Rapid Prototyping of Decomposition Algorithms

Part 1:

GAMS – Balancing Rapid Prototyping and High Performance

Michael Bussieck, GAMS Software GmbH, mbussieck@gams.com
Steffen Rebennack, Colorado School of Mines, srebenna@mines.edu

GOR Workshop *Herausforderungen der energiewirtschaftlichen Optimierung*

EnBW Karlsruhe, 19.-20. April, 2012

Agenda

- Introduction
- Declarative and Procedural Mix
- High Performance Prototypes
- Conclusion

Firefox | Algebraic modeling language - ...

en.wikipedia.org/wiki/Algebraic_modeling_language

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Algebraic modeling language

From Wikipedia, the free encyclopedia

Algebraic Modeling Languages (**AML**) are high-level computer programming languages for describing and solving high complexity problems for large scale mathematical computation (i.e. large scale optimization type problems).[1] One particular advantage of some algebraic modeling languages like AIMMS[1], AMPL[2] or GAMS[1] is the similarity of their syntax to the mathematical notation of optimization problems. This allows for a very concise and readable definition of problems in the domain of optimization, which is supported by certain language elements like sets, indices, algebraic expressions, powerful sparse index and data handling variables, constraints with arbitrary names. The algebraic formulation of a model does not contain any hints how to process it.

An AML does not solve those problems directly; instead, it calls appropriate external algorithms to obtain a solution. These algorithms are called solvers and can handle certain kind of mathematical problems like:

- linear problems
- integer problems
- (mixed integer) quadratic problems
- mixed complementarity problems
- mathematical programs with equilibrium constraints
- constrained nonlinear systems
- general nonlinear problems
- non-linear programs with discontinuous derivatives
- nonlinear integer problems
- global optimization problems

Algebraic Modeling Languages

What's that?

http://en.wikipedia.org/wiki/Algebraic_modeling_language

- High-level **computer programming languages** for the formulation of **complex mathematical optimization problems**
- **Notation similar to algebraic notation**: Concise and readable definition of problems in the domain of optimization
- **Do not solve problems directly**, but ready-for-use links to state-of-the-art algorithms

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General Algebraic Modeling System

From Wikipedia, the free encyclopedia

The **General Algebraic Modeling System (GAMS)** is a high-level modeling system for mathematical optimization. GAMS is designed for modeling and solving linear, nonlinear, and mixed-integer optimization problems. The system is tailored for complex, large-scale modeling applications and allows the user to build large maintainable models that can be adapted to new situations. The system is available for use on various computer platforms. Models are portable from one platform to another.

GAMS was the first algebraic modeling language (AML) and is formally similar to commonly used fourth-generation programming languages.[citation needed] GAMS contains an integrated development environment (IDE) and is connected to a group of third-party optimization solvers. Among these solvers are BARON, COIN solvers, CONOPT, CPLEX, DICOPT, GUROBI, MOSEK, SNOPT, and XPRESS.

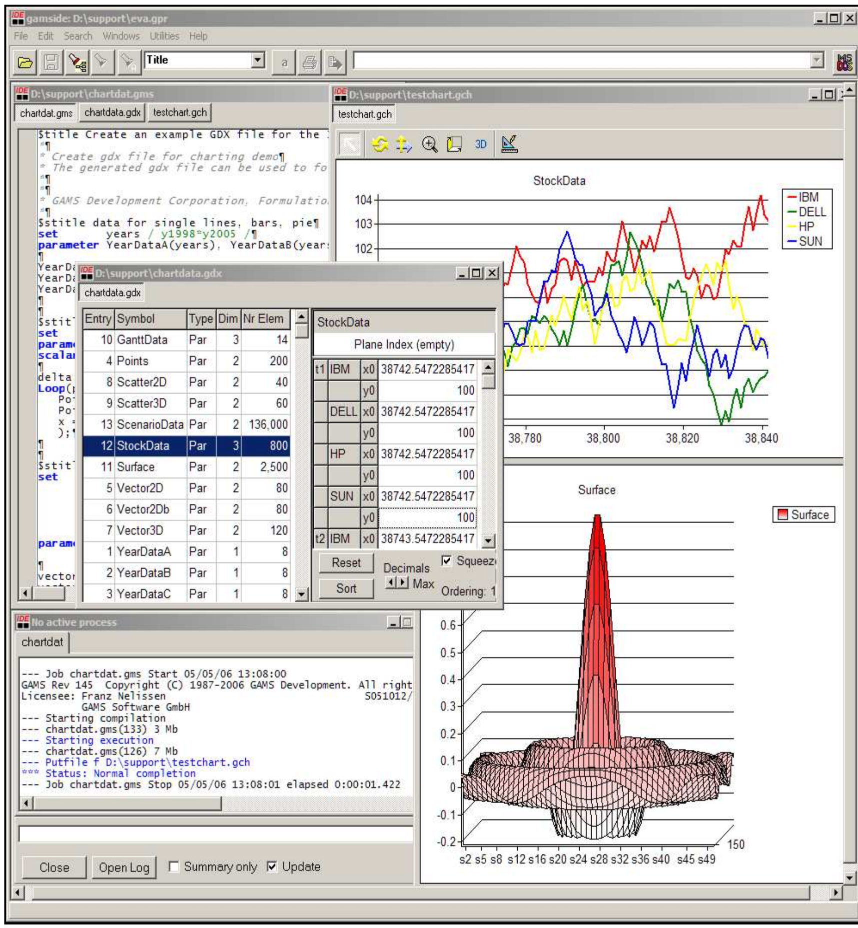
GAMS facilitates the users to implement a sort of hybrid algorithms combining different solvers in a seamless way. Models are described in concise algebraic statements which are easy to read, both for humans and machines. GAMS is among the most popular input formats for the NEOS Server for Optimization. Although initially designed for applications related to economics and management science, it has a large community of users from various backgrounds of engineering and science.

GAMS

Developer(s)	GAMS Development Corporation
Stable release	23.7.3 / August 23, 2011
Development status	Active
Platform	Cross-platform
Type	Algebraic Modeling Language (AML)
License	Proprietary
Website	GAMS USA GAMS Germany

Contents [hide]

GAMS Development / Software at a Glance



- Roots: World Bank, 1976
- Went commercial in 1987
- GAMS Development Corp. (US)
- GAMS Software GmbH (Europe)
- Technical tool provider (Software)
- Broad academic & commercial user community and network
  - GAMS is used in more than 120 countries
  - Half of licenses commercially used

GAMS

Broad Network

ClustrMaps archive for http://www.gams.com/download/

5177 visits from 19 Mar 2012 to 26 Mar 2012

⊢ distance in which individuals are clustered
Total number of visits depicted above = 4275

Dot sizes:

● = 1000 + ● = 100 - 999 • = 10 - 99 • = 1 - 9

Downloads (March 2012)

http://www.gams.com/download/

GAMS

[Home | Support | Sales | Solvers | Documentation | Model Libraries | Search

Download GAMS Distribution 23.8.1 - March 17, 2012

Note: To deliver GAMS with the best performance we are using the Amazon CloudFront web service, a global network of edge locations for content delivery.

***Microsoft Internet Explorer** users who have enabled SmartScreen Filter may get several warnings during the download of a GAMS system. If you do not want to ignore these m please cancel the download and download the current version for Windows 32 bit or Windows 64 bit as a zip-file and unzip this file before running the setup program.*

Please consult the release notes before downloading a system. The installation notes for Windows and UNIX and the complete system documentation are included in any system.

Windows	
Windows 32 bit	Windows 7, Windows Vista, Windows XP, Windows Server 2008, Windows Server 2003, and compatible on AMD- or Intel-based (x86_32) architectures
Windows 64 bit	Windows 7 x64, Windows Vista x64, Windows Server 2008 x64, Windows Server 2003 x64, and compatible on AMD- or Intel-based (x64_64) architecture
Unix	
AIX	AIX 5.3 or higher, PowerPC chip, 64 bit (ppc_64)
Linux 32 bit	AMD- or Intel-based 32-bit Linux systems. The software was built with the GNU Compiler Collection (GCC) toolset, ver 4.4 or higher.
Linux 64 bit	AMD- or Intel-based 64-bit Linux systems (x86_64). The software was built with the GNU Compiler Collection (GCC) toolset, ver 4.4 or higher.
Mac OS X Intel 32 bit	Macintosh Intel-based systems (x86_32) built on Darwin 10.6 (Snow Leopard). Please note that this is a Mac OS X Terminal application and must be install executed using the command line interface. Additional Information
Mac OS X Intel 64 bit	Macintosh Intel-based systems (x64_64) built on Darwin 10.6 (Snow Leopard). Please note that this is a Mac OS X Terminal application and must be install executed using the command line interface. Additional Information
Solaris SPARC 32 bit	Solaris 2.8 or higher on SUN Sparc (sparc_32). Missing Fortran Run-Time Environment?
Solaris SPARC 64 bit	Solaris 2.8 or higher on SUN Sparc (sparc_64)
Solaris x64 64 bit	Solaris 10 or higher on AMD- or Intel-based 64-bit (x64_64)
Wine	
Linux/Wine (beta)	AMD- or Intel-based Linux systems. The software uses the Windows 32bit GAMS build and Wine. No separate Wine installation is required. For more info please visit this page.

Please also visit the information about the distribution history, changes, and incremental updates. For older distributions please follow this link. There are some mailing lists, whi you about forthcoming releases, provide additional information, and are useful for questions about GAMS and modeling issues.

Amazon CloudFront Download Usage Report »			$67.04
United States			
	$0.120 per GB - first 10 TB / month data transfer out	197.126 GB	23.66
	$0.0100 per 10,000 HTTPS Requests	3 Requests	0.01
	$0.0075 per 10,000 HTTP Requests	52,154 Requests	0.04
			23.71
Europe			
	$0.120 per GB - first 10 TB / month data transfer out	212.982 GB	25.56
	$0.0120 per 10,000 HTTPS Requests	1 Request	0.01
	$0.0090 per 10,000 HTTP Requests	16,456 Requests	0.01
			25.58
Asia Pacific (Tokyo) Region			
	$0.201 per GB - first 10 TB / month data transfer out (includes consumption tax).	23.800 GB	4.78
	$0.0095 per 10,000 HTTP Requests (includes consumption tax).	4,676 Requests	0.01
			4.79
Asia Pacific (Singapore) Region			
	$0.190 per GB - first 10 TB / month data transfer out	39.512 GB	7.51
	$0.012 per 10,000 HTTPS Requests	1 Request	0.01
	$0.0090 per 10,000 HTTP Requests	18,087 Requests	0.02
			7.54
South America			
	$0.250 per GB - first 10 TB / month data transfer out	21.656 GB	5.41
	$0.0160 per 10,000 HTTP Requests	1,535 Requests	0.01
			5.42

Total: 495 GB ~ 5,500 monthly downloads

Agenda

- Introduction
- **Declarative and Procedural Mix**
- High Performance Prototypes
- Conclusion

What is a Model?

- **List of Equations**
  - ***Mathematical Programming (MP) Model***

- **Collection of several intertwined (MP) Models (polylithic models, Kallrath)**
  - **Data Preparation and Calibration**
  - **"*Solution*" Module**
  - **Reporting Module**

- **"*Solution*" Module often requires procedural /imperative programming**

Declarative and Procedural Language Mix

- Declarative Elements in GAMS:
  - Model Algebra

- Procedural Elements in GAMS:
  - Programming Flow Control Features:
    - LOOP, FOR, WHILE, REPEAT
    - IF ELSEIF ELSE
    - Access to external programs/libraries

Cutting Stock Optimization

Cutting Stock Optimization at GSE

GSE-TRIM is a fully integrated module of the ERP-System GSE-PPS for Cutting Stock Optimization. Close cooperation of our in-house specialists with scientists in the area of discrete optimization has led to a number of successfully deployed applications used by the paper industry. Exact and hybrid optimization techniques coded in GAMS and Fortran have been implemented in our software package GSE-TRIM.

GSE Software Solutions

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- Considering detailed operational restrictions
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Based on a daily basis GSE-TRIM improves our clients key indicators and has been proven very stable over 7 years.

For more information please contact: www.gse-software.de

http://www.gams.com/presentations/index.htm#Ads

C:\Users\bussieck\Documents\gamsdir\projdir\cutstock.gms

cutstock.gms

```
* Master model
Variable xp(p)      patterns used
         z          objective variable
Integer variable xp; xp.up(p) = sum(i, d(i));

Equation numpat     number of patterns used
         demand(i) meet demand;

numpat..       z =e= sum(pp, xp(pp));
demand(i)..    sum(pp, aip(i,pp)*xp(pp)) =g= d(i);

model master /numpat, demand/;

* Pricing problem - Knapsack model
Variable  y(i) new pattern;
Integer variable y; y.up(i) = ceil(r/w(i));

Equation defobj
         knapsack knapsack constraint;

defobj..       z =e= 1 - sum(i, demand.m(i)*y(i));
knapsack..     sum(i, w(i)*y(i)) =l= r;

model pricing /defobj, knapsack/;
```

C:\Users\bussieck\Documents\gamsdir\projdir\cutstock.gms

cutstock.gms

```
* Initialization - the initial patterns have a single width
pp(p) = ord(p)<=card(i);
aip(i,pp(p))$(ord(i)=ord(p)) = floor(r/w(i));
*display aip;

Scalar done  loop indicator /0/
Set     pi(p) set of the last pattern; pi(p) = ord(p)=card(pp)+1;

option optcr=0,limrow=0,limcol=0,solprint=off;

While(not done and card(pp)<card(p),
   solve master using rmip minimizing z;
   solve pricing using mip minimizing z;

* pattern that might improve the master model found?
   if(z.l < -0.001,
      aip(i,pi) = round(y.l(i));
      pp(pi) = yes; pi(p) = pi(p-1);
   else
      done = 1;
   );
);
display 'lower bound for number of rolls', master.objval;

option solprint=on;
solve master using mip minimizing z;
```

Advantage of Algebraic Modeling System

Independence of

- Model and data
- Model and solution methods (solver)
- Model and operating system
- Model and user interface

→Models benefit from

- Advancing hardware
- Enhanced / new solver technology
- Improved / upcoming interfaces to other systems

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Simple Transport Model

```
Sets
   i factories                                                  /f1*f3/
   j distribution centers                                       /d1*d5/

Parameter
   capacity(i) /f1 500, f2 450, f3 650/
   demand(j)   /d1 160, d2 120, d3 270, d4 325, d5 700 /
   prodcost  unit production cost                                 /14/
   price     sales price                                          /24/
   wastecost cost of removal of overstocked products /4/

Table transcost(i,j) unit transportation cost
         d1     d2     d3     d4     d5
  f1    2.49   5.21   3.76   4.85   2.07
  f2    1.46   2.54   1.83   1.86   4.76
  f3    3.26   3.08   2.60   3.76   4.45;
```

Simple Transport Model – Cont.

```
Variables
   ship(i,j)    shipments
   product(i)   units produced
   received(j)  unit received
   sales(j)     sales (actually sold)
   waste(j)     overstocked products
   profit
Positive variables ship,product,sales,waste;

Equations
   obj
   production(i)
   receive(j)
   selling(j)
   market(j);

obj.. profit =e= sum(j, price*sales(j)) - sum((i,j), transcost(i,j)*ship(i,j))
                 - sum(j, wastecost*waste(j)) - sum(i,prodcost*product(i));

production(i).. product(i) =e= sum(j, ship(i,j));
product.up(i) = capacity(i);

receive(j).. received(j) =e= sum(i, ship(i,j));
selling(j).. sales(j) =e= received(j) - waste(j);
market(j)..  sales(j) =l= demand(j);

model transport /all/;
solve transport maximizing profit using lp;
```

Benders Decomposition for 2-Stage SP

```
Set
  s scenarios /lo,mid,hi/

* Stochastic demand plus probabilities
Table ScenarioData(s,*)
      d1   d2   d3   d4   d5  prob
lo   150  100  250  300  600  0.25
mid  160  120  270  325  700  0.50
hi   170  135  300  350  800  0.25;
```

$$\begin{aligned} \min\ & c^T x + \sum_{\omega} p(\omega) d_\omega^T y_\omega \\ & Ax = b \\ & T_\omega x + W_\omega y_\omega = h_\omega \\ & x \geq 0, y_\omega \geq 0 \end{aligned}$$

$$\begin{aligned} \min\ & d_\omega^T y_\omega \\ & W_\omega y_\omega = h_\omega - T_\omega \bar{x}^\nu \\ & y_\omega \geq 0 \end{aligned}$$

$$\begin{aligned} \min\ & c^T x + \theta \\ & Ax = b \\ & \theta \geq \sum_{\omega \in \Omega} p_\omega \left(-\bar{\pi}_\omega^\ell [T_\omega x + W_\omega \bar{y}_\omega^\ell - h_\omega] \right), \ \ell = 1, \ldots, \nu - 1 \\ & x \geq 0 \end{aligned}$$

Benders Decomposition for 2-Stage SP

```
loop(iter$(not done),
* solve subproblems
   dyniter(iter) = yes;
   loop(s,
       demand(j) = ScenarioData(s,j);
       solve subproblem max zsub using lp;
       objsub(s) = zsub.l;
       cutconst(iter) = cutconst(iter) + p(s)*sum(j,market.m(j)*demand(j));
       cutcoeff(iter,j) = cutcoeff(iter,j) + p(s)*selling.m(j);
   );
   lowerbound = max(lowerbound, objmaster + sum(s, p(s)*objsub(s)));

* convergence test
   if( (upperbound-lowerbound) < 0.001*(1+abs(upperbound)),
      done = 1;
   else
* solve masterproblem
      solve masterproblem max zmaster using lp;
      upperbound = zmaster.l;
      objmaster = zmaster.l - theta.l;
   );
);
```

Benders GAMS Implementation

- GAMS Implementation (solver Cplex)
  - 17 iterations: (3+1)*17 = 68 small models
    - 10.4 secs (all default)
    - 9.1 secs (minimize listing file size)
    - 4.9 secs (GAMS stays in memory)
    - 0.6 secs (communicate with solver through memory)

```
option limrow=0, limcol=0, solprint=silent,
       solvelink=%Solvelink.LoadLibrary%;
```

- Smart update of sub-model (Scenario Solver/GUSS)
- Grid computing
- Object Oriented API (e.g. .NET)

GUSS: Gather-Update-Solve-Scatter

```
cost.. Z=e=sum((i,j),f*d(i,j)/1000*X(i,j));

Loop(s,
    d(i,j) = dd(s,i,j);
    f = ff(s);
    solve mymodel min Z using lp;
    rep(s) = Z.l;
);

set dict / s.scenario.''
           d.param   .dd
           f.param   .ff
           Z.level   .rep /

solve mymodel min z using lp scenario dict;
```

C:\Users\bussieck\Desktop\karlsruhe\t_guss.gms

stochbenders.gms | stochbenders.lst | t_emp.gms | t_gams.gms | t_grid.gms | t_guss.gms | trnsgrid.gms

```
* GUSS setup
Set dict / s.       scenario. ''
           demand. param.     sDemand
           market. marginal.  sMarket
           selling.marginal.  sSelling
           zsub.   level.     objsub /;

loop(iter$(not done),
* solve subproblems
   dyniter(iter) = yes;
   solve subproblem max zsub using lp scenario dict;
   cutconst(iter) = cutconst(iter)+sum(s,p(s)*sum(j,sMarket(s,j)*sDemand(s,j)));
   cutcoeff(iter,j) = cutcoeff(iter,j) + sum(s,p(s)*sSelling(s,j));

   lowerbound = max(lowerbound, objmaster + sum(s, p(s)*objsub(s)));

* convergence test
   if( (upperbound-lowerbound) < 0.001*(1+abs(upperbound)),
      done = 1;
   else
* solve masterproblem
      solve masterproblem max zmaster using lp;
      upperbound = zmaster.l;
      objmaster = zmaster.l - theta.l;
   );
);
abort$(not done) "Too many iterations";
display zmaster.l, ship.l;
```

GUSS: Gather-Update-Solve-Scatter

Setting	Solve time (secs)
Solvelink=0 (default)	40.297
Solvelink=%Solvelink.LoadLibrary%	03.625
GUSS	00.797

- Updates model data instead of matrix coefficients/rhs
- Hot start (keeps the model hot inside the solver and uses solver’s best update mechanism)
- Saves model generation and solver setup time
- Transport model solution time: 0.3 secs
- A priori knowledge of all scenario data

Parallel Power – GAMS Grid Facility

```
demand=42; cost=14;
solve mymodel min obj using minlp;
report = var.l;
```

Parallel Power – GAMS Grid Facility

```
loop(scenario,
  demand=sdemand(scenario); cost=scost(scenario);
  solve mymodel min obj using minlp;
  report(scenario) = var.l);
```

GAMS

Parallel Power – GAMS Grid Facility

```
mymodel.solvelink=3;
loop(scenario,
  demand=sdemand(scenario); cost=scost(scenario);
  solve mymodel min obj using minlp;
  h(scenario)=mymodel.handle);

Repeat
  loop(scenario$handlecollect(h(scenario)),
     report(scenario)=var.l;
     h(s) = 0);
  display$sleep(card(h)*0.02) 'sleep some time';
until card(h)=0 or timeelapsed > 100;
```


```
 dyniter(iter) = yes;
* Submission loop
 loop(s,
     demand(j) = ScenarioData(s,j);
     solve subproblem max zsub using lp;
     h(s) = subproblem.handle;
 );
* Collection loop
repeat
   loop(s$handlecollect(h(s)),
     objsub(s) = zsub.l;
     cutconst(iter) = cutconst(iter) + p(s)*sum(j,market.m(j)*sDemand(s,j));
     cutcoeff(iter,j) = cutcoeff(iter,j) + p(s)*selling.m(j);
     display$handledelete(h(s)) 'trouble deleting handles' ;
     h(s) = 0 );
   display$sleep(card(h)*0.02) 'was sleeping for some time';
until card(h) = 0;
lowerbound = max(lowerbound, objmaster + sum(s, p(s)*objsub(s)));

* convergence test
 if( (upperbound-lowerbound) < 0.001*(1+abs(upperbound)),
```

Object Oriented GAMS API

- High demand for OO API to GAMS
  - Embedding GAMS Model into IT infrastructure
  - GAMS .NET is currently in Alpha Client Testing
  - Java, Python, … will follow
  - OO API has the concept of a Model Instance
  - Build algorithms with GAMS objects in C#, Java, …

- GAMS solve statement
  - Update against the GAMS database (traditional)
  - Model Instance *Object (new)*
  - Use OO API to experiment
  - Introduction of Model Instance Object into GAMS

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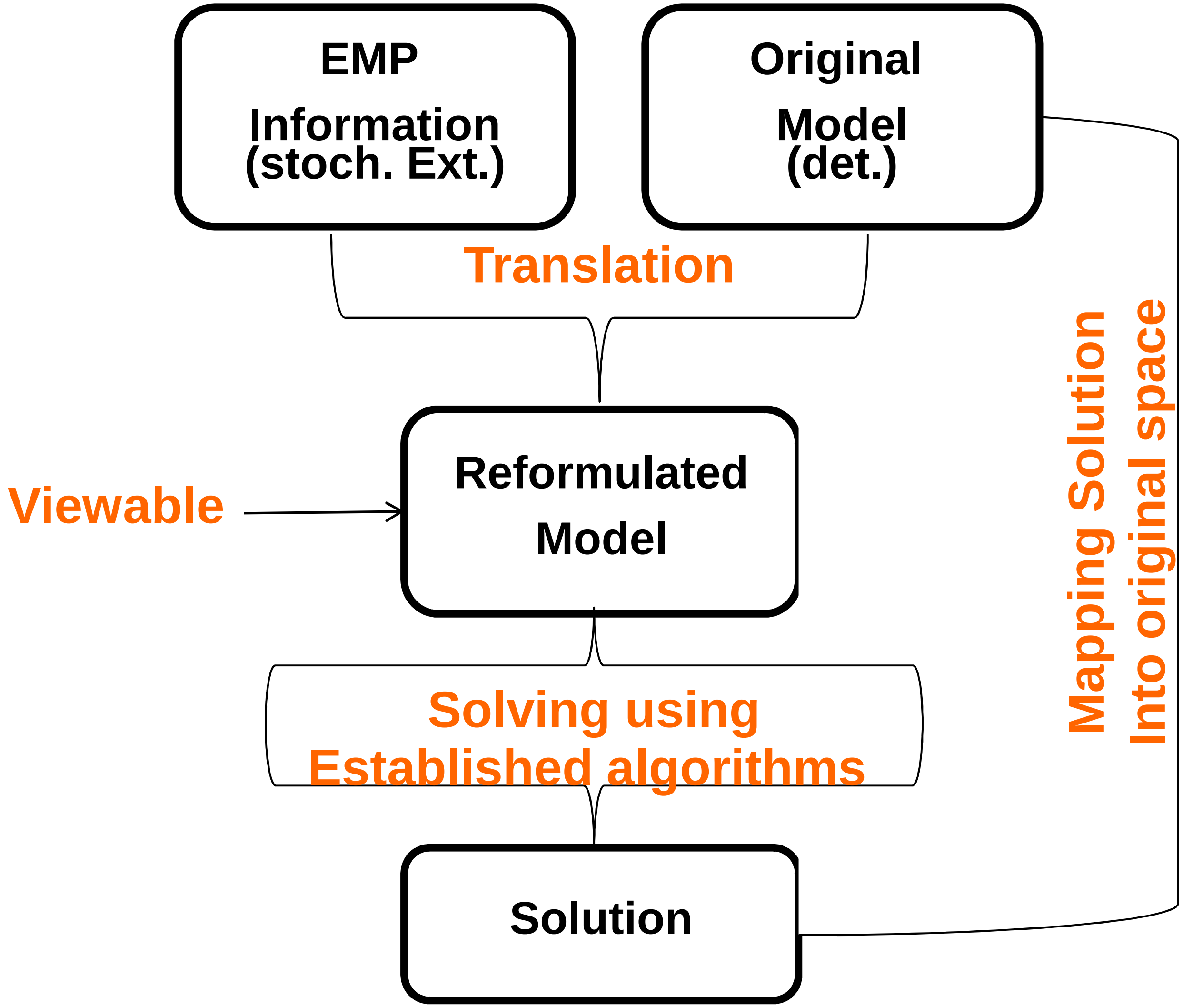
Stochastic Programming with EMP



C:\Users\bussieck\Desktop\karlsruhe\t_emp.gms

stochbenders.gms | stochbenders.lst | t_emp.gms | t_gams.gms | t_grid.gms | t_guss.gms | trnsgrid.gms

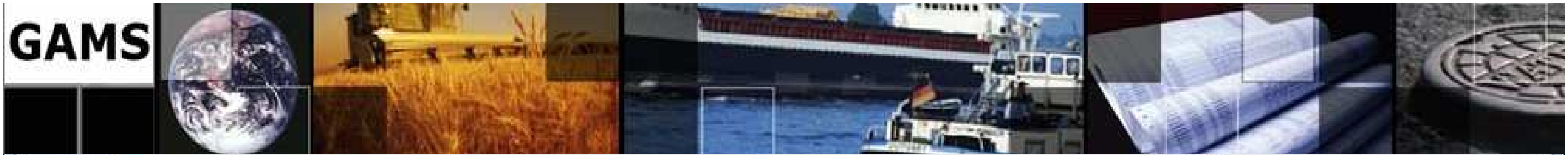
```
model transport /all/;
solve transport maximizing profit using lp;

file emp / '%emp.info%' /; put emp '* problem %gams.i%'/;
$onput
jrandvar demand('d1') demand('d2') demand('d3') demand('d4') demand('d5')
    0.25     150          100          250          300          600
    0.5      160          120          270          325          700
    0.25     170          135          300          350          800
stage 2 demand sales waste profit obj selling market
$offput
putclose emp;

Set scen Scenarios / s1*s3 /;
Parameter
   sc_demand(scen,j)       demand by scenario
   sc_sales(scen,j)        sales by scenario
   sc_waste(scen,j)        waste by scenario
   sc_profit(scen)         profit by scenario;

Set dict / scen          .scenario.''
           demand        .randvar. sc_demand
           sales         .level.   sc_sales
           waste         .level.   sc_waste
           profit        .level.   sc_profit /;

option emp=de;
solve transport maximizing profit using emp scenario dict;
display ship.l, sc_demand, sc_sales, sc_waste, sc_profit;
```



Yet Another Math Programming Consultant

So I am now a full time math programming consultant... I will try to post my (technical) notes here. Keeping a searchable list of them will make this useful for me in my daily life.

Sunday, April 15, 2012

Parallel GAMS jobs (2)

In http://yetanothermathprogrammingconsultant.blogspot.com/2012/04/parallel-gams-jobs.html I described a simple approach I suggested to a client allowing to run multiple scenarios in parallel.

For a different client we needed to run a randomized algorithm that solves many small MIP models. They are so small that using multiple threads inside the MIP solver does not give much performance boost (much of the time is spent outside the pure Branch & Bound part – such as preprocessing etc.). However as the MIP problems are independent of each other we could generate all the necessary data in advance and then call the scenario solver (http://www.gams.com/modlib/adddocs/gusspaper.pdf). This will keep the generated problem in memory, and does in-core updates, so we don't regenerate the model all the time.

The implementation does not win the beauty contest, but it could be developed quickly.

Besides the MIP models there is also a substantial piece of GAMS code that implements other parts of the algorithm.

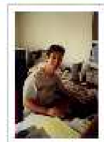
Implementation	number of MIP models	solve time	rest of algorithm	total time
Traditional GAMS loop (call solver as DLL)	100,000	1068 sec	169 sec	1237 sec
Scenario Solver	100,000	293 sec	166 sec	459 sec

To get more performance I tried to run the scenario solver in parallel. That is not completely trivial as the solver has a number glitches (e.g. scratch files with fixed, hard coded names). I also run parts of the GAMS algorithm in parallel, but some parts had to be done in the master model after merging the results.

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

The implementation does not win the beauty contest, but it could be developed quickly. For these larger

About Me



ERWIN KALVELAGEN

Mathematical Programming Consultant

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Thank You !

<u>USA</u>

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

<u>Europe</u>

GAMS Software GmbH
Eupener Str. 135-137
50933 Cologne
Germany

Phone: +49 221 949 9170
Fax: +49 221 949 9171

http://www.gams.com
info@gams.de
support@gams.com