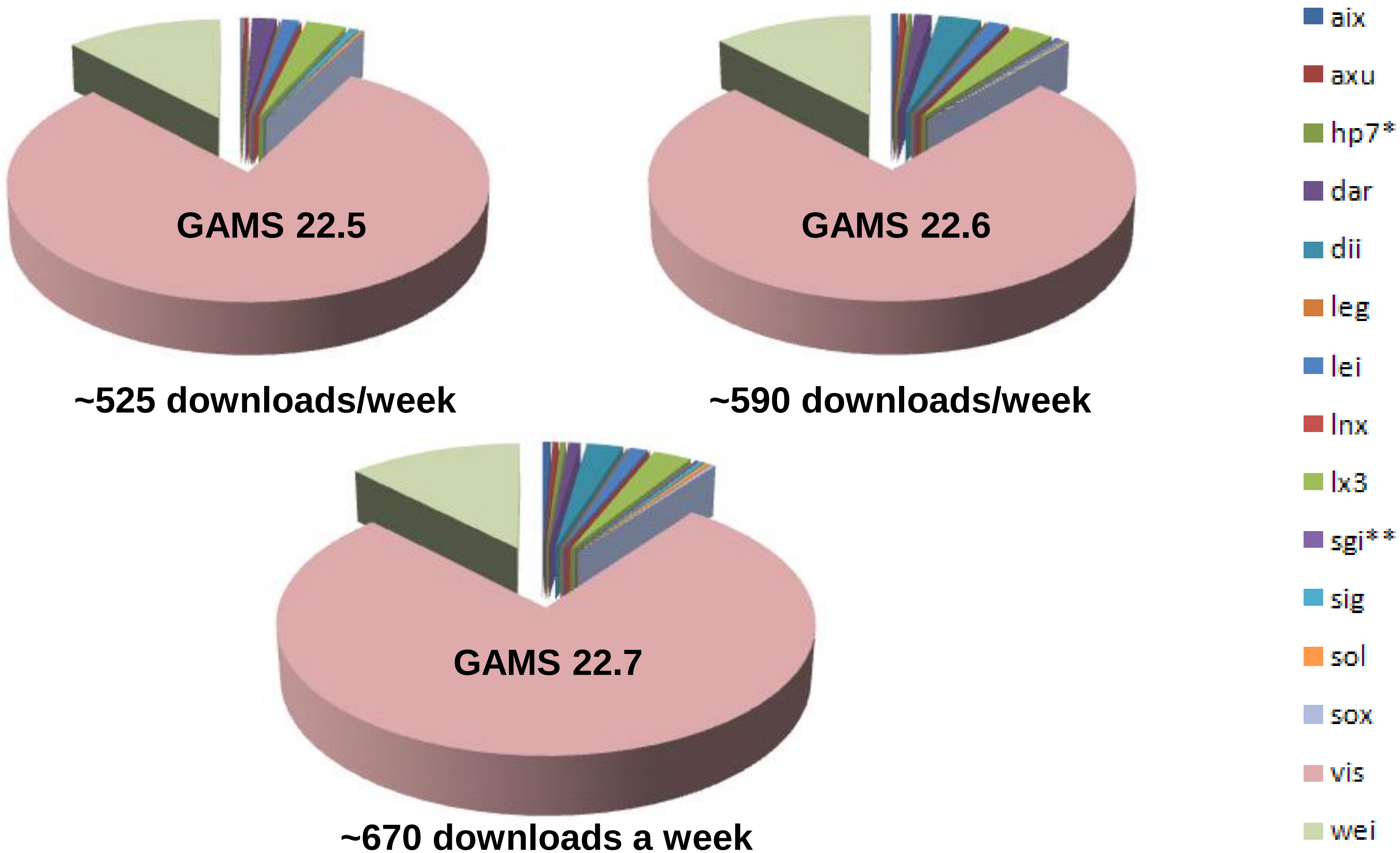
Supported Platforms

Solver/Platform availability - 22.7: May 1, 2008	x86 MS Windows	x86_64 MS Windows	x86 Linux	x86_64 Linux	Sun Sparc SOLARIS	Sun Sparc64 SOLARIS	Sun Intel SOLARIS	HP 9000 HP-UX 11[1]	DEC Alpha Digital Unix 4.0	IBM RS-6000 AIX 4.3	Mac PowerPC Darwin	Mac Intel32 Darwin	SGI IRIX[2]
ALPHAECP	✔	✔	✔	✔	✔	✔	✔		✔	✔	✔	✔	
BARON 8.1	✔	32bit	✔	32bit						✔			
BDMLP	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
COIN	✔	✔	✔	✔			✔				✔	✔	
CONOPT 3	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
CPLEX 11.0	✔	✔	✔	✔	✔	✔	✔	10.0	8.1	✔		✔	9.1
DECIS	✔	✔	✔	✔	✔	32bit	✔	✔	✔	✔			✔
DICOPT	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
EMP	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
KNITRO 5.1	✔	32bit	✔	✔	✔	32bit					✔	✔	
LINDOGLOBAL 5.0	✔	✔	✔	✔	✔	✔					✔	✔	
LGO	✔	✔	✔	✔	✔	✔	✔	✔	✔		✔	✔	✔
LOGMIP	✔	✔									✔	✔	
MILES	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
MINOS	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
MOSEK 5	✔	✔	✔	✔	✔	✔	✔	3.2			✔	✔	
MPSGE	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
MSNLP	✔	✔	✔	✔	✔	32bit		✔			✔	✔	
NLPEC	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
OQNLP	✔	32bit	✔	32bit									
OSL V3	✔	32bit	✔	32bit	✔	32bit		V2		✔			V2
OSLSE	✔	32bit	✔	32bit	✔	32bit				✔			
PATH	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
SBB	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
SNOPT	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
XA	✔	32bit	✔	✔	✔	32bit		✔	✔	✔			
XPRESS 18.00	✔	32bit	✔	32bit	✔	32bit		16.10		✔			
Contributed Plug&Play solvers													
AMPLwrap	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔			
DEA	✔	✔	✔	✔	✔	✔		✔	✔				
Kestrel	✔	32bit	✔	32bit	✔								

1) GAMS distribution for HP 9000/HP-UX is 22.1.

2) GAMS distribution for SGI IRIX is 22.3.

Downloads by Platform



Agenda

- **G**eneral **A**lgebraic **M**odeling **S**ystem
- Impact, Compatibility, and Innovation
- Example

Impact

- Impact of AML (like GAMS) to Optimization

  Optimization -> OR -> Society

- Algebraic modeling systems
  - Improve productivity of OR/Optimization specialists
  - Opens world of optimization to domain experts
  - Adds quickly value
  - Extends the reach of OR (methods like optimization) to communities outside classical OR

GAMS Design

- Universal language: Algebra
  - Algebra (Expressions): model equations
  - Relational Algebra (SQL): data manipulation
  - Scalability/Sparsety
  - Necessary procedural elements

- Avoid pitfalls of traditional/imperative languages:
  - Addressing
  - Memory management

- Independence of data, model, and solution technology (platform, data/user interface)
  - Development/debug versus production/stress test
  - Solvers become a commodity
  - No porting work

Backward Compatibility

- Life time of a model: 15+ years:
  - New maintainer, platform, solver, user interface
  - Protection of investment in a model

- Blessing for the user (mostly) – Curse for developers
  - Old concepts in new situations
    - Example GAMS Listing file, OptCR
  - Language additions have to be supported in the future
  - GAMS is extremely conservative when it comes to syntax additions

- Danger of becoming a barrier for innovation

Platform for Innovation

- Reliable, high performance system for developing and deploying optimization applications
- Research tool:
  - new modeling paradigms (e.g. SDP, bilevel, GDP, …)
  - emerging solution technology (e.g. MPEC)
  - new computing environments (e.g. Grid)
- GAMS tries to serve both worlds (synergy)
  - Large user base in industry and academia
  - Dissemination of research ideas
  - Challenging/relevant problems from industry

Agenda

- **G**eneral **A**lgebraic **M**odeling **S**ystem
- Impact, Compatibility, and Innovation
- Example

User Extensions of GAMS

- GAMS open architecture

- User developed tools complement GAMS system
  - Main contributors: Michael Ferris, Erwin Kalvelagen, Bruce McCarl, Tom Rutherford, …

- Often interaction with GAMS syntax required
  - difficult, GAMS is not context free language
  - MPSGE (Rutherford, early integration into GAMS)
  - NLP2MCP (Ferris), GAMS-F (Ferris, Rutherford, Starkweather), LogMIP (Grossmann, Vecchietti)

- “Solvers” for special models: DEA (Ferris, Voelker)

Generalized Disjunctive Programming

- Generalized Disjunctive Program

- Ignacio Grossmann, CMU Pittsburgh
- Aldo Vecchietti, U. Tecnológica Nacional, Argentinia

- Interest in
  - Applications of GDP
  - Formulations/Reformulations
  - Algorithms (e.g. Logic Based Outer Approximation)

- LogMiP
  - GAMS parser
  - Various solvers (reformulation, algorithms)

Non-linear Discrete/Continuous Optimization: GDP Model

Lee & Grossmann I.E. (2000) (GDP)

$$Min\ Z = \sum_{k \in K} c_k + f(x)$$ *Objective function*

$$s.t. \quad r(x) \le 0$$ *Common constraints*

$$\bigvee_{j \in J_k} \begin{bmatrix} Y_{jk} \\ g_{jk}(x) \le 0 \\ c_k = \gamma_{jk} \end{bmatrix} \quad k \in K$$ *Disjunctive constraints*

$$\underline{\vee}_{j \in J_k} Y_{jk} \quad k \in K$$

$$\Omega(Y) = True$$ *Logic constraints*

$$x^L \le x \le x^U$$

$$Y_{jk} \in \{True, False\} \quad j \in J_k, k \in K$$

$$c_k \in \mathbf{R}^1 \quad k \in K$$

$f(x), r(x), g_{jk}(x)$

convex functions

Logical OR operator

Boolean variables

Generalized Disjunctive Prog. Example

Raman & Grossmann, Comp. & Chem. Eng., 18, 7, p.563-578, 1994.

- Three jobs (A,B,C) must be executed sequentially in three steps, but not all jobs require all the stages. Once a job has started it cannot be interrupted.

- The objective is to obtain the sequence of task, which minimizes the completion time.

Stage Job	1	2	3
A	5	-	3
B	-	3	2
C	2	4	-

Data Definition

```
table p(j,s) processing time

    1    2    3
A   5         3
B        3    2
C   2    4

alias (j,jj),(s,ss);

parameter c(j,s)  stage completion time
          w(j,jj) maximum pair wise waiting time
          pt(j)   total processing time;
set       less(j,jj) upper triangle;

c(j,s)   = sum(ss$(ord(ss)<=ord(s)), p(j,ss));
w(j,jj)  = smax(s, c(j,s) - c(jj,s-1));
pt(j)    = sum(s, p(j,s));
less(j,jj)= ord(j) < ord(jj);
```

Basic Model Definition

```
variables t          completion time
          x(j)       job starting time
positive variable x;

equations comp(j)    job completion time
          seq(j,jj)  job sequencing j before jj;

comp(j).. t =g= x(j) + pt(j);

seq(j,jj)$(not sameas(j,jj)).. x(j) + w(j,jj) =l= x(jj);
```

Above equation is incomplete!

If (j,jj) is active then (jj,j) should be relaxed

New Modeling and Solution Concepts

- Breakouts of traditional MP classes
  - Extended Nonlinear Programs
  - Chance Constraints
  - CVaR Constraints
  - Robust Programming
  - Bilevel Programs
  - Generalized Disjunctive Programs
  - …

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

What now?

Do not:

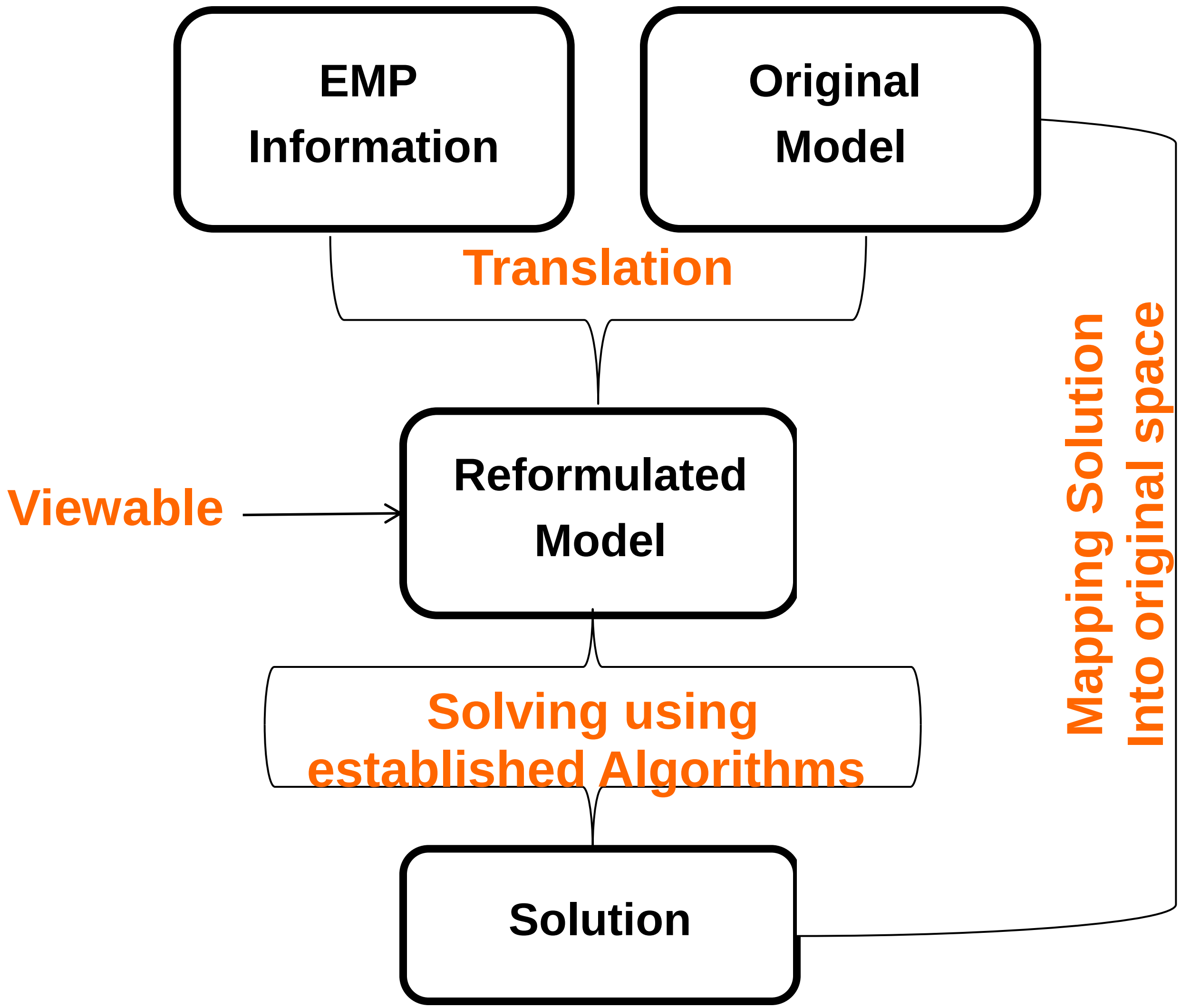
- overload existing GAMS notation right away !
- attempt to build new solvers right away !

But:

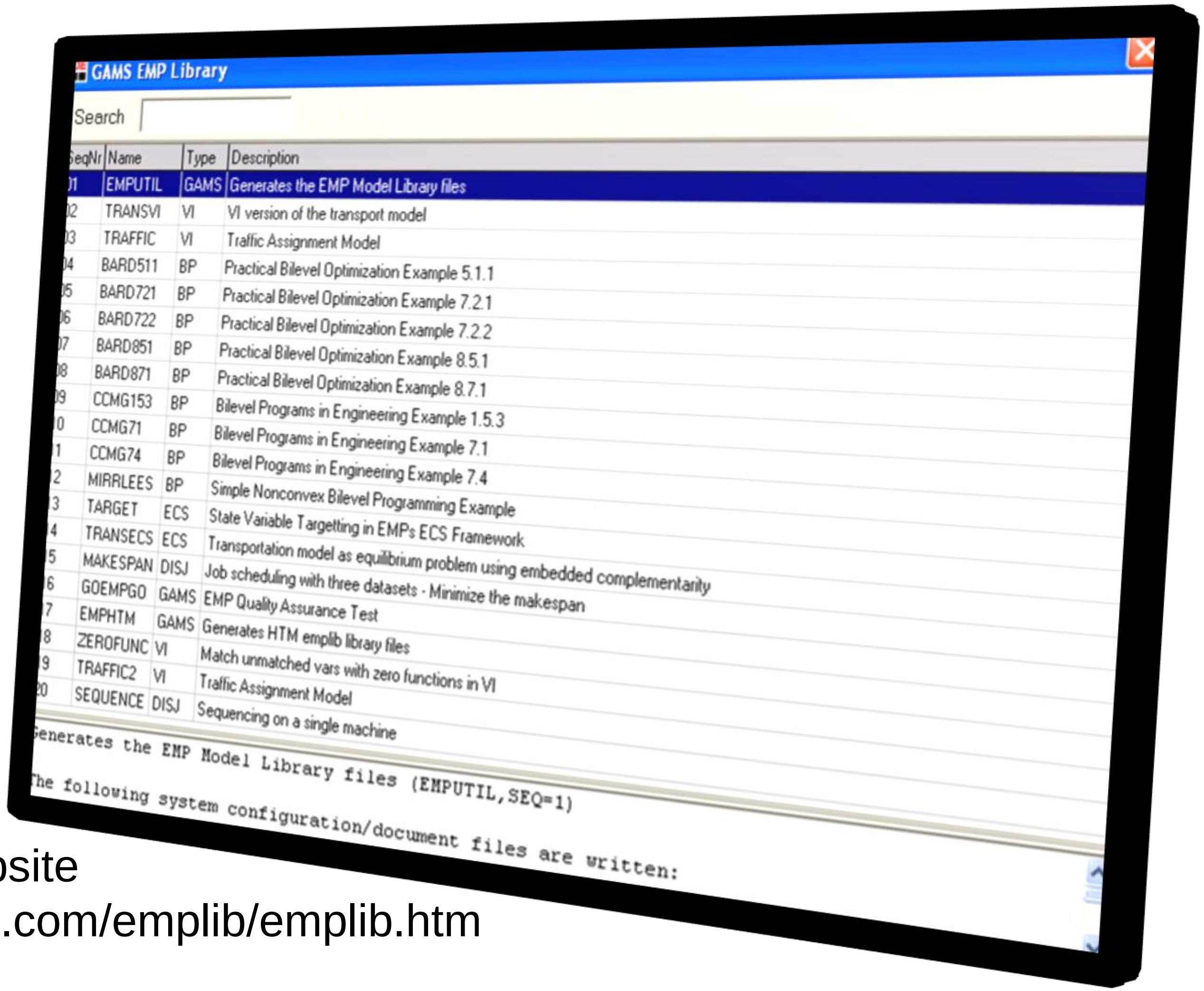
- Use existing language features to specify additional model features, structure, and semantics
- Express extended model in symbolic (source) form and apply existing modeling/solution technology
- Package new tools with the production system

→ **Extended Mathematical Programming (EMP)**

JAMS: a GAMS EMP Solver



EMP Library



- Distributed with GAMS
- Available on website http://www.gams.com/emplib/emplib.htm

Conclusions

- Algebraic Model Languages/Systems
  - Support the dissemination of optimization into non-classical OR fields
  - Make a scarce resource (*good modelers*) more productive

- Balancing act between
  - backward compatible, reliable, high performance software
  - research tool with open architecture to foster innovative research on new model paradigms, formulations and algorithms

Thank you!

USA

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

sales@gams.com
support@gams.com

Europe

GAMS Software GmbH
Eupener Str. 135-137
50933 Cologne
Germany
Phone: +49 221 949 9170
Fax: +49 221 949 9171
http://www.gams.de

info@gams.de
support@gams-software.com