GAMS

Deploying GAMS Models with GAMS MIRO (Technology Workshop)

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Agenda

GAMS at a Glance

Model Development and Model Deployment

GAMS MIRO Demo

Algebraic Modeling Languages (AML)

What's that?

- High-level computer **programming languages** for the formulation of complex **mathematical optimization problems**
- **Notation similar to algebraic notation**: Concise and human 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 (solver)

What did this give us?

Simplified model development & maintenance

Increased productivity tremendously

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

One of the success stories of OR!

- **1976:** Initial version of an AML
- **2012:** INFORMS Impact Prize awarded to „Godfathers“ of Algebraic Modeling Languages
- **Nowadays:**
  - Established environment to build robust and fail safe systems
  - Commodity in a lot of different flavors

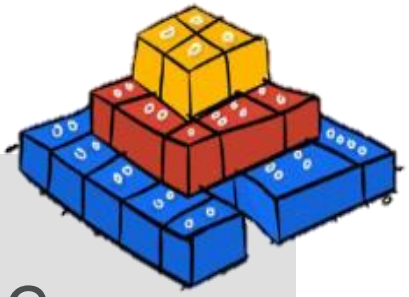
Foundation of GAMS

Powerful algebraic modeling language

Open architecture, independent layers

Evolved and Matured System

Declarative Language



- Similar to mathematical notation
- Easy to learn, only few basic language elements: sets, parameters, variables, equations, models

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

Decision Variables:

x_{ij} = amount of commodity to ship from plant i to market j
where $x_{ij} \geq 0$, for all i, j

Constraints:

Observe supply limit at plant i: $\sum_j x_{ij} \leq a_i$ for all i (cases)
Satisfy demand at market j: $\sum_i x_{ij} \geq b_j$ for all j (cases)
Objective Function: Minimize $\sum_i \sum_j c_{ij} x_{ij}$ ($K)

```
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/ ;
```

Procedural Language Elements

- Control Flow Statements (e.g. loops, for, if, macros, functions, …)
- Build complex problem algorithms within GAMS
- Simplified interaction with other systems through OO-APIs:
  - Data exchange
  - GAMS Control

Welcome | 6_trnsport_solvelink_seq.gms | 6_trnsport_solvelink_seq.lst | 7_trnsport_solvelink_async.gms | 7_trnsport_s

```
64   Model transport /all/ ;
65
66 set s  scenarios / s1*s100 /
67     sl solvelink / aSyncGrid, aSyncThreads /;
68 parameter dd(s,i,j)  distance by scenario
69           time(*)    time for 100 scenarios
70           sl_val(sl) solvelink value / aSyncGrid    %solveLink
71                                        aSyncThreads %solveLink
72           h(s)       scenario handle;
73 scalar    tmp;
74
75 dd(s,i,j) = uniform(0.9,1.1)*d(i,j);
76 option limrow=0, limcol=0, solprint=silent, lp=cplexd;
77 * Async SOLVE
78 loop(sl,
79   tmp = jnow;
80   transport.solvelink=sl_val(sl);
81
82   loop(s,
83     d(i,j) = dd(s,i,j);
84     Solve transport using lp minimizing z ;
85     h(s) = transport.handle;    // save instance handle
86   );
87   repeat
88     display$readycollect(h) 'Waiting for next instance to comp
89     loop(s$handlecollect(h(s)),
90        display$handledelete(h(s)) 'trouble deleting handles';
91        h(s) = 0;    // indicate that we have loaded the soluti
92     );
93   until card(h) = 0 or timeelapsed > 180;  // wait until all m
94   time(sl) = (jnow-tmp)*24*60*60;
95 );
96 display time;
97
```

Open Architecture

Designed to interact with other systems

Model independent of
- Platform
- Solver
- Data
- User-Interface

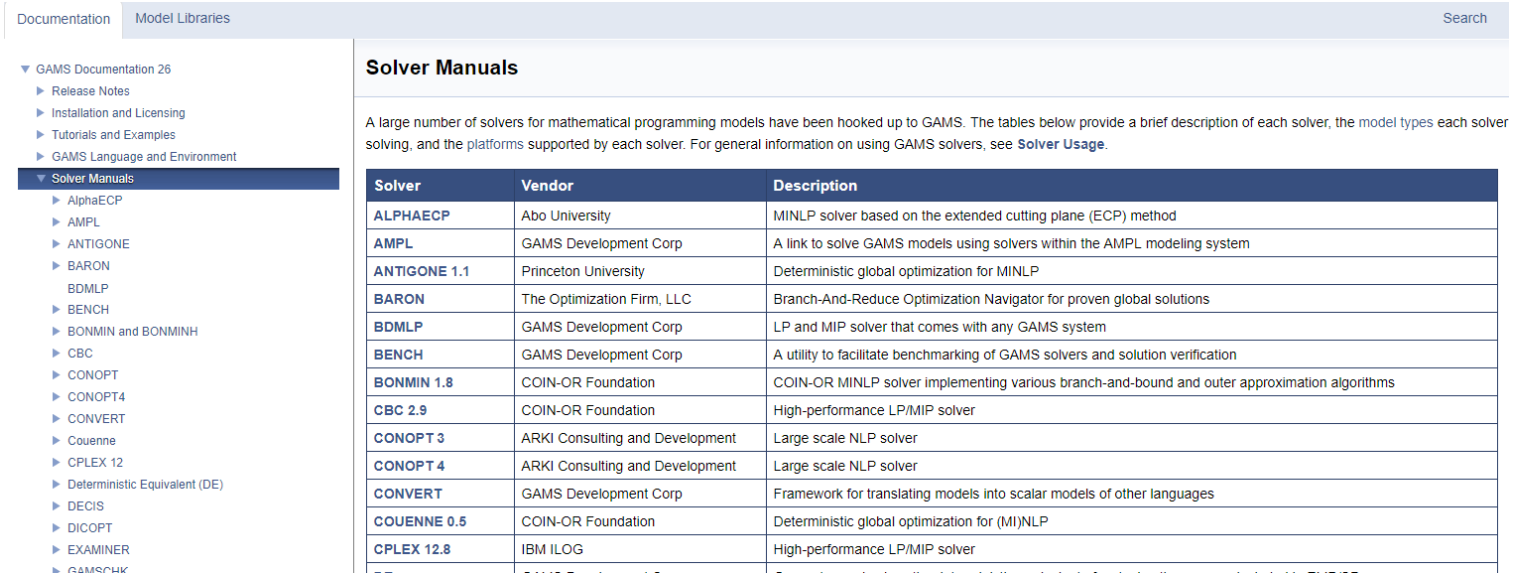
Platform Independence

- GAMS available on all major computing platforms
- Move your models between platforms with ease

Solver Independence

Uniform interface to all major solvers

- More than 30 academic and commercial solvers connected to GAMS
- Switch between solvers with one line of code
- Documentation
- Licensing (GAMS as a „license broker“)



Documentation | Model Libraries | Search

- GAMS Documentation 26
  - Release Notes
  - Installation and Licensing
  - Tutorials and Examples
  - GAMS Language and Environment
  - Solver Manuals
    - AlphaECP
    - AMPL
    - ANTIGONE
    - BARON
    - BDMLP
    - BENCH
    - BONMIN and BONMINH
    - CBC
    - CONOPT
    - CONOPT4
    - CONVERT
    - Couenne
    - CPLEX 12
    - Deterministic Equivalent (DE)
    - DECIS
    - DICOPT
    - EXAMINER
    - GAMSCHK

Solver Manuals

A large number of solvers for mathematical programming models have been hooked up to GAMS. The tables below provide a brief description of each solver, the model types each solver solving, and the platforms supported by each solver. For general information on using GAMS solvers, see **Solver Usage**.

Solver	Vendor	Description
ALPHAECP	Abo University	MINLP solver based on the extended cutting plane (ECP) method
AMPL	GAMS Development Corp	A link to solve GAMS models using solvers within the AMPL modeling system
ANTIGONE 1.1	Princeton University	Deterministic global optimization for MINLP
BARON	The Optimization Firm, LLC	Branch-And-Reduce Optimization Navigator for proven global solutions
BDMLP	GAMS Development Corp	LP and MIP solver that comes with any GAMS system
BENCH	GAMS Development Corp	A utility to facilitate benchmarking of GAMS solvers and solution verification
BONMIN 1.8	COIN-OR Foundation	COIN-OR MINLP solver implementing various branch-and-bound and outer approximation algorithms
CBC 2.9	COIN-OR Foundation	High-performance LP/MIP solver
CONOPT 3	ARKI Consulting and Development	Large scale NLP solver
CONOPT 4	ARKI Consulting and Development	Large scale NLP solver
CONVERT	GAMS Development Corp	Framework for translating models into scalar models of other languages
COUENNE 0.5	COIN-OR Foundation	Deterministic global optimization for (MI)NLP
CPLEX 12.8	IBM ILOG	High-performance LP/MIP solver

Platform / Solver Independence

(Parallel) Local and distributed/remote execution

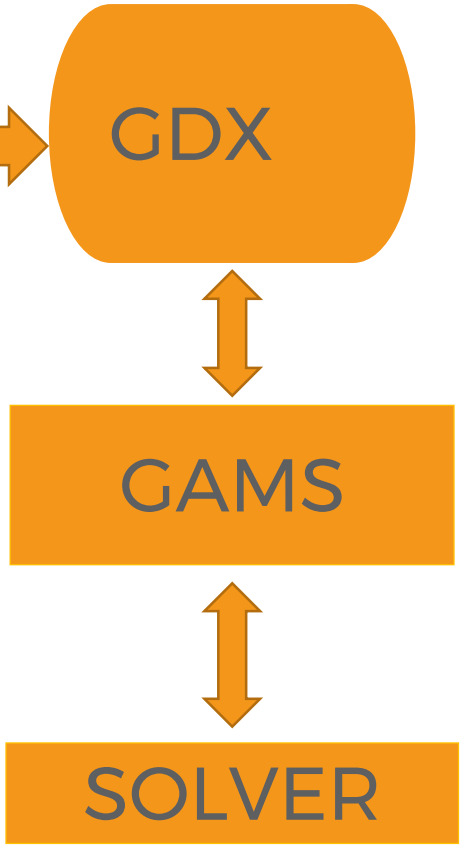
- Solver execution
  - Remote Object Server / Compute Server
  - Distributed MIP (CPLEX, GUROBI)
  - Distributed LP (PIPS-IPM)
- Model execution
  - Grid Computing Facility
  - NEOS (Kestrel)

Data Independence

- Declarative Modeling
- Sparse Data Structures
- →Scalable Models

- ASCII: Initial model

- GDX: Data layer (“contract”) between GAMS and applications
  - Platform independent
  - Direct GDX interfaces and general API’s…



User Interface Independence

No preference for a particular User Interface

- Smart Links to popular environments, like Excel, MATLAB, R, Databases, …
- Object Oriented APIs: .Net, Java, Python, C++
- Embedded Code Facility
- Web Interface (GAMS MIRO)

Evolved and Matured System

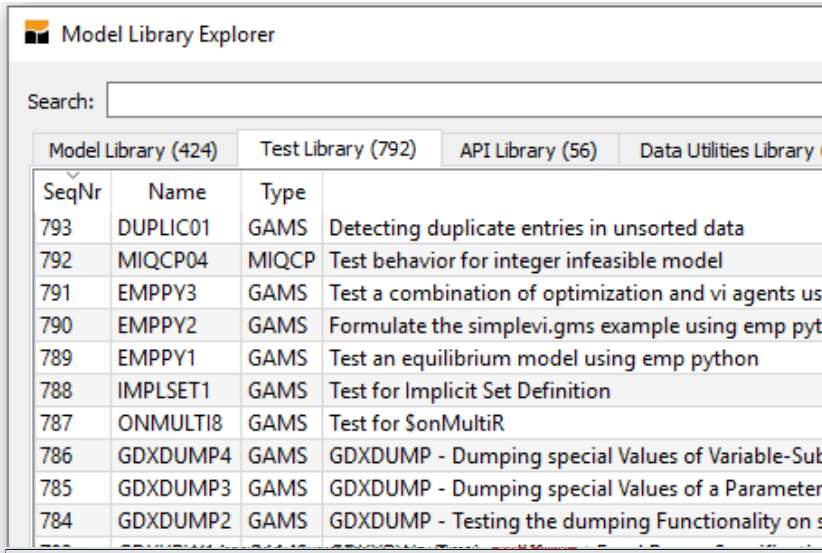
- Evolution through decades of R&D
- Maturity through experience and rigorous testing
- Lots of Development and Debugging Tools: Model Profiler, GAMSCHK, CONVERT, PAVER,…
- Quality Assurance

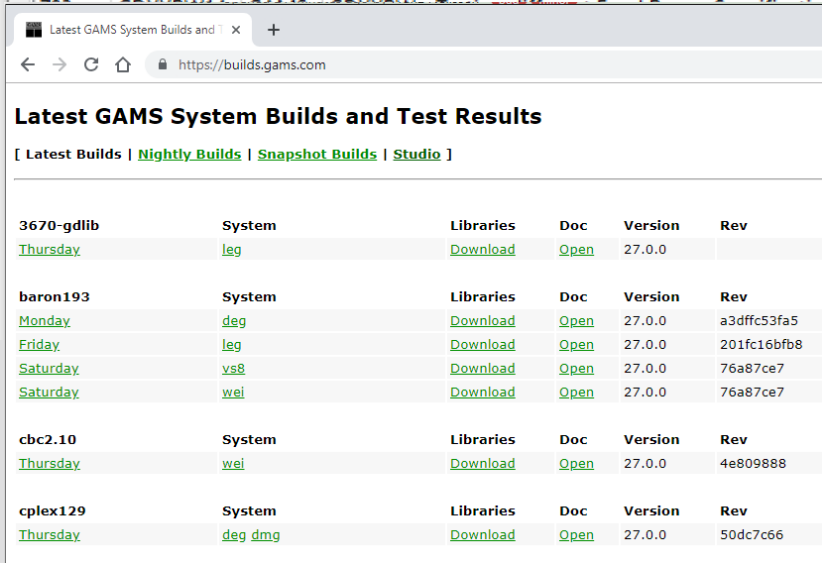
- 2009 GAMS available on the Amazon Elasti
- 2009 GAMS supports extended mathematica
- 2010 GAMS is awarded the company award
- 2010 GDXMRW interface between GAMS
- 2011 Support for Extrinsic Function Libraries
- 2012 The Winners of the 2012 INFORMS Im
  important algebraic modeling languages [1]
- 2012 Introduction of Object Oriented API for
- 2012 The winners of the 2012 Coin OR Cup
- 2013 Support for distributed MIP (Cplex/Gur
- 2013 Stochastic programming extension o
- 2013 GDXRRW interface between GAMS
- 2014 Local search solver LocalSolver added
- 2015 LaTeX documentation from GAMS sou
- 2016 New Management Team
- 2017 EmbeddedCode Facility
- 2017 C++ API
- 2018 GAMS Studio (Beta)
- 2019 GAMS MIRO - Model Interface with Ra

Quality Assurance

- What are the impacts of new features, updated modules or platforms?
- Is the new distribution backward compatible?

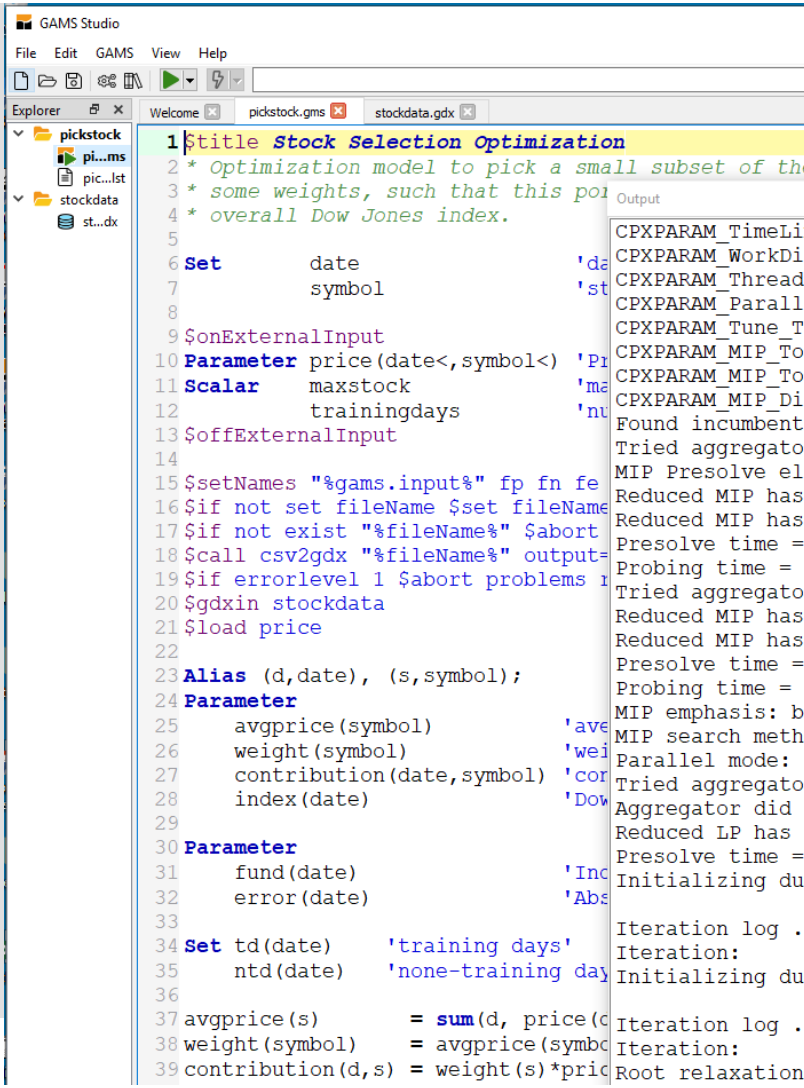
- GAMS Test Library: ~800 quality tests
- Automatically executed every night for all solver combinations (13,000+ runs/platform





GAMS Studio

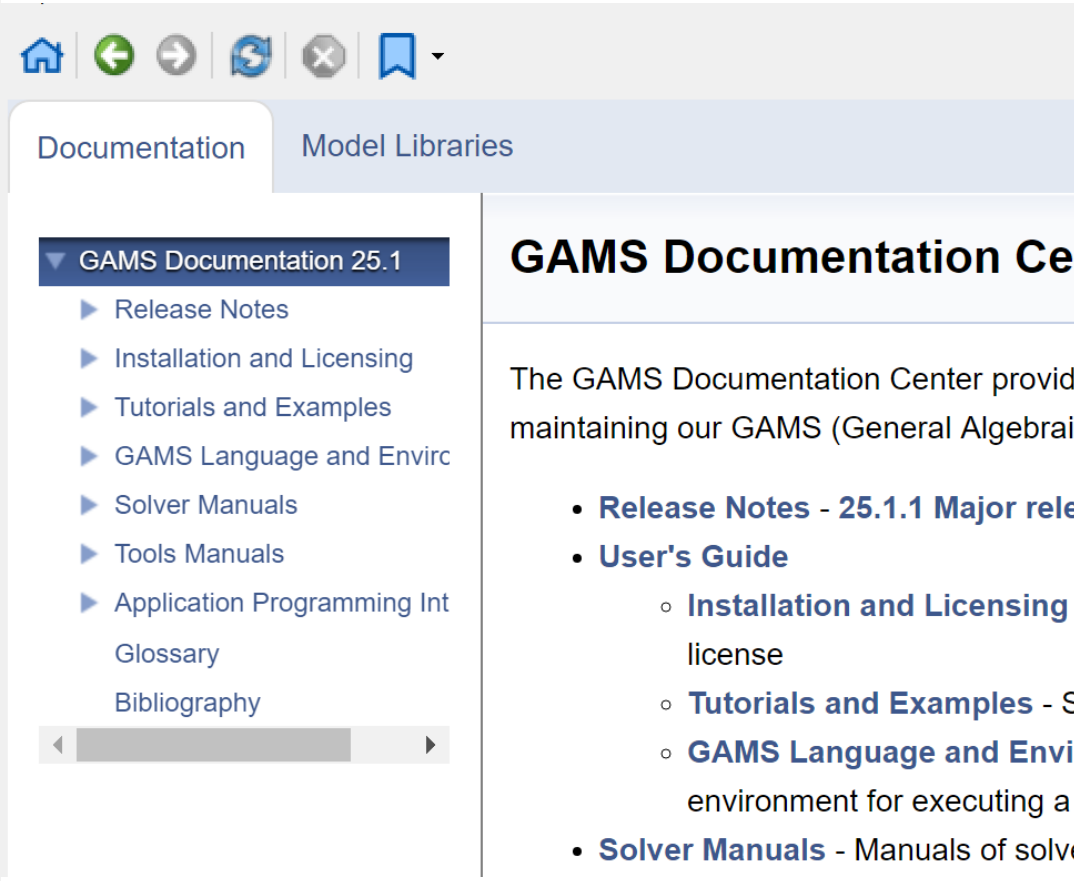
- Development Environment for GAMS Models
- Platform Independent (Win/Mac/Linux)
- Open source Qt project, published on GitHub (GPL)
- All features for efficient model development



Uniform System Documentation

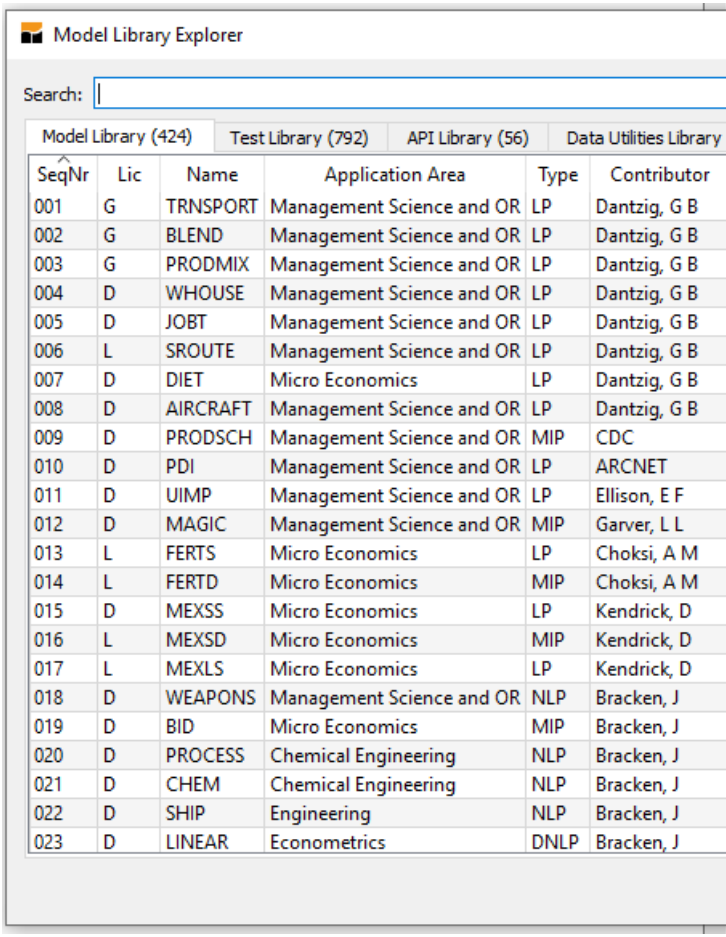
GAMS STUDIO

- Tutorials
- GAMS Language
- Solver
- Tools
- APIs
- Online/Offline



Free Model Libraries

- More than 1,600 models
- Part of any distribution
- Organized in different libraries
  - Application Specific e.g. Finance, Energy
  - Data Connections
  - System Tests



SeqNr	Lic	Name	Application Area	Type	Contributor
001	G	TRNSPORT	Management Science and OR	LP	Dantzig, G B
002	G	BLEND	Management Science and OR	LP	Dantzig, G B
003	G	PRODMIX	Management Science and OR	LP	Dantzig, G B
004	D	WHOUSE	Management Science and OR	LP	Dantzig, G B
005	D	JOBT	Management Science and OR	LP	Dantzig, G B
006	L	SROUTE	Management Science and OR	LP	Dantzig, G B
007	D	DIET	Micro Economics	LP	Dantzig, G B
008	D	AIRCRAFT	Management Science and OR	LP	Dantzig, G B
009	D	PRODSCH	Management Science and OR	MIP	CDC
010	D	PDI	Management Science and OR	LP	ARCNET
011	D	UIMP	Management Science and OR	LP	Ellison, E F
012	D	MAGIC	Management Science and OR	MIP	Garver, L L
013	L	FERTS	Micro Economics	LP	Choksi, A M
014	L	FERTD	Micro Economics	MIP	Choksi, A M
015	D	MEXSS	Micro Economics	LP	Kendrick, D
016	L	MEXSD	Micro Economics	MIP	Kendrick, D
017	L	MEXLS	Micro Economics	LP	Kendrick, D
018	D	WEAPONS	Management Science and OR	NLP	Bracken, J
019	D	BID	Micro Economics	MIP	Bracken, J
020	D	PROCESS	Chemical Engineering	NLP	Bracken, J
021	D	CHEM	Chemical Engineering	NLP	Bracken, J
022	D	SHIP	Engineering	NLP	Bracken, J
023	D	LINEAR	Econometrics	DNLP	Bracken, J

Striving for Innovation and Compatibility

Models must benefit from

- Advancing hardware / New Platforms
- Enhanced / New solver and solution technology
- New Modeling Concepts
- Improved / New interfaces

Protect Investments of Users

- Life time of a model: 15+ years
- New maintainer, platform, solver, user interface
- Backward Compatibility
- Don't lock developers and users into a certain environment.

Agenda

GAMS at a Glance

Model Development and Model Deployment

GAMS MIRO Demo

OR Modeler's Perspective

- Problem class
- Algorithm / Algebra
- Data
- Solver
- Solution


```
29
30 Parameter
31     fund(date)               'Index fund report parameter'
32     error(date)              'Absolute error';
33
34 Set td(date)     'training days'
35     ntd(date)    'none-training days';
36
37 avgprice(s)       = sum(d, price(d,s))/card(d);
38 weight(symbol)    = avgprice(symbol)/sum(s, avgprice(s));
39 contribution(d,s) = weight(s)*price(d,s);
40 index(d)          = sum(s, contribution(d,s));
41
42 Variable
43     p(symbol)    'is stock included?'
44     w(symbol)    'what part of the portfolio'
45     slpos(date)  'positive slack'
46     slneg(date)  'negative slack'
47     obj          'objective';
48
49 Positive variables w, slpos, slneg;
50 Binary variable p;
51
52 Equation
53     deffit(date)     'fit to Dow Jones index'
54     defpick(symbol)  'can only use stock if picked'
55     defnumstock      'few stocks allowed'
56     defobj           'absolute violation (L1 norm) from index';
57
58 deffit(td)..  sum(s, price(td,s)*w(s)) =e= index(td) + slpos(td) - slneg(td);
59
60 defpick(s)..  w(s) =l= p(s);
61
62 defnumstock.. sum(s, p(s)) =l= maxstock;
63
64 defobj..      obj =e= sum(td, slpos(td) + slneg(td));
65
66 Model pickStock /all/;
67
68 option optCR=0.01;
69
70 td(d) = ord(d)<=trainingdays;
71 ntd(d) = not td(d);
72
73 solve pickStock min obj using mip;
74
75 fund(d)  = sum(s, price(d, s)*w.l(s));
76 error(d) = abs(index(d)-fund(d));
77
```

```
Output
--- Job pickstock.gms                                    9 r9d038bd1a89 WEX-WEI x86 64bit/M
GAMS 26.1.9    Copyri                                    ght. All rights reserved
*** ************* B
*** GAMS for MIRO r                                     ) WEI x86 64bit/MS Windows
*** ************* F
Licensee: Franz Nel                                     S190118/0001CN-GEN
          GAMS Soft                                     DC3459
          FNelissen(
--- Starting compila
--- pickstock.gms(18)
--- call csv2gdx "D:\te                                ut=stockdata.gdx ValueDim=0 id=price
No errors, CSV2GDX time =
--- pickstock.gms(20) 2 Mb
--- GDXin=D:\temp\stockdata.gdx
--- pickstock.gms(107) 3 Mb
--- Starting execution: elapsed 0:00:00.051
--- pickstock.gms(71) 5 Mb
--- Generating MIP model pickStock
--- pickstock.gms(73) 5 Mb
---   131 rows  259 columns  3,457 non-zeroes
---   30 discrete-columns
--- Executing CPLEX: elapsed 0:00:00.087

IBM ILOG CPLEX   26.1.0 rf2b37b9 Released Feb 02, 2019
--- GAMS/Cplex licensed for continuous and discrete prc
Cplex 12.8.0.0

Reading data...
Starting Cplex...
Space for names approximately 0.01 Mb
Use option 'names no' to turn use of names off
CPXPARAM_Advance                                 0
CPXPARAM_Simplex_Limits_Iterations               2000000000
CPXPARAM_TimeLimit                               1000
CPXPARAM_WorkDir                                 "D:\temp\225a\"
CPXPARAM_Threads                                 1
CPXPARAM_Parallel                                1
CPXPARAM_Tune_TimeLimit                          200
CPXPARAM_MIP_Tolerances_AbsMIPGap                0
CPXPARAM_MIP_Tolerances_MIPGap                   0.01
CPXPARAM_MIP_Display                             4
Found incumbent of value 9912.095248 after 0.00 sec. (0.05 ticks)
Tried aggregator 1 time.
MIP Presolve eliminated 1 rows and 1 columns.
Reduced MIP has 130 rows, 258 columns, and 3258 nonzeros.
Reduced MIP has 30 binaries, 0 generals, 0 SOSs, and 0 indicators.
Presolve time = 0.00 sec. (0.67 ticks)
Probing time = 0.00 sec. (0.09 ticks)
Tried aggregator 1 time.
Reduced MIP has 130 rows, 258 columns, and 3258 nonzeros.
Reduced MIP has 30 binaries, 0 generals, 0 SOSs, and 0 indicators.
Presolve time = 0.00 sec. (1.03 ticks)
Probing time = 0.00 sec. (0.09 ticks)
MIP emphasis: balance optimality and feasibility.
MIP search method: dynamic search.
Parallel mode: none, using 1 thread.
Tried aggregator 1 time.
Aggregator did 30 substitutions.
Reduced LP has 100 rows, 228 columns, and 3198 nonzeros.
Presolve time = 0.02 sec. (0.44 ticks)
Initializing dual steep norms . . .

Iteration log . . .
Iteration:     1   Dual objective     =             0.000000
Initializing dual steep norms . . .

Iteration log . . .
Iteration:     1   Dual objective     =             0.000000
Root relaxation solution time = 0.02 sec. (1.92 ticks)

        Nodes                                         Cuts/
   Node  Left     Objective  IInf  Best Integer    Best Bound    ItCnt     Gap

*     0+    0                         9912.0952        0.0000           100.00%
Found incumbent of value 9912.095248 after 0.02 sec. (4.49 ticks)
      0     0        0.0000    29     9912.0952        0.0000       29  100.00%
*     0+    0                          381.4598        0.0000           100.00%
```

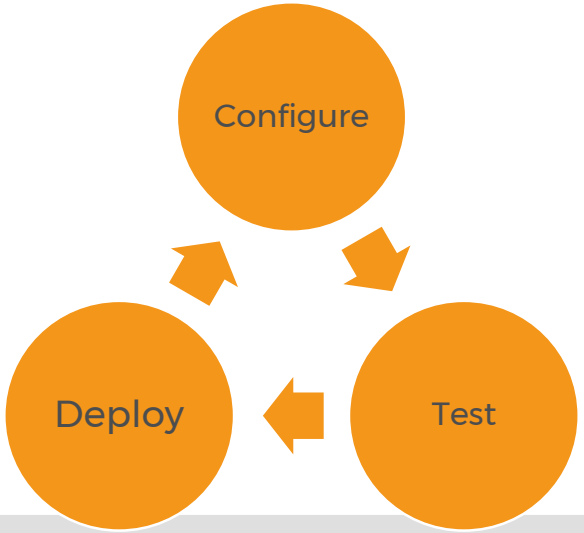
Separation of Tasks

- Use **GAMS for modeling and optimization**

- Use **Object oriented GAMS APIs** for connecting GAMS to other environments
  - ASCII (e.g. CSV)
  - Smart Links to Databases, Spreadsheets, Matlab, R,…
  - .Net, Java, Python, C++
  - Embedded Code Facility (Python)
  - Communication through Memory or Files

→ ***(Some) Programming required***

Model Deployment



- Increasing importance for intuitive deployment and visualization
- Need for easy-to-use tools
- End-users are not modeling experts

→ **Configuration instead of Programming**

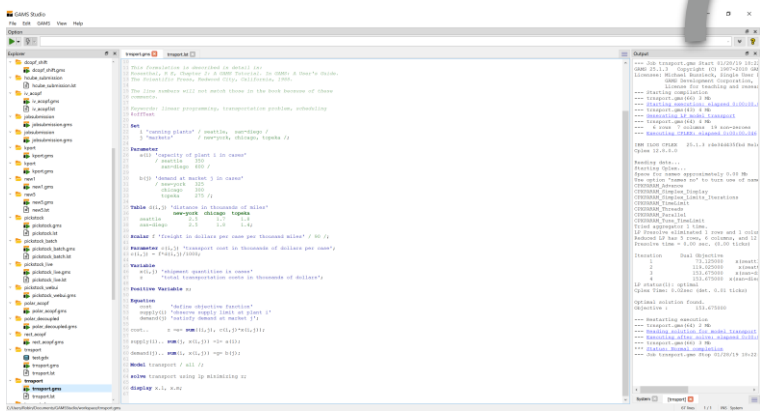
GAMS MIRO

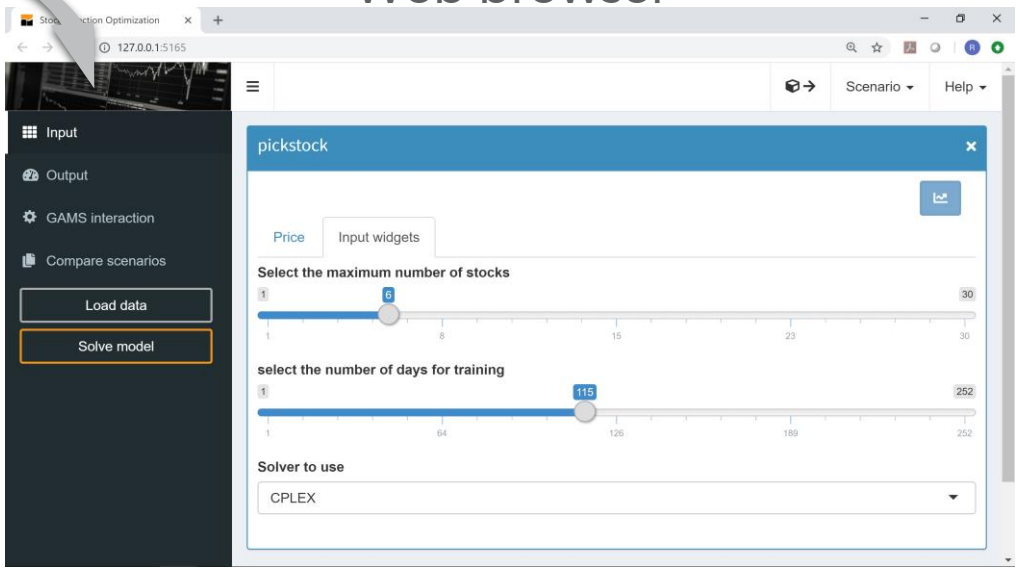
- **M**odel **I**nterface with **R**apid **O**rchestration
- A web interface for GAMS models
- Based on Shiny (R), open source (GPL)
- Desktop / Server Version

Develop GAMS model

Click to deploy

Web browser





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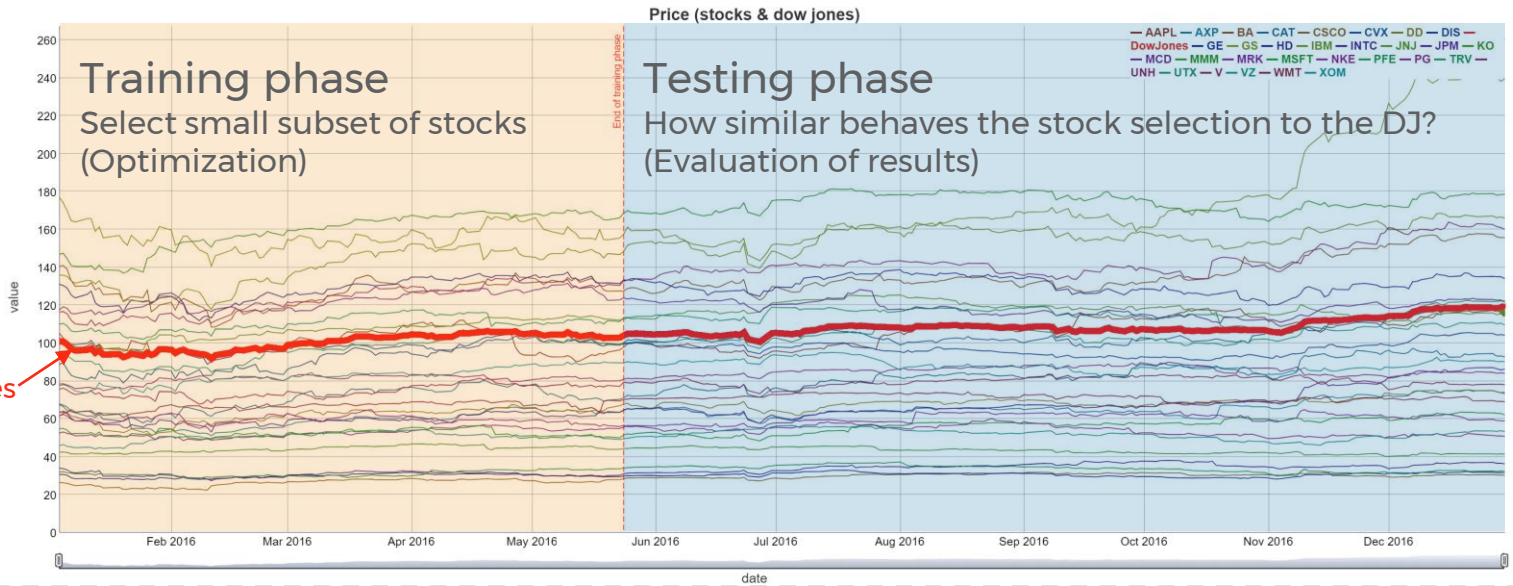
GAMS at a Glance

Model Development and Model Deployment

GAMS MIRO Demo

Model: *Pickstock*



- **Data**: Performance of all shares of the Dow Jones index over one year
- **Goal**: Find a small selection of stocks that follows the Dow Jones as closely as possible
- **Optimization model**: Select a subset (≤ `maxstock`) of Dow Jones stocks, along with weights, so that this portfolio behaves similarly to the overall index (in the training phase)

$$\text{minimize} \quad \text{obj} := \sum_{ds} \text{slpos}_{ds} + \text{slneg}_{ds}$$

$$\text{subject to} \quad \sum_{s} \text{price}_{ds,s} \cdot w_s = \text{index}_{ds} + \text{slpos}_{ds} - \text{slneg}_{ds} \qquad (\forall ds)$$

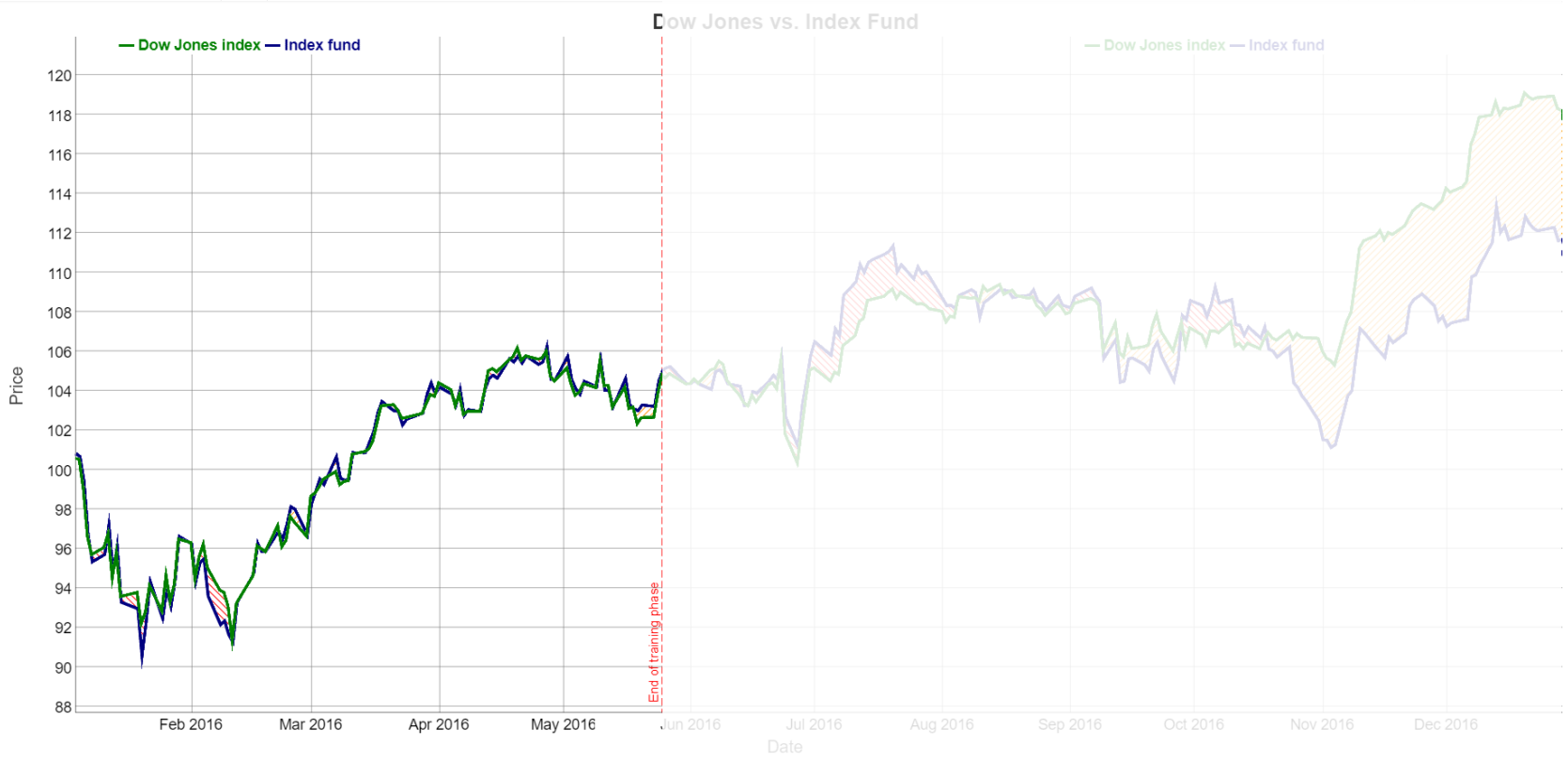
$$w_s \le p_s \qquad (\forall s)$$

$$\sum_{s} p_s \le \text{maxstock}$$

$$w_s \ge 0, \qquad p_s \in \{0,1\} \qquad (\forall s)$$

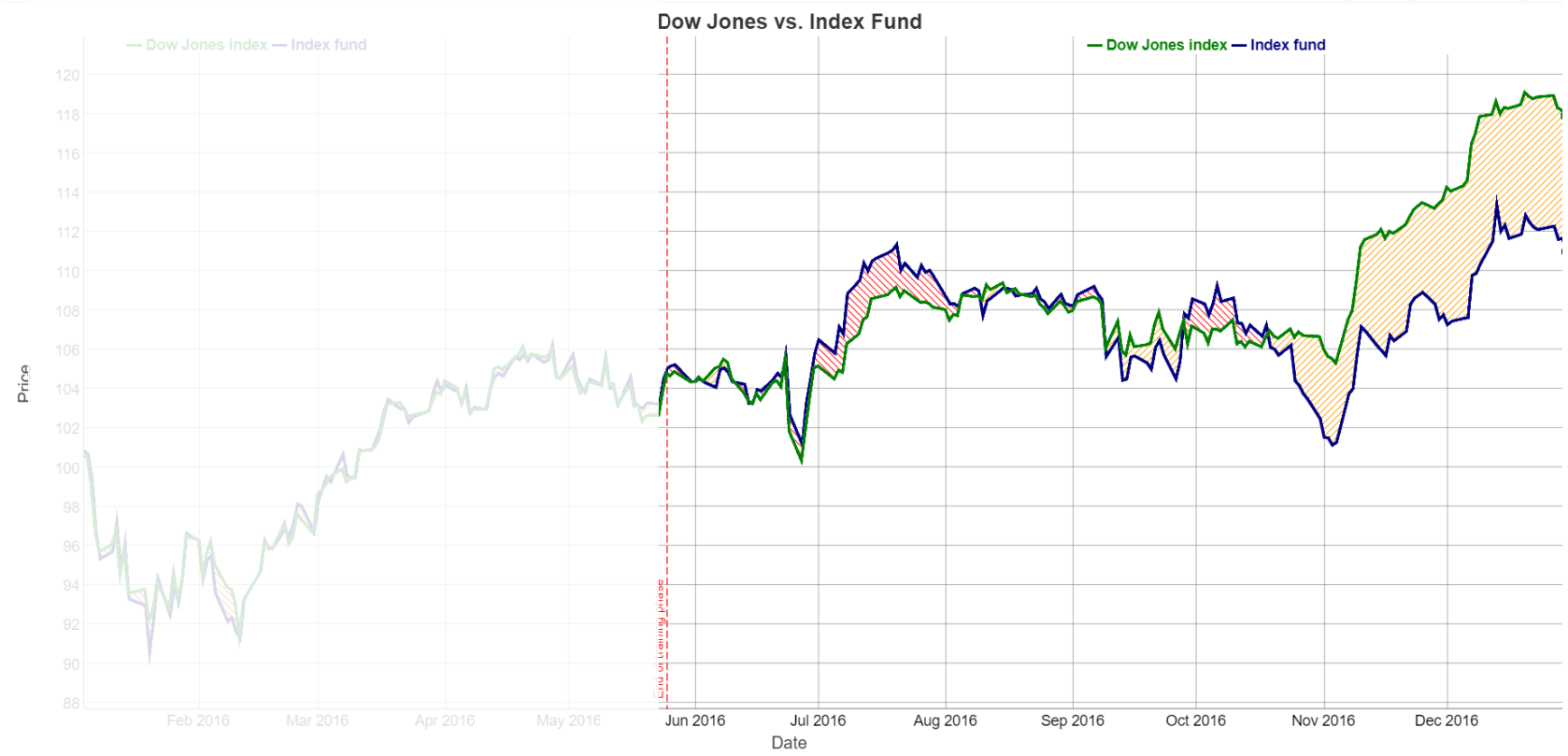
$$\text{slpos}_d \ge 0, \qquad \text{slneg}_d \ge 0 \qquad (\forall d)$$

Model: *Pickstock*



$$\text{minimize} \qquad \text{obj} := \sum_{ds} \text{slpos}_{ds} + \text{slneg}_{ds}$$

Model: *Pickstock*



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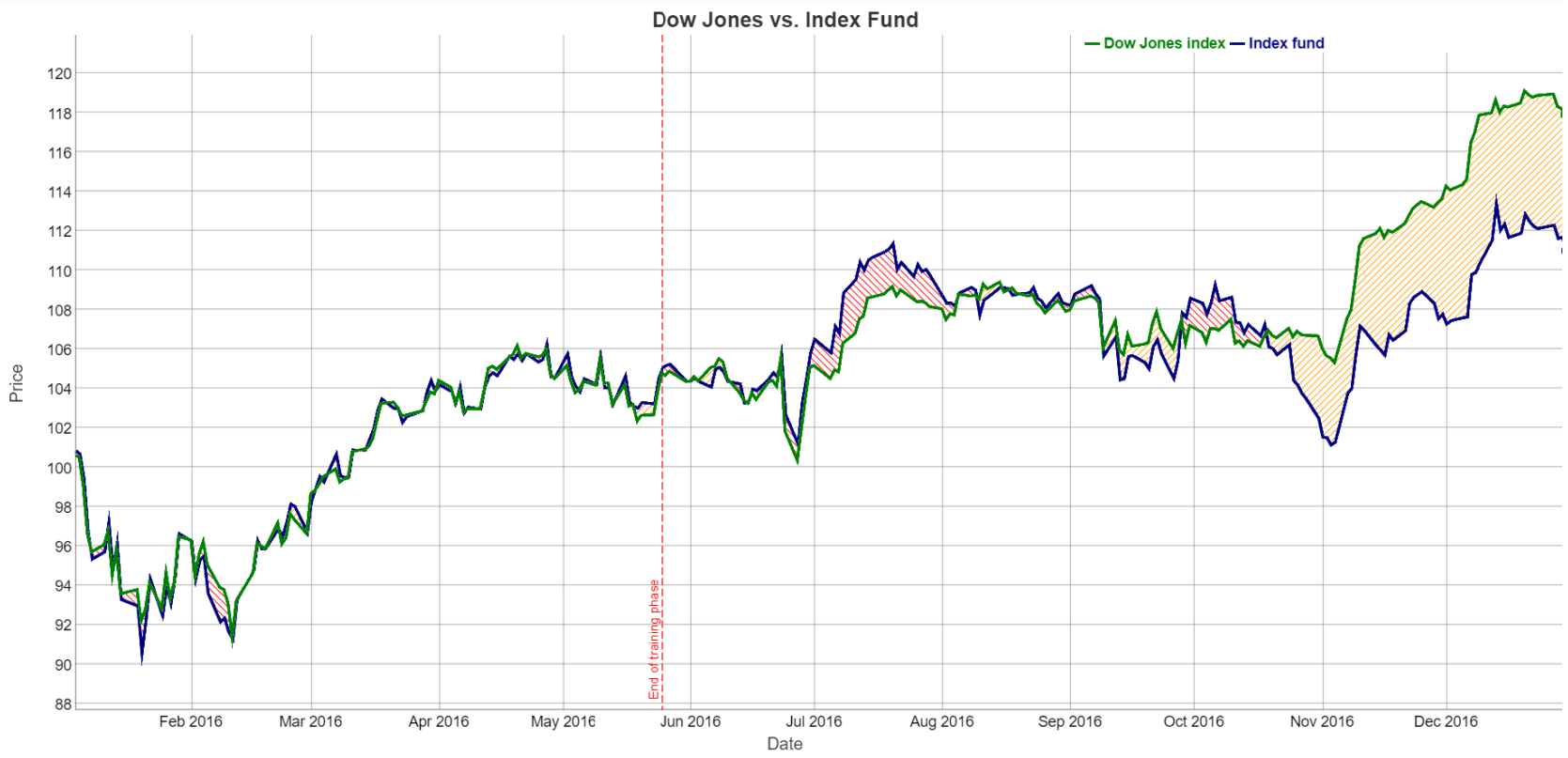
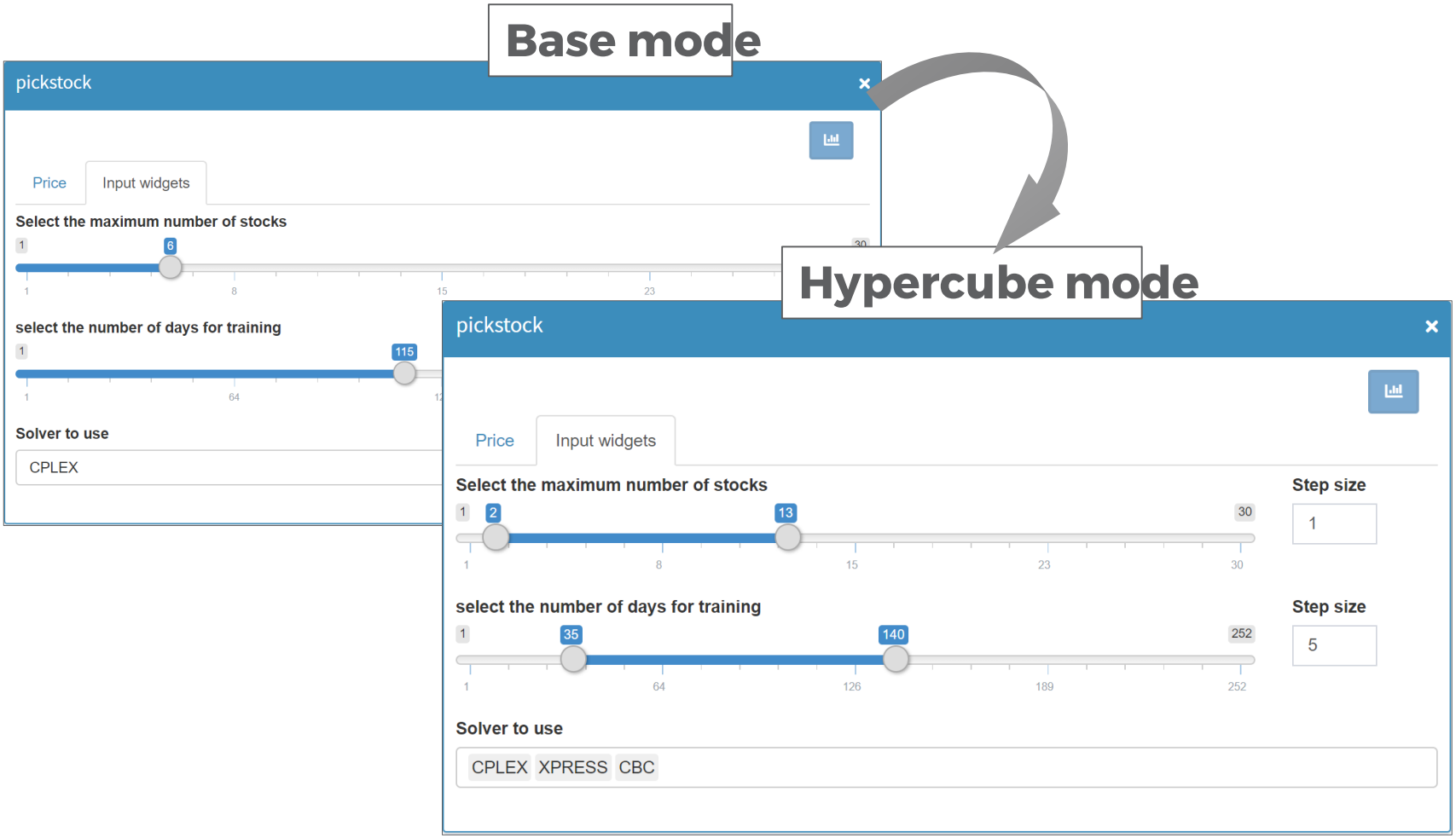
Model: *Pickstock*

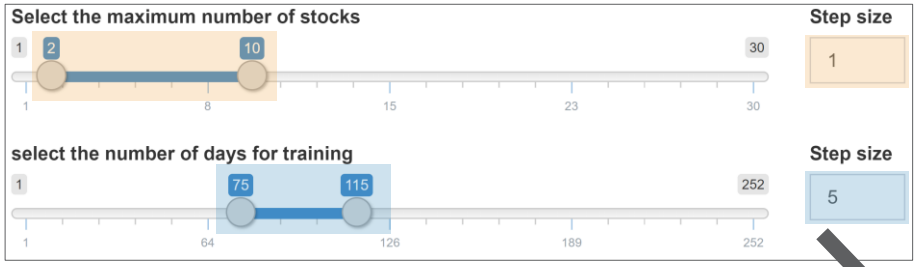


$$\text{minimize} \qquad \text{obj} := \sum_{ds} \text{slpos}_{ds} + \text{slneg}_{ds}$$

Hypercube mode
scenario generation



Hypercube mode
scenario generation



+1

+5

	2	3	4	5	6	7	8	9	10
75	1	2	3	4	5	6	7	8	9
80	10	11		13	14	15	16	17	18
85	19	20					25	26	27
90	28	2						5	36
95	37							4	45
100	46							53	54
105	55	56	57					62	63
110	64	65	66	67	68	69		71	72
115	73	74	75	76	77	78	79	80	81

Number of scenarios
=
Cartesian product of scalar input combinations

Key points

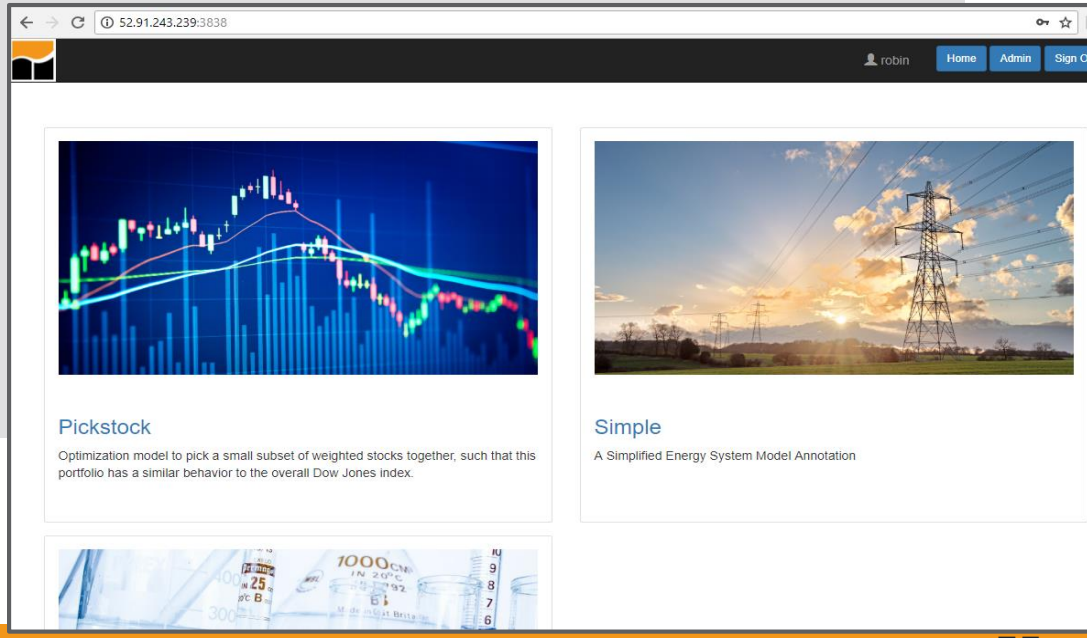
- Quick deployment of GAMS models
- Intuitive usage without GAMS knowledge

- Easy and convenient data management
- Powerful data visualization

- Scenario Management
- Data export

GAMS MIRO on a server

- Based on docker technology
- Authentication: LDAP, OAuth 2.0, Google,…
- Multi-user and -application management
- Load balancing
- Rolling Updates



Conclusions

GAMS MIRO

- Desktop / Server Version
- Commercially supported

- Currently a BETA version
- Used in commercial projects

- Installer for Windows, MacOS, (and Linux)
- Configuration Generator
- Comprehensive Documentation

More Information

GAMS MIRO

Documentation & Software
https://www.gams.com/miro/

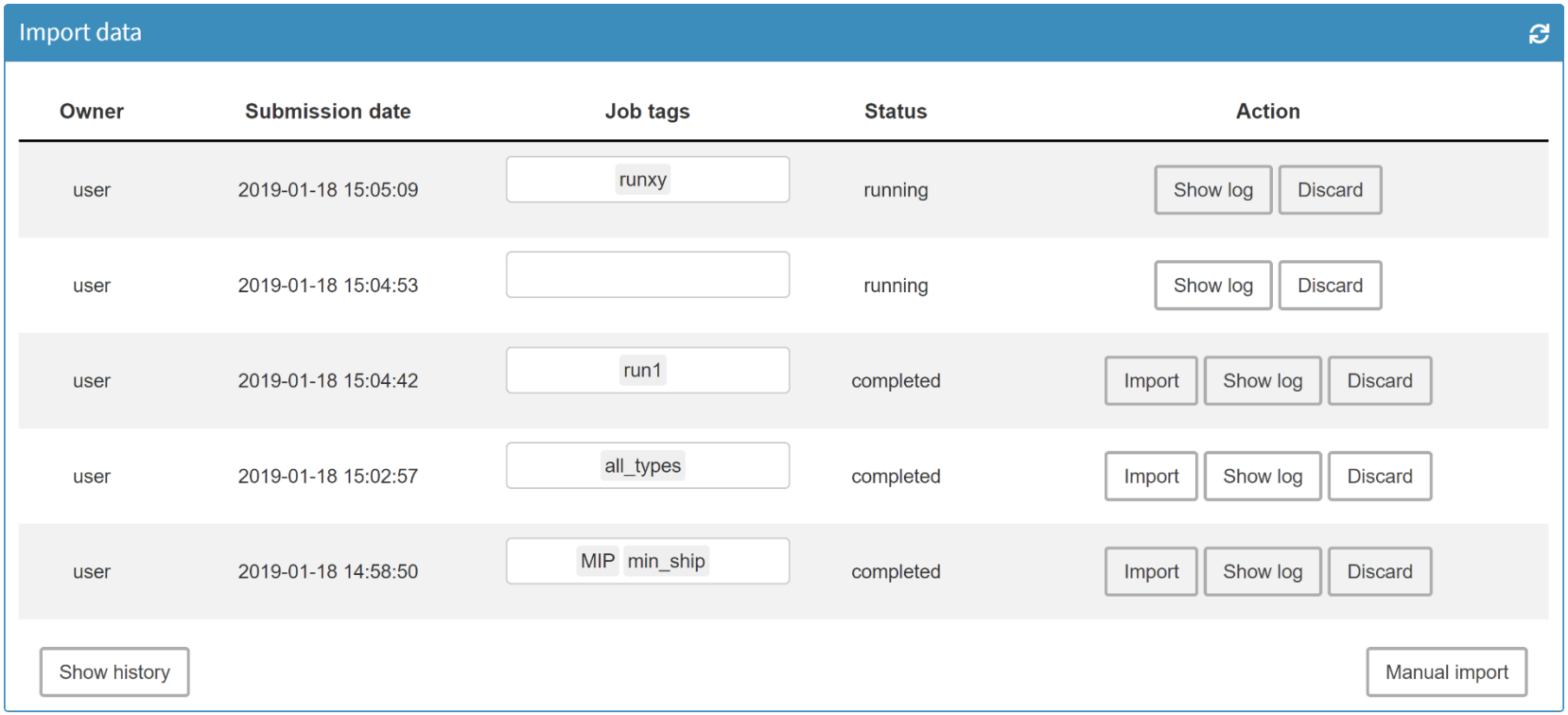
Video
https://youtu.be/7pUrZ-u9ZcQ

Thank you!

Scenario runs and sensitivity analysis

The GAMS MIRO Hypercube mode

Hypercube mode
Data import & monitoring of scenario runs



Hypercube mode
Scenario management

Load scenarios

Time created | between | 2019-02-01 | to | 2019-02-21 | -

Job tags | is | superman | -

AND

Time created | between | 2019-02-22 | to | 2019-03-04 | -

Job tags | is | wonder woman | -

-

AND

OR

Fetch results

Show 10 entries Search:

Owner	Time created	Job tags	maximum number of stocks to select	MIP-Solver	number of days for training	Ratio between error test and error train	Absolute error in entire testing phase	Absolute error in entire training phase	last date of training period
user	2/15/2019, 2:53:55 PM	superman	8	CPLEX	99	13.7001401311091	170.448122203935	12.4413415171496	2016-05-24
user	2/15/2019, 2:53:55 PM	superman	3	CPLEX	99	5.13673004574033	229.061239845358	44.592812510229	2016-05-24
user	2/15/2019, 2:53:55 PM	superman	24	CPLEX	99	19.3422042295776	15.0432531197135	0.777742440373459	2016-05-24
All	All	All	All	All	All	All	All	All	

Showing 1 to 10 of 220 entries

Previous 1 2 3 4 5 … 22 Next

Choose selected scenarios | Choose current page | Choose all | Show hash

Hypercube mode
Analysis

GAMS MIRO

Analyze Scenarios

Index | stat_Status | stat_Efficiency | stat_SolutionQuality | solvedata | documentation