OR 2016
HAMBURG

GAMS

Solving Scenarios in the Cloud

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GAMS - History

- *Roots: World Bank, 1976*
- Alex Meeraus founded GAMS Development Corp. (USA) in 1987 and GAMS Software GmbH (Germany) in 1995

- New management team in 2016

GAMS - Product

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

- Pioneered Algebraic Modeling Languages: Model is executable algebraic description of optimization problem
  - ➢ Made mathematical optimization available to broader audience (domain experts)
  - ➢ Increased productivity tremendously
  - ➢ 2012 INFORMS Impact Prize
- Evolution through more than 25 years of R&D and user feedback
- Maturity through experience and rigorous testing

Agenda

GAMS – Basic Concepts

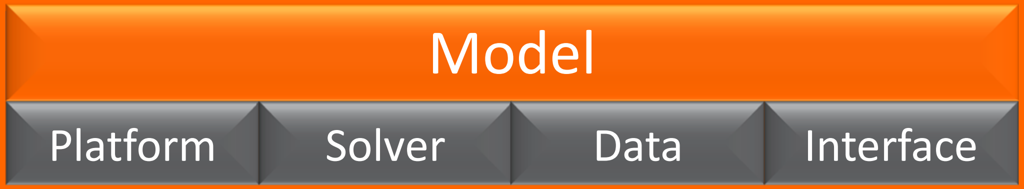
Application: Solving Scenarios in the Cloud

GAMS at a Glance

Powerful algebraic modeling language with open architecture and uniform interface to all major commercial and academic solvers (30+ integrated)

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

Different layers



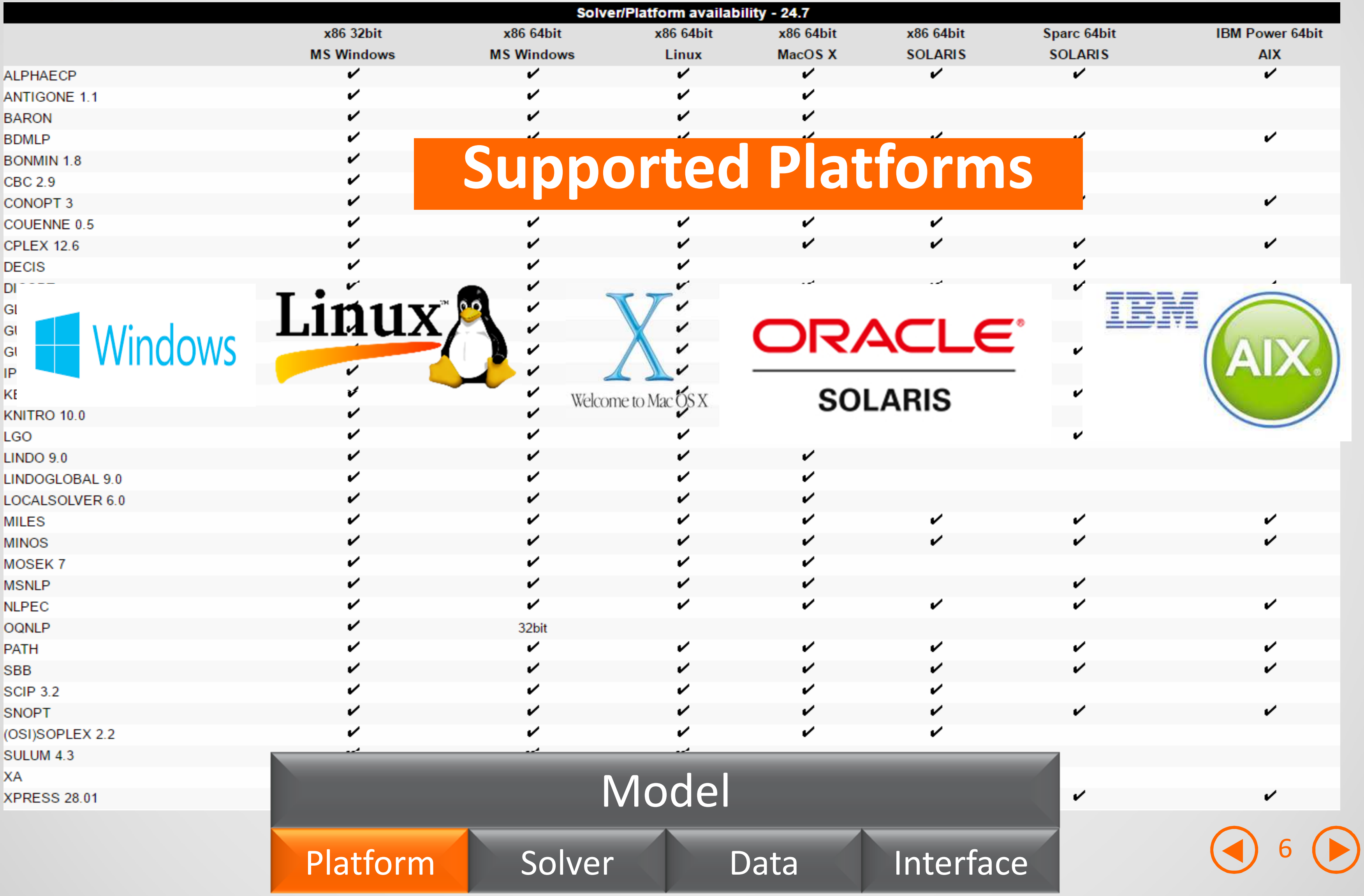
Model

Platform Solver Data Interface

GENERAL ALGEBRAIC MODELING SYSTEM

GAMS

Separation of Model and Platform



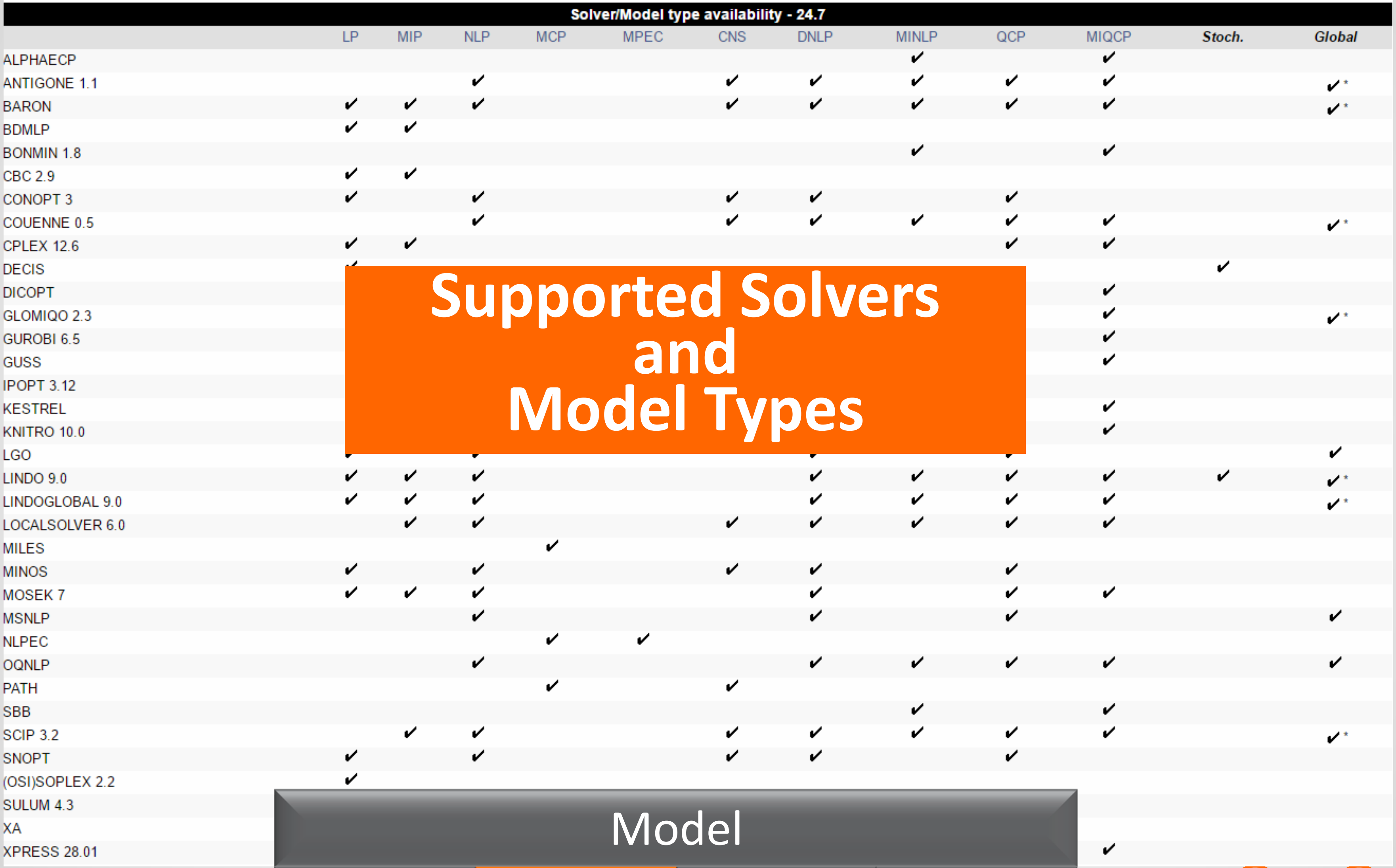
Solver/Platform availability - 24.7							
	x86 32bit	x86 64bit	x86 64bit	x86 64bit	x86 64bit	Sparc 64bit	IBM Power 64bit
	MS Windows	MS Windows	Linux	MacOS X	SOLARIS	SOLARIS	AIX
ALPHAECP	✔	✔	✔	✔	✔	✔	✔
ANTIGONE 1.1	✔	✔	✔	✔			
BARON	✔	✔	✔	✔			
BDMLP	✔	✔	✔	✔	✔	✔	✔
BONMIN 1.8	✔						
CBC 2.9	✔						
CONOPT 3	✔					✔	✔
COUENNE 0.5	✔	✔	✔	✔	✔		
CPLEX 12.6	✔	✔	✔	✔	✔	✔	✔
DECIS	✔	✔	✔			✔	
DI	✔	✔	✔	✔	✔	✔	✔
GI		✔	✔				
GI	✔	✔	✔				
GI	✔	✔	✔			✔	
IP	✔	✔	✔				
KE	✔	✔	✔			✔	
KNITRO 10.0	✔	✔	✔				
LGO	✔	✔	✔			✔	
LINDO 9.0	✔	✔	✔	✔			
LINDOGLOBAL 9.0	✔	✔	✔	✔			
LOCALSOLVER 6.0	✔	✔	✔	✔			
MILES	✔	✔	✔	✔	✔	✔	✔
MINOS	✔	✔	✔	✔	✔	✔	✔
MOSEK 7	✔	✔	✔	✔			
MSNLP	✔	✔	✔	✔		✔	
NLPEC	✔	✔	✔	✔	✔	✔	✔
OQNLP	✔	32bit					
PATH	✔	✔	✔	✔	✔	✔	✔
SBB	✔	✔	✔	✔	✔	✔	✔
SCIP 3.2	✔	✔	✔	✔	✔		
SNOPT	✔	✔	✔	✔	✔	✔	✔
(OSI)SOPLEX 2.2	✔	✔	✔	✔	✔		
SULUM 4.3	✔	✔	✔				
XA							
XPRESS 28.01						✔	✔

Supported Platforms

Model

Platform | Solver | Data | Interface

Separation of Model and Solver



Solver/Model type availability - 24.7

	LP	MIP	NLP	MCP	MPEC	CNS	DNLP	MINLP	QCP	MIQCP	*Stoch.*	*Global*
ALPHAECP								✓		✓		
ANTIGONE 1.1			✓			✓	✓	✓	✓	✓		✓*
BARON	✓	✓	✓			✓	✓	✓	✓	✓		✓*
BDMLP	✓	✓										
BONMIN 1.8								✓		✓		
CBC 2.9	✓	✓										
CONOPT 3	✓		✓			✓	✓		✓			
COUENNE 0.5			✓			✓	✓	✓	✓	✓		✓*
CPLEX 12.6	✓	✓							✓	✓		
DECIS	✓										✓	
DICOPT										✓		
GLOMIQO 2.3										✓		✓*
GUROBI 6.5										✓		
GUSS										✓		
IPOPT 3.12												
KESTREL										✓		
KNITRO 10.0										✓		
LGO	✓		✓				✓		✓			✓
LINDO 9.0	✓	✓	✓				✓	✓	✓	✓	✓	✓*
LINDOGLOBAL 9.0	✓	✓	✓				✓	✓	✓	✓		✓*
LOCALSOLVER 6.0		✓	✓			✓	✓	✓	✓	✓		
MILES				✓								
MINOS	✓		✓			✓	✓		✓			
MOSEK 7	✓	✓	✓				✓		✓	✓		
MSNLP			✓				✓		✓			✓
NLPEC				✓	✓							
OQNLP			✓				✓	✓	✓	✓		✓
PATH				✓		✓						
SBB								✓		✓		
SCIP 3.2		✓	✓			✓	✓	✓	✓	✓		✓*
SNOPT	✓		✓			✓	✓		✓			
(OSI)SOPLEX 2.2	✓											
SULUM 4.3												
XA												
XPRESS 28.01										✓		

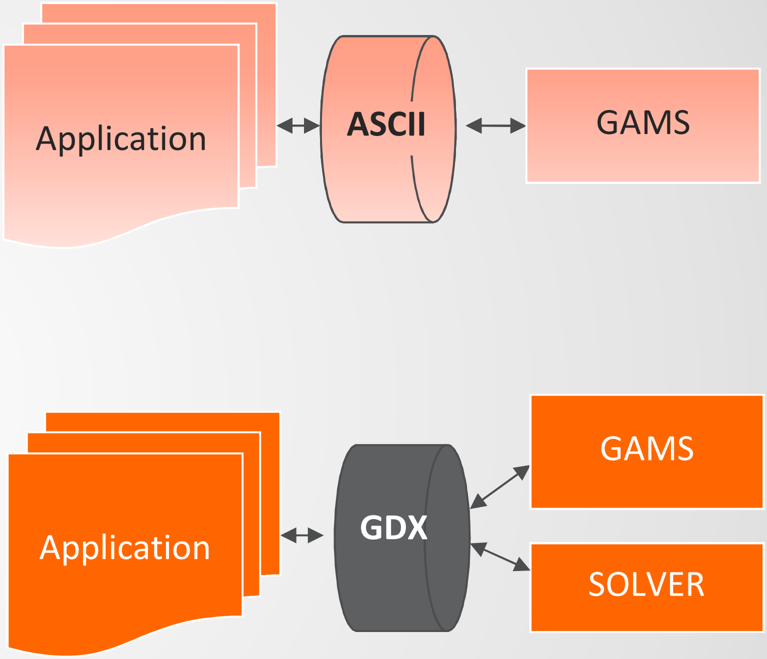
Supported Solvers and Model Types

Model

Platform | Solver | Data | Interface

Separation of Model and Data

- **Declarative Modeling**: *x(j), j∈{1,...}*
  - ASCII: Initial model development
  - GDX: Binary Data layer ("contract") between GAMS and applications
    - Platform independent
    - Direct GDX interfaces and general API

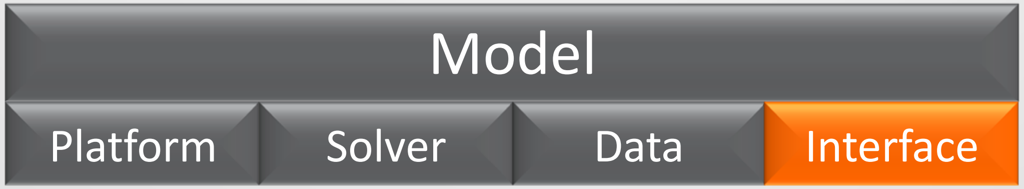


Separation of Model and User Interface

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

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

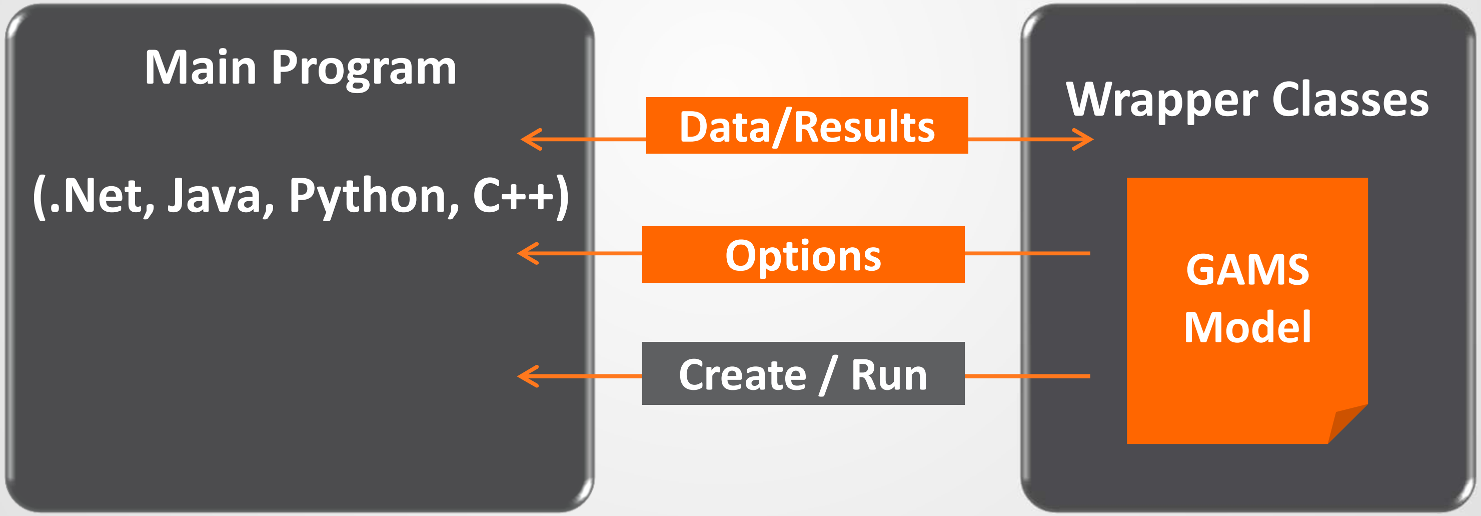
- **O**bject **O**riented **A**pplication **P**rogramming **I**nterfaces
  - .Net, Java, Python, C++,...
  - Wrapper classes that encapsulates a GAMS model
  - No modeling capability: Model is written in GAMS



Encapsulation of a GAMS Model

Simple Interface to interact with GAMS

- Classes to **communicate input data and results**
- Classes to **change options** like the solver to use
- Classes to **create and run model instance(s)**



Agenda

GAMS – Basic Concepts

Application: Solving Scenarios in the Cloud

Solving “many” independent Scenarios

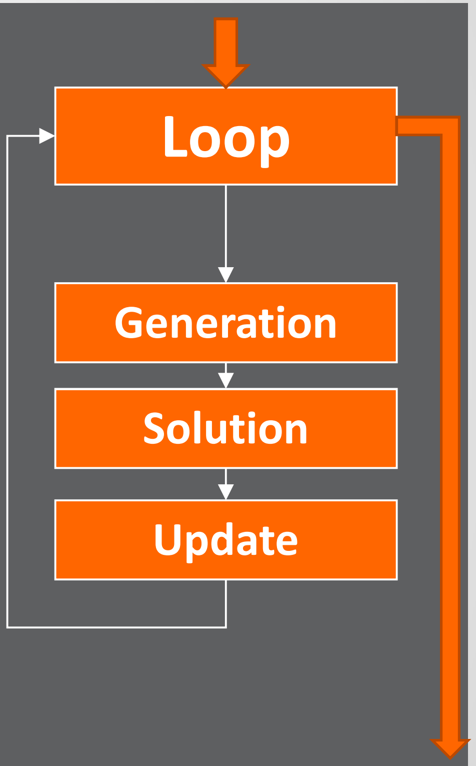
1. Small Ratio of MP solution time/GAMS overhead
   → GUSS/Scenario Solver

Simple Serial Solve Loop - Basics

Both declarative and imperative Elements

```
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);

    );
```

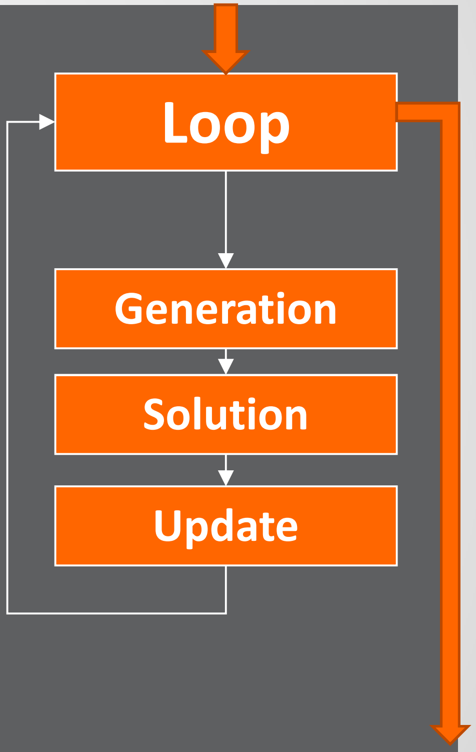


Simple Solve Loop - Performance

Different options to call the solver from GAMS

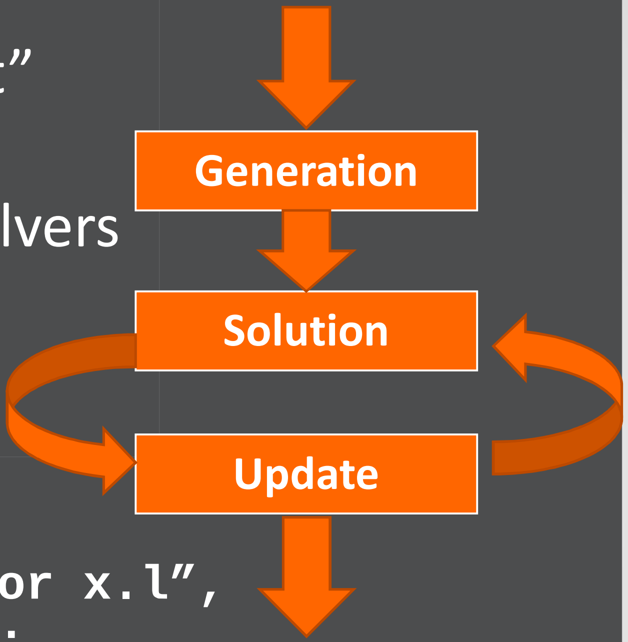
- trnsport.gms (LP) solved 500 times (CPLEX)

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



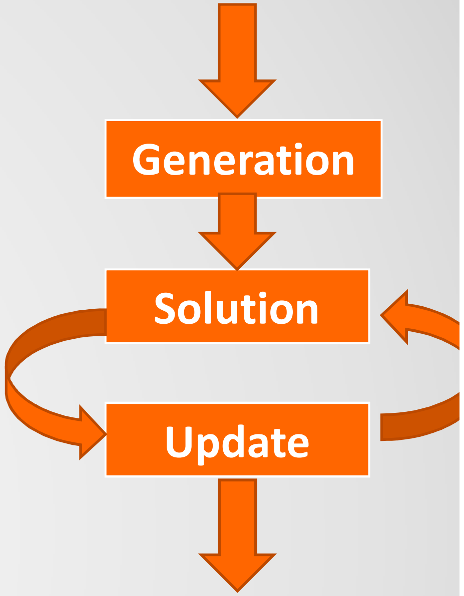
Scenario Solver - Basics

- 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;
```

Scenario Solver - Performance



Stochastic model: 66,320 (linear) instances

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

Solving “many” independent Scenarios

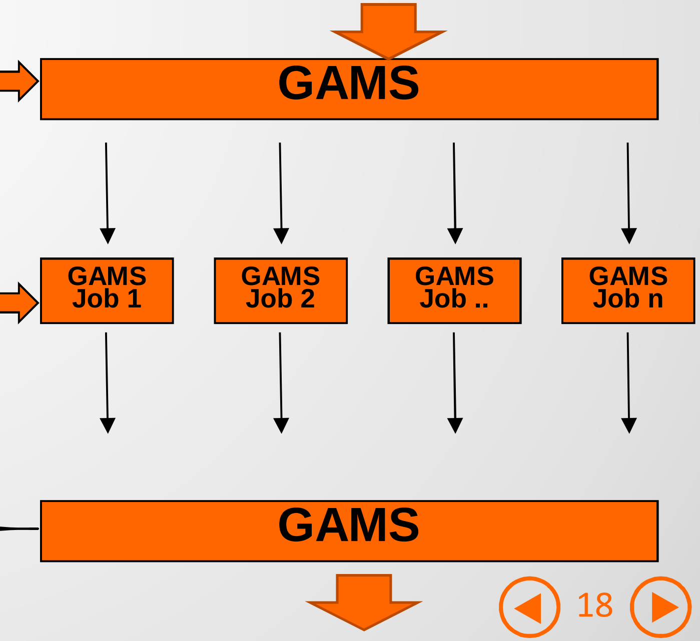
1. Small Ratio of MP solution time/GAMS overhead
   → GUSS/Scenario Solver
2. **Large ratio i.e. only MP time is relevant (pre/post processing not critical)**
   → Grid Facility, NEOS, Gurobi/Cplex Server

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



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 (NEOS)

```
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
```

Solving “many” independent Scenarios

1. Small Ratio of MP solution time/GAMS overhead
   → GUSS/Scenario Solver
2. Large ratio i.e. only MP time is relevant (pre/post processing not critical)
   → Grid Facility, NEOS, Gurobi/Cplex Server
3. **If entire model run including pre processing/MP solve/post processing is costly**
   → Parallel/asynchronous execution of entire model in the cloud

Application – Cloud Computing

xyz Energy Company

Challenge

- Scenario Analysis: Solve 1,000+ scenarios (MIPs, one hour) every week overnight

Issues:

- Automation
- Security
- Licensing

Application – Cloud Computing

xyz – Energy Company

Implementation:

- Amazon Cloud: 1,000+ parallel machines (instances), Python, GAMS + OO Python API
- Automated setup, including
  - Starting instances
  - Prepare / Submit / Run GAMS jobs
  - Collect results
  - Stop instances

Application – Cloud Computing

Protecting IP and Sensitive Data

Options to hide sensitive information:

- Extrinsic function libraries / External Equations
- Encrypted source files / secure work files
- Obfuscated work files: change all the names and other documentation related to a specific model run

Application – Cloud Computing

Obfuscated Files – An Example

Normal Solver Log

```
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 Solver Log

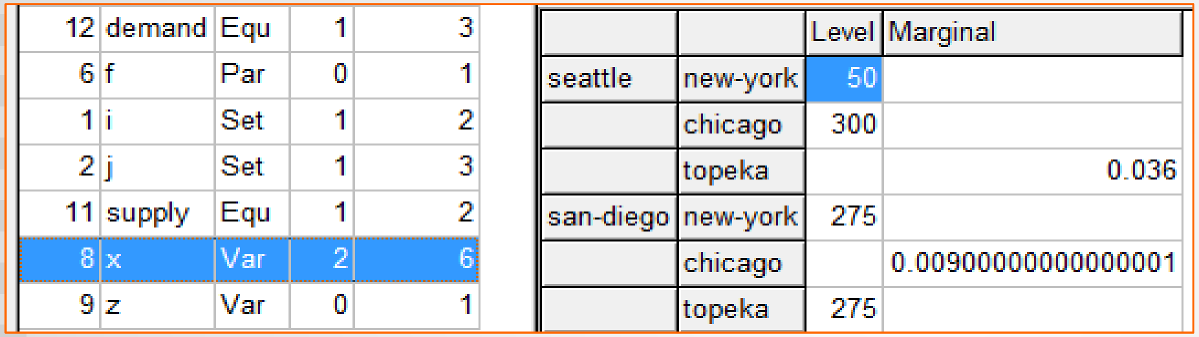
```
Reduced LP has 5 rows, 6 columns, and 12 nonzeros.
Presolve time = 0.00 sec. (0.00 ticks)

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
```

Application – Cloud Computing

Obfuscated Files – An Example

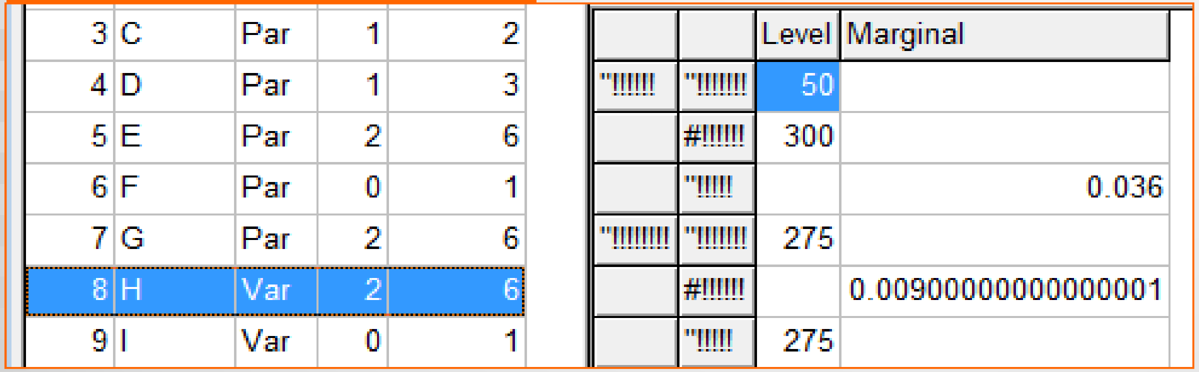
Normal gdx file



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		0.00900000000000001
	topeka	275	

Obfuscated gdx file



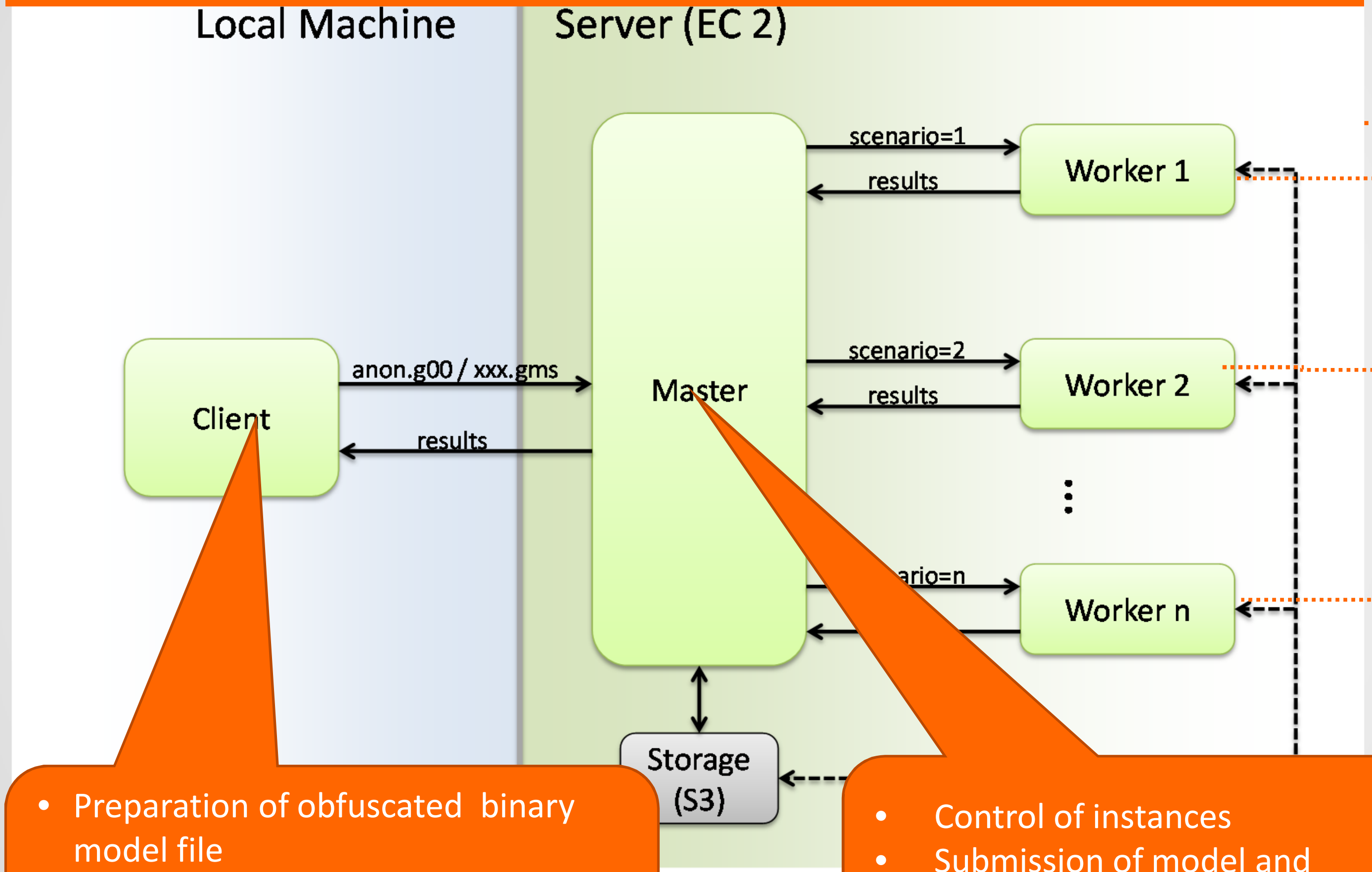
3	C	Par	1	2
4	D	Par	1	3
5	E	Par	2	6
6	F	Par	0	1
7	G	Par	2	6
8	H	Var	2	6
9	I	Var	0	1

		Level	Marginal
"!!!!!!	"!!!!!!!	50	
	#!!!!!!	300	
	"!!!!!		0.036
"!!!!!!!!	"!!!!!!!	275	
	#!!!!!!		0.00900000000000001
	"!!!!!	275	

Application – Cloud Computing

Setup

amazon web services™



Configured AWS Instances

- Python
- GAMS

- 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

Application – Cloud Computing

Commercial Aspects

“Hardware” Amazon Cloud (1,000 instances) :

Hardware Costs / run: **$70!**

(1,000 instances/run * $0.07 instance / hour)

Software Licensing:

- Gurobi and IBM offer per-usage license
- Client with strong preference for annual license fee, not a per-usage license

Application – Cloud Computing

45 Provided Model Instances

- Statistics:
  - 163,608 – 1,959,550 rows
  - 84,930 – 983,587 var. (32,240-258,796 dis.)
  - 447,537 – 6,068,729 NZ
- CPLEX, SCIP, and CBC
- 60 minutes, gap max. 1%
- Manual option tuning for SCIP (thanks to Gerald Gamrath & Ambros Gleisner)

Application – Cloud Computing

Results

- CPLEX: All instances solved to optimality
- SCIP:
  - Could solve all 45 instances
  - But: After 60 min. 2 instances with gap > 20%
- CBC:
  - Did also well
  - But: After 60 min. no solution for some instances (< 10%)

Application – Cloud Computing

Proposed Strategy

- Run all instances simultanuesly with SCIP and CBC

  → *„hardware“ costs: $0,07 per instance hour*

- After 60 minutes take the best solution

- If necessary solve „difficult“ instances with CPLEX (outside the cloud)

GAMS

Thank You

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