Pre-Conference Workshops

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Outline

Part I: An Introduction to GAMS

Part II: Stochastic programming in GAMS

Part III: The GAMS Object-Oriented API's

Part IV: Code embedding in GAMS
An Introduction to GAMS: Agenda

- GAMS at a Glance
- Foundation and Design Principles
- GAMS – A simple Example
- Wrap-Up
Company

- Went commercial in 1987
- GAMS Development Corp. (USA), GAMS Software GmbH (Germany)
- 2016: New management team
- Software Tool Provider
GAMS at a Glance

- Pioneered Algebraic Modeling Languages
- Robust, scalable state-of-the-art algebraic modeling technology for complex, large-scale optimization
- Open architecture and uniform interface to all major commercial and academic solvers (30+ integrated)
- Evolution through more than 25 years of R&D and user feedback, maturity through experience and rigorous testing
### GAMS Users and Application Areas

- **13,500+ licenses**
- **Users: 50% academic, 50% commercial or governmental**
- **Used in more than 120 countries**

#### Broad Range of Application Areas

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Strong Development Environment

- Project management
- Editor / Syntax coloring / Spell checks
- Model Debugging / Profiling
- Solver selection / Option selection
- Data viewer
- GAMS Processes Control
Uniform System Documentation

GAMS Documentation Center

The GAMS Documentation Center provides you with the technical information on getting started, using and maintaining our GAMS (General Algebraic Modeling System) products.

- Release Notes - What's new in GAMS and all changes.
- Installation Notes - GAMS Installation guides on different platforms.
- Licensing - GAMS Licensing
- Tutorials and Examples - Step-by-step guides included.

GAMS Language - This part introduces the components of the GAMS language in an ordered way, interspersed with detailed examples that are often drawn from the model library. All models from the model library are enclosed in square parenthesis (for example, [TRANSPORT]).

- GAMS Programs - The structure of the GAMS language and its components
- Set Definition - The declaration and initialization of sets, subsets, and domain checking.
- Dynamic Sets - The membership assignment, the usage of dollar controls, and set operations.
- Sets as Sequences: Ordered Sets - Special features used to deal with a set as if it were a sequence.
- Data Manipulations with Parameters - The declaration and assignment of GAMS parameters.
- Data Entry: Parameters, Scalars and Tables - Three basic forms of GAMS data types: Parameters, Scalars and Tables.

Model Libraries

The Model Libraries contain a large number of GAMS Models including:

- GAMS Model Library - GAMS models representing interesting applications to problems in fields such as microeconomics stabilization, applied general equilibrium, model of marine networks, and many more.

- GAMS Test Library - GAMS models developed for testing and many solvers distributed with the GAMS system.

- GAMS Data Library - GAMS models demonstrating a wide variety of modeling techniques including spreadsheets and database interfaces.

- GAMS EMP Library - GAMS Extended Mathematical Programming library.

- GAMS API Library - GAMS Models used as scripts to compile a model, and make it run in a Jupyter notebook.

- NLM Library - GAMS nonlinear optimization applications model.
Simple Integration of GAMS Models

Object Oriented API’s

- Use GAMS for modeling and optimization tasks
- Connects GAMS to other environments
  - Programming languages (.Net, C++, Java, Python)
- Applications (through Smart Links)
- (New) Embedded Code (Python)
- Communication through Memory or Files
Free Model Libraries

- GAMS Model Library
- GAMS Test Library
- GAMS Data Utilities Models
- GAMS EMP Library
- GAMS API Library
- Practical Financial Optimization Models
- Nonlinear Optimization Applications (N. Andrei)

More than 1400 models!
COURSES AND WORKSHOPS 2017

June
Online Course
Introduction to Practical Global CGE Modeling with GAMS

Prague, Czech Republic
- Practical General Equilibrium Modeling with GAMS
- Energy and Environmental CGE Modeling with GAMS
- Advanced Techniques in General Equilibrium Modeling with GAMS
- Overlapping Generation General Equilibrium Modeling with GAMS

August
Annapolis, MD, USA
- Single Country General Equilibrium Modelling with GAMS and STAGE
- Global CGE Modelling with GAMS and GLOBE

Frisco, CO, USA
- Basic GAMS Modeling - An Introductory Class
- Advanced GAMS Modeling

September
Essen, Germany
- Trade Policy Analysis with GAMS and MPSGE

November
Weisenheim a.B., Germany
- Modeling and Optimization with GAMS (basic)
- Modeling and Optimization with GAMS (advanced)

Continuous
- Online Practical General Equilibrium Modeling with GAMS
- Online Advanced Techniques in General Equilibrium Modeling with GAMS
Where to Find Help?

- Documentation Center: https://www.gams.com/latest/docs/
- Mailing Lists, Newsletters, and Forum: https://www.gams.com/community/newsletters-mailing-list/
- //forum.gamsworld.org/
- YouTube Channel: https://www.youtube.com/user/GAMSLessons
- GAMS Support: support@gams.com
Foundation of GAMS

Powerful algebraic modeling language

Open architecture with interfaces to other systems

Independent layers
General Algebraic Modeling System

**Powerful Declarative Language**

- Similar to mathematical notation
- Easy to learn - few basic language elements: sets, parameters, variables, equations, models
- Model is executable (algebraic) description of the problem
- Lots of code optimization under the hood
Mix of Declarative and Imperative Elements

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

Advantages:
- Build complex problem algorithms within GAMS
- Simplified interaction with other systems:
  - Data exchange
  - GAMS process control
Foundation of GAMS

- Powerful algebraic modeling language
- Open architecture with interfaces to other systems
- Independent layers
Foundation of GAMS

- Powerful algebraic modeling language
- Open architecture with interfaces to other systems
- Independent layers
Separation of Model and Platform

- Move models between platforms with ease!

Supported Platforms:
- Windows
- Linux
- MacOS
- Solaris
- AIX
Separation of **Model and Solver**

One environment for a wide range of solvers

- All major commercial LP/MIP solver
- Open Source Solver (COIN)
- Also solver for NLP, MINLP, global, and stochastic optimization

- More than 30 Solvers integrated!
Separation of Model and Solver

Local and distributed / remote execution

- Distributed Algorithm (CPLEX, GUROBI)
- Remote Execution
  - DoCloud (IBM), Gurobi Instant Cloud
  - Solve Engine (Satalia)
  - NEOS (Kestrel)
- Grid Computing Facility
Separation of **Model and Solver**

**Uniform interface to all major solvers**
- Switching between solvers with one statement
- Unified Documentation
- Licensing (GAMS as a „license broker“)

**Av. number of commercial solvers per license**
- Academic clients: 2.9
- Commercial: 2.2
GENERAL ALGEBRAIC MODELING SYSTEM

Separation of Model and Data

- Declarative Modeling
- Sparse Data Structures
- Various ways to exchange data
  - ASCII
  - Binary

```
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) distance in thousands of miles
c(i,j) transport cost in thousands of dollars per case ;
Scalar f ;

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/ ;
```
Separation of Model and User Interface

- No preference for a particular user interface
- Open architecture and interfaces to other systems
- OO-API’s for seamless integration
- Smart Links
- Mode of Operation
  - Interactive or Embedded / Batch
  - Local or Remote
Application – Cloud Computing

xyz Energy Company

Scenario Analysis in the Cloud

- Solve 1,000+ scenarios (MIPs, one hour) every week overnight
- Issues:
  - Costs (Licensing)
  - Automation / Security
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

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

- Tests with 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 simultaneously with SCIP and CBC
  → “hardware” costs: $0.07 per instance hour
- After 60 minutes take the best solution
- If necessary solve “difficult” model instances with CPLEX (outside the cloud)
Agenda

GAMS at a Glance

Foundation and Design Principle

GAMS – A simple Example

Wrap-Up
Minimize Transportation cost subject to Demand satisfaction at markets Supply constraints
Model types in this example

- **LP**: Determine minimum transportation cost. Result: city to city shipment volumes.
- **MIP**: Allows discrete decisions, e.g. if we ship, then we ship at least 100 cases.
- **MINLP**: Allows non-linearity, e.g. a smooth decrease in unit cost when shipping volumes grows.
**Indices:**
- $i$ (Canning plants)
- $j$ (Markets)

**Decision variables:** $x_{ij}$ (Number of cases to ship)

**Data:**
- $c_{ij}$ (Transport cost per case)
- $a_i$ (Capacity in cases)
- $b_i$ (Demand in cases)

Minimize $\sum_i \sum_j c_{ij} \cdot x_{ij}$ (Minimize total transportation cost)

subject to

- $\sum_j x_{ij} \leq a_i \quad \forall i$ (Shipments from each plant $\leq$ supply capacity)
- $\sum_i x_{ij} \geq b_j \quad \forall j$ (Shipments to each market $\geq$ demand)
- $x_{ij} \geq 0 \quad \forall i, j$ (Do not ship from market to plant)
- $i, j \in \mathbb{N}$ (Indices belong to natural numbers)
GENERAL ALGEBRAIC MODELING SYSTEM

GAMS Algebra (declarative Model)

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) distance in thousands of miles
c(i,j) transport cost in thousands of dollars per case;
Scalar f freight in dollars per case per thousand miles;

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/ ;

Model is executable description of the problem
Agenda

GAMS at a Glance

Foundation and Design Principle

GAMS – A simple Example

Wrap-Up
What does a modeler have to think about?

1. Problem
2. Mathematics
3. Programming
4. Performance
5. Scalability
6. Connectivity
7. Deployment
8. Maintenance (Life Cycle)
9. ...

GAMS eases the transitions between these domains

- Simplifies Modeling
- Increases Productivity
GAMS - Evolution

Timeline
- 1976 GAMS idea is presented at the International Symposium on Mathematical Programming (ISMP), Budapest.
- 1979 Phase II: GAMS supports nonlinear programming.
- 1981 GAMS becomes a commercial product.
- 1986 First PC System (16 bit).
- 1988 Alex Meeraus, the initiator of GAMS and founder of GAMS Development Corporation, is awarded the INFORMS Computing Society Prize.
- 1990 32 bit DOS Extender.
- 1990 GAMS moves to Georgetown, Washington, D.C.
- 1991 Mixed Integer Non-Linear Programs capability (DICOPT).
- 1994 GAMS supports mixed complementarity problems.
- 1995 MPSGE language is added for CGE modeling.
- 1996 European branch opens in Germany.
- 1998 Stochastic programming capability (OSL/ISE, DECIS).
- 1999 Introduction of the GAMS integrated development environment (IDE).
- 2000 GAMS World initiative started.
- 2001 GAMS Data Exchange (GDX) is introduced.
- 2002 GAMS is listed on OR/MS 50th Anniversary list of milestones.
- 2003 Conic programming is added.
- 2003 Global optimization in GAMS.
- 2004 Quality assurance initiative starts.
- 2004 Support for Quadratic Constrained programs.
- 2005 Support for 64 bit PC Operating systems.
- 2006 GAMS supports parallel grid computing.
- 2007 GAMS supports open-source solvers from COIN-OR.
- 2008 Support for 32 and 64 bit Mac OS X.
- 2009 GAMS available on the Amazon Elastic Compute Cloud.
- 2009 GAMS supports extended mathematical programs (EMP).
- 2010 GAMS is awarded the company awards of the German Society of Operations Research (GOR).
- 2010 GDXMRW interface between GAMS and Matlab.
- 2012 The Winners of the 2012 INFORMS Impact Prize included Alexander Meeraus. The prize was awarded to the originators of the five most important algebraic modeling languages.
- 2012 Introduction of Object Oriented API for .NET, Java, and Python.
- 2012 The winners of the 2012 Com OR Cup included Michael Bussieck, Steven Dirkse, & Stefan Vigerske for GAMSlinks.
- 2013 Support for distributed MIP (Cplex/Gurobi).
- 2013 Stochastic programming extensions of GAMS EMP.
- 2013 GDXMRW interface between GAMS and R.
- 2014 Local search solver LocalSolver added to solver portfolio.
- 2015 Latex documentation from GAMS source (Model2TeX).
Striving for **Innovation and Compatibility**

**Users must benefit from**
- Advancing hardware / New Platforms
- Enhanced / new solver and solution technology
- Improved / upcoming interfaces to other systems
- New Modeling Concepts

**Protect Investments of Users**
- Life time of a model: 15+ years
- New maintainer, platform, solver, user interface
- Backward Compatibility
- Quality Assurance
New Modeling and Solution Concepts

Examples:
- Bilevel Programs
- Extended Nonlinear Programs
- Stochastic Programming
- Disjunctive Programs

Issues:
- Breakouts of traditional Mathematical Programming classes
- Limited support with common model representation
- Incomplete/experimental solution approaches
- New and interesting solver features driven by implementation choices → May break solver independence of models

Challenge:
- Find a concept that combines the essentials of new features independent of the particular implementation choices.
Striving for **Innovation** and **Compatibility**

**Users must benefit from**
- Advancing hardware / New Platforms
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- New Modeling Concepts

**Protect Investments of Users**
- Life time of a model: 15+ years
- New maintainer, platform, solver, user interface
- Backward Compatibility
- Quality Assurance
Quality Assurance

- What are the impacts of new features / updated modules / platforms?
- Is the new distribution backward compatible?
- 700+ quality test models (GAMS Test Library)
- Automatically executed every night for all solver combinations (13,000+ runs / platform)
Recent Enhancements

Release Notes

Distribution History

24.9.0 (Beta release) July 20, 2016

GAMS Beta Release 24.9.0 - July 20, 2016

This is a BETA version of the software and not the final product. Use it at your own risk.

Acknowledgments

We would like to thank all of our users who have reported problems and made suggestions for improving this release. In particular, we thank Etienne Ayotte-Sauvé, Wolfgang Brix, Florian Habemacher, Ignacio Herrero, Hanspete Höschele, Erwin Kalvelagen, Yuri Lastusilta, John Ross, and Tom Rutherford.

Platforms

- The set of supported platforms has not changed, but we’ve divided it into the core platforms (Windows 32-bit, Windows 64-bit, Linux, and Mac OS X) and the peripheral platforms (AIX, x86-64 Solaris, and Sparc64 Solaris) to recognize and better describe how the two sets of platforms have evolved. The user communities for core platforms are large, active, and well-identified, but not so for the peripheral platforms. For the core platforms, we’ll continue to make each new release of GAMS directly available for download, while the peripheral platforms will be available by request only. Finally, we expect that any change in the availability of core platforms will be announced well in advance of the event, while changes to support for peripheral platforms may occur with little or no notice. Please note, however, that we are not changing the content or behavior of GAMS based on this division: GAMS models will continue to work in the same cross-platform way for both core and peripheral platforms.

- We will drop support for x86-64 Solaris with GAMS 25.0.
- We may increase the minimal required OLIBC version on Linux to 2.12 with GAMS 25.0.
- We may increase the minimal required MacOS X version to 10.11 with GAMS 25.0.

GAMS System

GAMS

- New feature, the Embedded Code Facility: This extends the connectivity of GAMS to other programming languages. It allows the use of Python code during compile and execution time. GAMS symbols are shared with the external code, so no communication via disk is necessary. This feature is available on Linux, MacOS X, and Windows only.

Why GAMS?

- Algebraic modeling technology for complex, large-scale optimization.
- Uniform interface to all major solvers
- Design principles: Simple, but powerful modeling language, open architecture, independent layers
- More than 25 years of R&D and user feedback
- Open for new developments
- Protecting investments of users
Embedded Code in GAMS - Using Python as an Example  
Given by: Lutz Westermann  
Wednesday (Sep. 06), 13:30-15:00 [WC-02] / WGS|102

High Performance Computing with GAMS  
Given by: Fred Fiand, Michael Bussieck  
Thursday (Sep. 07), 11:00-12:30 [TB-02] / WGS|102

A distributed Optimization Bot/Agent Application Framework for GAMS Models  
Given by: Franz Nelissen  
Thursday (Sep. 07), 14:45-16:15 [TD-02] / WGS|102

Exam scheduling at United States Military Academy West Point  
Given by: Frederik Proske, Robin Schuchmann  
Friday (Sep. 08), 09:00-10:30 [FA-02] / WGS|102
Thank You

Meet us at the GAMS booth!
Outline

Part I: An Introduction to GAMS

Part II: Stochastic programming in GAMS

Part III: The GAMS Object-Oriented API's

Part IV: Code embedding in GAMS
Stochastic Programming - Introduction

Stochastic programs are mathematical programs that involve **uncertain** data.

**Motivation:**
Real world problems frequently include some uncertain parameters. Often these uncertain parameters follow a probability distribution that is known or can be estimated.

**Goal:**
Find some policy that is feasible for all (or almost all) the possible data instances and that maximizes the expectation of some function of the decision variables and the random variables.

**Example:**
In a two-stage stochastic programming problem with recourse the decision maker has to make a decision now and then to minimize the expected costs of the consequences of that decision.
Simple Example: Newsboy (NB) Problem

- **Data:**
  - A newsboy faces a certain demand for newspapers \( d = 63 \)
  - He can buy newspapers for fixed costs per unit \( c = 30 \)
  - He can sell newspapers for a fixed price \( v = 60 \)
  - For leftovers he has to pay holding costs per unit \( h = 10 \)
  - He has to satisfy his customers demand or has to pay a penalty \( p = 5 \)

- **Decisions:**
  - How many newspapers should he buy: \( X \)
  - How many newspapers should he sell: \( S \)

- **Derived Outcomes:**
  - How many newspapers need to be disposed: \( I \)
  - How many customers are lost: \( L \)
Variable  Z  Profit;
Positive Variables
   X  Units bought
   I  Inventory
   L  Lost sales
   S  Units sold;

Equations  Row1, Row2, Profit;

* demand = UnitsSold + LostSales
Row1..  d =e=  S + L;

* Inventory = UnitsBought - UnitsSold
Row2..  I =e=  X - S;

* Profit, to be maximized;
Profit..  Z =e=  v*S - c*X - h*I - p*L;

Model  nb  / all /;

Solve  nb  max z use lp;

⇒ nbsimple.gms
NB Problem – Add Uncertainty

• Uncertain demand $d$

• Decisions to make:
  • How much newspaper should he buy “here and now” (without knowing the outcome of the uncertain demand)? → First-stage decision
  • How many customers are lost after the outcome becomes known?
  • How many unsold models go to the inventory? → Second-stage or recourse decision
• Recourse decisions can be seen as
  • penalties for bad first-stage decisions
  • variables to keep the problem feasible

Demand

Prob: 0.7
Val: 45

Prob: 0.2
Val: 40

Prob: 0.1
Val: 50
Stochastic NB Problem – GAMS Extension

Idea:
Use deterministic model formulation plus some annotation to define uncertainty.

- randvar d discrete 0.7 45
  - 0.2 40
  - 0.1 50

stage 2 I L S d
stage 2 Row1 Row2

Make demand d uncertain
Define (non-default) stage 2 variables and equations
Stochastic NB Problem – GAMS Extension

```gams
file emp / '%emp.info%' /; put emp 'problem %gams.i%';

randvar d discrete 0.7 45
     0.2  40
     0.1  50

stage 2 I L S d
stage 2 Row1 Row2
$offput
putclose emp;
```

Syntax to write an EMP info file, e.g. [...]\225a\empinfo.dat

EMP, what?  
→  Excursus
EMP stands for Extended Mathematical Programming

Idea:
- 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
The EMP Framework

1. EMP Information
2. Reformulated Model
3. Solution

Translation

Solve using established Algorithms

Mapping Solution into original space

Viewable
Dictionary with output-handling information

- The expected value of the solution can be accessed via the regular .L (and .M) fields
- Additional information can be stored in a parameter by scenario, e.g.:
  - `level`: Levels of variables or equations
  - `randvar`: Realization of a random variable
  - `opt`: Probability of each scenario

- This needs to be stored in a separate dictionary:

  ```plaintext
  Set scen Scenarios / s1*s3 /;
  Parameter
    s_d(scen) Demand realization by scenario
    s_x(scen) Units bought by scenario
    s_s(scen) Units sold by scenario
    s_o(scen,*) scenario probability / #scen.prob 0 /;
  Set dict / scen .scenario."
    d .randvar .s_d
    s .level .s_s
    x .level .s_x
    " .opt .s_o /;
  solve nb max z use emp scenario dict;
  ```
3 parts of a GAMS EMP stochastic model

1. The deterministic *core* model

2. EMP annotations in EMP info file

3. The *dictionary* with output-handling information
Extended Example: Newsboy (NB) Problem

Data:
- A newsboy faces a certain demand for newspapers $d = 63$
- He can buy newspapers for fixed costs per unit $c = 30$
- He can sell newspapers for a fixed price $v = 60$
- For leftovers he has to pay holding costs per unit $h = 10$
- He has to satisfy his customers demand or has to pay a penalty $p = 5$
- He can return units for a refund (stage 3) $r = 9$

Stage 1: Decisions:
- How many newspapers should he buy: $X$

Stage 2: Decisions & Derived Outcomes
- How many newspapers should he sell: $S$
- How many newspapers go to his inventory: $I$
- How many customers are lost: $L$

Stage 3: Decisions & Derived Outcomes
- How many units returned for refund: $Y$
- How many units kept for holding cost $h$ again: $E$
Stages [stage]

- Defines the stage of random variables (rv), equations (equ) and variables (var):

  \[
  \text{stage stageNo rv | equ | var \{rv | equ | var\}}
  \]

- \textit{StageNo} defines the stage number

- The default \textit{StageNo} for the objective variable and objective equation is the highest stage mentioned

- The default \textit{StageNo} for all the other random variables, equations and variables not mentioned is 1
Random Variables

Discrete Distribution

Poisson Distribution

Normal Distribution

Exponential Distribution
Random Variables (RV) [randVar]

Defines both discrete and parametric random variables:

\[ \text{randVar rv discrete prob val \{prob val\}} \]

The distribution of discrete random variables is defined by pairs of the probability prob of an outcome and the corresponding realization val.

\[ \text{randVar rv distr par \{par\}} \]

The name of the parametric distribution is defined by distr, par defines a parameter of the distribution.

For parametric distributions a sample can be created.
Independent vs. Joint Random Variables

Demand

- Prob: 0.2
  - d: 40
- Prob: 0.7
  - d: 45
- Prob: 0.1
  - d: 50

Demand / Price

- Prob: 0.04
  - d: 40 / p: 55
- Prob: 0.14
  - d: 40 / p: 60
- Prob: 0.02
  - d: 40 / p: 65
- Prob: 0.14
  - d: 45 / p: 55
- Prob: 0.49
  - d: 45 / p: 60
- Prob: 0.07
  - d: 50 / p: 55
- Prob: 0.02
  - d: 50 / p: 60
- Prob: 0.07
  - d: 50 / p: 65
- Prob: 0.01
  - d: 50 / p: 65

Price

- Prob: 0.2
  - d: 40
  - p: 55
- Prob: 0.7
  - d: 45
  - p: 60
- Prob: 0.1
  - d: 50
  - p: 65

Demand / Price

- Prob: 0.04
  - d: 40 / p: 55
- Prob: 0.14
  - d: 40 / p: 60
- Prob: 0.02
  - d: 40 / p: 65
- Prob: 0.14
  - d: 45 / p: 55
- Prob: 0.49
  - d: 45 / p: 60
- Prob: 0.07
  - d: 50 / p: 55
- Prob: 0.02
  - d: 50 / p: 60
- Prob: 0.07
  - d: 50 / p: 65
- Prob: 0.01
  - d: 50 / p: 65

vs.
Joint RVs [jRandVar]

- Defines discrete random variables and their joint distribution:
  
  \[
  \text{jRandVar rv rv \{rv\} prob val val \{val\} }
  \]

- At least two discrete random variables \( rv \) are defined and the outcome of those is coupled

- The probability of the outcomes is defined by \( \text{prob} \) and the corresponding realization for each random variable by \( \text{val} \)
Correlation between RVs [correlation]

• Defines a correlation between a pair of random variables:

```plaintext
correlation rv rv val
```

• `rv` is a random variable which needs to be specified using the `randvar` keyword and `val` defines the desired correlation \((-1 \leq val \leq 1)\).
Chance Constraints

OBJ..  Z =e= X1 + X2;
E1..  om1*X1 +   X2 =g=  7;
E2..  om2*X1 + 3*X2 =g= 12;
Model sc / all /;
solve sc min z use lp;

Prob: 0.25
val: 1
Prob: 0.25
val: 2
Prob: 0.25
val: 3
Prob: 0.25
val: 4

Prob: 0.33
val: 1
Prob: 0.33
val: 2
Prob: 0.33
val: 3

chance E1 0.6
chance E2 0.6
Chance Constraints

3 out of 4 must be true
\[0.75 \geq 0.6\]

\[
\begin{align*}
1 \times X_1 + X_2 & \geq 7; \\
2 \times X_1 + X_2 & \geq 7; \\
3 \times X_1 + X_2 & \geq 7; \\
4 \times X_1 + X_2 & \geq 7;
\end{align*}
\]

2 out of 3 must be true
\[0.66 \geq 0.6\]

\[
\begin{align*}
1 \times X_1 + 3 \times X_2 & \geq 12; \\
2 \times X_1 + 3 \times X_2 & \geq 12; \\
3 \times X_1 + 3 \times X_2 & \geq 12;
\end{align*}
\]
Chance Constraints [\texttt{chance}]

- Defines individual or joint chance constraints (CC):
  
  $$\texttt{chance equ \{equ\} [holds] minRatio [weight|varName]}$$

- Individual CC: A single constraint \texttt{equ} has to hold for a certain ratio ($0 \leq \text{minRatio} \leq 1$) of the possible outcomes

- Joint CC: A set of constraints \texttt{equ} has to hold for a certain ratio ($0 \leq \text{minRatio} \leq 1$) of the possible outcomes

- If \texttt{weight} is defined, the violation of a CC gets penalized in the objective ($\text{weight violationRatio}$)

- If \texttt{varName} is defined the violation get multiplied by this existing variable
The Extended Mathematical Programming (EMP) framework can be used to replace parameters in the model by random variables.

Support for Multi-stage recourse problems and chance constraint models.

Easy to add uncertainty to existing deterministic models, to either use specialized algorithms (e.g. solvers Lindo, DECIS) or create Deterministic Equivalent (free solver DE).

Besides the expected value, EMP also supports optimization of other risk measures (e.g. VaR).

GAMS/Scenred2 interfaces GAMS with the well-known scenario reduction software Scenred (https://www.gams.com/latest/docs/T_SCENRED2.html).

More information: https://www.gams.com/latest/docs/UG_EMP_SP.html
Thank You
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Pre-Conference Workshops

Fred Fiand
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Lutz Westermann
Outline

Part I: An Introduction to GAMS

Part II: Stochastic programming in GAMS

Part III: The GAMS (Object-Oriented) API's

Part IV: Code embedding in GAMS
Excel and GAMS

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</tbody>
</table>

GAMS Directory: \C:\GAMS\win64,24,8.5\n
Working Directory: \c:tmp\n
Solver: CPLEX

SOLVE LP    SOLVE MIP

Hands-On TransXLS
Excel and GAMS

• VBA GAMS API to call GAMS from Excel

• Exchange of input data and results using either GDXXRW or GDX API
Embedding GAMS in your Application

Creating Input for GAMS Model
→ Data handling using GDX API

Callout to GAMS
→ GAMS option settings using Option API
→ Starting GAMS using GAMS API

Reading Solution from GAMS Model
→ Data handling using GDX API
Low level APIs ➔ Object Oriented API

- Low level APIs
  - GDX, OPT, GAMSX, GMO, ...
  - High performance and flexibility
  - Automatically generated imperative APIs for several languages (C, Delphi, Java, Python, C#, ...)

- Object Oriented GAMS API
  - Additional layer on top of the low level APIs
  - Object Oriented
  - Written by hand to meet the specific requirements of different Object Oriented languages
Features of the object oriented API

• No modeling capability! Model is still written in GAMS

• Prepare input data and retrieve results in a convenient way → **GAMSDatabase**

• Control GAMS execution → **GAMSJob**

• Scenario Solving: Feature to solve multiple very similar models in a dynamic and efficient way → **GAMSModelInstance**

• Seamless integration of GAMS into other programming environments

• .NET, C++, Java and Python APIs are part of the current GAMS release available at [www.gams.com](http://www.gams.com). Many examples available:
  • Sequence of Transport examples (Tutorial)
  • Cutstock, Warehouse, Benders Decomposition, ...
using System;
using GAMS;
	namespace TransportSeq {
	
class Transport1 {
		static void Main(string[] args) {
			GAMSWorkspace ws = new GAMSWorkspace();
			GAMSJob t1 = ws.AddJobFromGamsLib("transport");

			t1.Run();
			foreach (GAMSVariableRecord rec in t1.OutDB.GetVariable("x")) {
				Console.WriteLine("x(" + rec.Key(0) + "," + rec.Key(1) + "): ");
				Console.WriteLine(" level=" + rec.Level);
				Console.WriteLine(" marginal=" + rec.Marginal);
			}
		}
	}
}
Seamless **Integration**

- GAMS concept: Separation of tasks
  - Use GAMS for modeling and optimization tasks
  - Programming languages like C# (.NET), C++, Java and Python are well-suited for developing applications
    - Frameworks available for a wide range of specific task:
      - GUI
      - Web development
      - ...
  - The object oriented GAMS API provides a convenient link to run GAMS in such environments
Seamless Integration

- Example: Small Transport Desktop application written in C#
- Convenient data preparation
- Representation of the results in a predefined way
- Modeling details are hidden from the user
Scenario Solving

Solving Transport in a loop with different scenarios for the demand:

\[
\text{Loop}(s, \quad d(i,j) = dd(s,i,j); \\
\text{solve transport using lp minimizing } z; \\
\text{objrep}(s) = \text{transport.objval}; \\
); \\
\]

Scenario Solving – GUSS

set dict / s.scenario.'\n  d.param .dd
  z.level .objrep /
solve transport using lp minimizing z;

- Save model generation and solver setup time
- Hot start (keep the model hot inside the solver and use solver’s best update and restart mechanism)
- Apriori knowledge of all scenario data
- Model rim unchanged from scenario to scenario
foreach (string s in scen) 
{
    f.FirstRecord().Value = v[s];
    modelInstance.Solve();
    objrep[s] = z.FirstRecord().Level;
}

• Save model generation and solver setup time
• Hot start (keep the model hot inside the solver and use solver’s best update and restart mechanism)
• Data exchange between solves possible
• Model rim unchanged from scenario to scenario
**GAMSJob**
- Manages the execution of a GAMS program given by GAMS model source

**GAMSCheckpoint**
- Captures the state of a GAMSJob

**GAMSModelInstance**
- A single mathematical model generated by a GAMS solve statement

**GAMSModifier**
- Marks elements of a GAMSModelInstance to be modifiable
**bmult** is one parameter of the model which gets modified before we solve the instance:

```java
GAMSParameter bmult = mi.SyncDB.AddParameter("bmult", 0, "demand multiplier");
bmult.AddRecord().Value = 1.0;
mi.Instantiate("transport us lp min z", opt, new GAMSModifier(bmult));
double[] bmultlist = new double[] { 0.6, 0.7, 0.8, 0.9, 1.0, 1.1, 1.2, 1.3 };

foreach (double b in bmultlist)
{
    bmult.FirstRecord().Value = b;
    mi.Solve();
    <...>
    Console.WriteLine("Obj: " + mi.SyncDB.GetVariable("z").FindRecord().Level);
}
```
GAMSModelInstance – Example

- Updating bounds of a variable:

```gams
GAMSVariable x = mi.SyncDB.AddVariable("x", 2, VarType.Positive, "");
GAMSParameter xup = mi.SyncDB.AddParameter("xup", 2, "upper bound on x");
mi.Instantiate("transport us lp min z", modifiers: new GAMSModifier(x, UpdateAction.Upper, xup));

foreach (GAMSSetRecord i in t7.OutDB.GetSet("i"))
    foreach (GAMSSetRecord j in t7.OutDB.GetSet("j"))
    {
        xup.Clear();
        xup.AddRecord(i.Keys[0], j.Keys[0]).Value = 0;
        mi.Solve();
        <...>
        Console.WriteLine("Obj: " + mi.SyncDB.GetVariable("z").FindRecord().Level);
    }
```
GAMSModelInstances in Parallel

- Multiple GAMSModelInstances running in parallel with one common data source (work):
Threads consume data from source dynamically instead of getting a fixed amount of data at thread initialization time

Implicit load balancing by architecture:
- Number of solves in a thread depend on its speed
- Keeps all threads busy as long as possible

Typical applications:
- Scenario analysis
- Decomposition algorithms (Benders, CG, ...)

Communication between threads for “dynamic” algorithms
Summary

- Object Oriented API provides an additional abstraction layer of the low level GAMS APIs

- Powerful and convenient link to other programming languages

- Versions for .NET, C++, Java, and Python are available and part of the current distribution

- Many examples are available:
  - Sequence of Transport examples (→ Tutorial)
  - Cutstock, Warehouse, Benders Decomposition, …
Thank You

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24.9.1 Major release *(August 30, 2017)*

Acknowledgments

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GAMS System

- **New feature, the Embedded Code Facility:** This extends the connectivity of GAMS to other programming languages. It allows the use of Python code during compile and execution time. GAMS symbols are shared with the external code, so no communication via disk is necessary.

  The embedded code feature is available on Linux, MacOS X, and Windows. For these platforms, a Python 3.6 installation is included with the GAMS distribution. If the user wants to work with a different Python 3.6, installed separately, for models with embedded code the new command line option `pySetup` needs to be set to 0.

  **Note**

  This feature is currently in beta status. Any feedback to support@gams.com is appreciated.

- **New command line option procDirPath:** Specifies the directory where the process directory should be created.
Motivation – Avoid Unreadable/Slow Code

- GAMS code for parallel assignment and equation definition is compact, elegant, and efficient

- GAMS uses relational data tables as a base data structure
  - No arrays, lists, dictionaries, trees, graphs, ...

- GAMS can represent such traditional data structures but ...
  - GAMS code becomes quickly unreadable

  $t(tt) = t(tt-1); \quad // \text{advances set element } t \text{ to } t+1$

  - Performance with naïve representation is very inefficient

  $t(tt) = \text{ord}(tt)=t\text{Cnt}; \quad // \text{advances set element } t \text{ to } t+1$

  - Writing code that executes efficiently requires deep understanding of underlying GAMS internal data structures and often results in even more unreadable code
Motivation –

Data Input/Transformation at Compile Time

- GAMS data input (ASCII) follows strict syntax
- Practical GAMS models get data (via ASCII input files) that is often not in a proper shape
  - Hence GAMS code is often augmented with execution of scripts and programs to get data files into a GAMS readable shape
  - GAMS even ships a selection of POSIX text utilities (sed, grep, awk, ...) on Windows to support a somewhat standardized way of transforming text files into GAMS readable format
  - Scripts spawned by GAMS cannot (easily) access data that is already available in GAMS
- GAMS has no string editing facilities to e.g.
  - modify labels
  - change content of compile time variables
    - “Solution”: $xxx new and weird compile time constructs, e.g. $setNames, $splitOption, ...
Motivation – Other

- Connecting libraries for special algorithms (e.g. graph algorithms like connected components, matrix operations like Cholesky factorization) to GAMS is not easy
- Current “solution” has issues
  - $unload/$call/$load or execute_unload/execute/execute_load
    - Performance: disk IO + process creation
    - Knowledge of data API (GDX or OO-API)
    - Remapping of relational data (plus concept of UELs) into other data structures
  - Add compile time directives to perform a single special task (e.g. $splitOption)
  - Introduce unreadable option or put_utility syntax to perform a single special task (e.g. option a<b;)
- Object Oriented API/Framework versus Embedded Code
  - OO-API: Framework in control
  - Embedded Code: GAMS in control
Embedded Code

- Support the use of external code during GAMS compile and execution time
- Provide support for off-line debugging of embedded code
- Share GAMS symbols (sets, parameters, variables, and equations) structure and content with the external code in memory
- Communication of the data between GAMS and the embedded code inspired by the existing interface to GDX in many ways:
  - Records access by both labels and label indices
  - Data in GAMS can be merged with or replaced by data from embedded code
  - Data from embedded code can be send to GAMS database filtered or domain checked
- Provide automatically generated, additional source code for common tasks

→ Allows the user to concentrate on the task at hand and not the mechanics
Split Example – Data

Set cc  /  "France - Paris",  "France - Lille",
      "France - Toulouse",
      "Spain - Madrid",  "Spain - Cordoba",
      "Spain - Seville",  "Spain - Bilbao",
      "USA - Washington DC",
      "USA - Houston",  "USA - New York",
      "Germany - Berlin",
      "Germany - Munich",  "Germany - Bonn" /

country / system.empty /

mccCountry(cc,country)

mccCity (cc,city);
Split Example – Embedded Code

$onEmbeddedCode Python:
country = set()
city = set()
mccCountry = []
mccCity = []
for cc in gams.get("cc"):
    r = str.split(cc, " - ", 1)
country.add(r[0])
city.add(r[1])
mccCountry.append((cc,r[0]))
mccCity.append((cc,r[1]))
gams.set("country",list(country))
gams.set("city",list(city))
gams.set("mccCountry",mccCountry)
gams.set("mccCity",mccCity)
$offEmbeddedCode

country city mccCountry mccCity
Split Example – Output

Display country, city;

---- 27 SET country

France, USA, Spain, Germany

---- 27 SET city

Seville, Washington DC, New York, Paris
Munich, Madrid, Toulouse, Berlin
Bonn, Lille, Houston, Bilbao
Cordoba
Sorting Example

Set i / i1*i10 /;
Parameter a(i) Random Data
aIndex(i) Sorted index of a;

a(i) = uniformInt(1, 10*card(i));

embeddedCode Python:
    a = list(gams.get("a"))
    tmp = [r[0] for r in sorted(enumerate(a),
        key=lambda x:x[1][-1])]
    aIndex = len(a)*[-1]
    for idx in range(len(tmp)):
        aIndex[tmp[idx]] = (a[tmp[idx]][0], idx+1)
    gams.set("aIndex",aIndex)
endEmbeddedCode aIndex
Display a, aIndex;

---- 44 PARAMETER a Random Data

1  18.000,  2  85.000,  3  56.000,
4  31.000,  5  30.000,  6  23.000,
7  35.000,  8  86.000,  9   7.000,
10  51.000

---- 44 PARAMETER aIndex Sorted Index of a

1  2.000,  2  9.000,  3  8.000,
4  5.000,  5  4.000,  6  3.000,
7  6.000,  8 10.000,  9  1.000,
10  7.000
Exchange via Files

```python
f = open('i.txt', 'w')
for i in range(int(gams.arguments)):
    f.write('i'+str(i+1)+'
')
f.close()
```

Set i /
$include i.txt /
Display i;

---- 21 SET i

i1,  i2,  i3,  i4,  i5,  
i6,  i7,  i8,  i9,  i10
Exchange via Environment Variables

Set  i   / i1*i5 /;
Parameter b(i) / i1 2, i2 7, i3 59, i4 2, i5 47 /;
Set   k  "from 0 to max(b)" / k0*k? /;

$onEmbeddedCode Python:
    import os
    kmax = int(max([b[1] for b in list(gams.get("b"))]))
    gams.printLog('max value in b is ' + str(kmax))
    os.environ['MAXB'] = str(kmax)
$offEmbeddedCode

$if x%sysEnv.MAXB==x $abort MAXB is not set
Set   k  "from 0 to max(b)" / k0*k%sysEnv.MAXB% /;
Scalar card_k;
card_k = card(k);
Display card_k;

---- 15 PARAMETER card_k = 60.000
$if not %sysEnv.GMSPYTHONMULTINST%==1
$abort.noError Set command line option pyMultInst=1

Set       i       / i1*i3 /;
Parameter h(i)
          ord_i / 0 /;

loop(i,
     ord_i = ord(i);
     embeddedCode Python:
        i = int(list(gams.get("ord_i"))[0])
        gams.printLog(str(i))
     pauseEmbeddedCode
     h(i) = embeddedHandle;
);

loop(i,
     continueEmbeddedCode h(i):
     gams.printLog(str(i))
     endEmbeddedCode
);
Multiple Independent Python Sessions – Log

--- Initialize embedded library embpycclib.dll
--- Execute embedded library embpycclib.dll
--- 1
--- Initialize embedded library embpycclib.dll
--- Execute embedded library embpycclib.dll
--- 2
--- Initialize embedded library embpycclib.dll
--- Execute embedded library embpycclib.dll
--- 3
--- Execute embedded library embpycclib.dll
--- 1
--- Execute embedded library embpycclib.dll
--- 2
--- Execute embedded library embpycclib.dll
--- 3
Performance Considerations

Set  i / i1*i50 /, p(i,i);  Alias (i,ii);
Parameter c(i,i);  c(i,ii) = uniform(-50,50);

Set  iter / 1*100 /;
Scalar tcost, minTCost / +inf /;
loop(iter,
   embeddedCode Python:
        import random
        i = list(gams.get("i"))
        p = list(i)
        random.shuffle(p)
        for idx in range(len(i)):
            p[idx] = (i[idx], p[idx])
        gams.set("p", p)
    endEmbeddedCode
    tcost = sum(p, c(p));
    if (tcost < minTCost, minTCost = tcost);
);
Display minTCost;

EXECUTION TIME = 16.375 SECONDS
Performance Considerations

\textbf{Set} \ i / i1\cdots i50 /, \ p(i,i); \ \textbf{Alias} \ (i,ii);
\textbf{Parameter} \ c(i,i); \ c(i,ii) = \text{uniform}(-50,50);

\texttt{embeddedCode} Python:
   \begin{verbatim}
   import random
   
   Set iter / 1*1000 /;
   Scalar tcost, minTCost / +\infty /;
   loop(iter,
      continueEmbeddedCode:
      i = list(gams.get("i"))
      p = list(i)
      random.shuffle(p)
      for idx in range(len(i)):
         p[idx] = (i[idx], p[idx])
      gams.set("p", p)
      pauseEmbeddedCode p
      tcost = sum(p, c(p));
      if (tcost < minTCost, minTCost = tcost);
   );
   continueEmbeddedCode:
   pass
   endEmbeddedCode
\texttt{Display} \ minTCost;
\end{verbatim}

\textbf{EXECUTION TIME} = 1.797 SECONDS
Performance Considerations

Set \( i / i1*i150 /, \ p(i,i); \) \textbf{Alias} \( (i,ii); \)
Parameter \( c(i,i); \) \( c(i,ii) = \text{uniform}(-50,50); \)

embeddedCode Python:
   import random
   i = list(gams.get("i"))
pauseEmbeddedCode

Set \( \text{iter} / 1*1000 /; \)
Scalar \( \text{tcost}, \ \text{minTCost} / \ +\text{inf} /; \)
loop(\text{iter},
   continueEmbeddedCode Python:
      p = list(i)
      random.shuffle(p)
      for idx in range(len(i)):
         p[idx] = (i[idx], p[idx])
      gams.set("p", p)
pauseEmbeddedCode\text{p}
      tcost = sum(p, c(p));
   if (tcost < minTCost, minTCost = tcost);
); continueEmbeddedCode:
pass
endEmbeddedCode
Display \( \text{minTCost}; \)

EXECUTION TIME \( = \ 1.593 \text{ SECONDS} \)
Performance Considerations

Set \( i / i1*i50 /, \) \( p(i,i); \) **Alias** \( (i,ii); \)
Parameter \( c(i,i); c(i,ii) = \text{uniform}(-50,50); \)

**embeddedCode** Python:
```python
import random
i = list(gams.get("i", keyType=KeyType.INT))
```
**pauseEmbeddedCode**

**Set** \( \text{iter} / 1*1000 /; \)
**Scalar** \( tcost, \text{minTCost} / +\text{inf} /; \)
**loop**(iter,
  **continueEmbeddedCode** Python:
    \( p = \text{list}(i) \)
    random.shuffle(p)
    for idx in range(len(i)):
      \( p[idx] = (i[idx], p[idx]) \)
    gams.set("p", p)
  **pauseEmbeddedCode**
  \( tcost = \sum(p, c(p)); \)
  **if** (tcost < \text{minTCost}, \text{minTCost} = tcost);
)**continueEmbeddedCode:**
  **pass**
**endEmbeddedCode**
**Display** \( \text{minTCost}; \)

**EXECUTION TIME \= 1.437 SECONDS**
Syntax: **GAMS**

Compile Time:

\[
\text{\$onEmbeddedCode}[S|V] \text{ Python: [arguments]}
\]

\[
\text{Python code}
\]

\[
\text{\$offEmbeddedCode} \text{ {output symbol}}
\]

- \$onEmbeddedCode[S] Python: [arguments]
  - Starts a section with Python code
  - Parameter substitution is activated
  - The optional arguments can be accessed in the Python code

- \$onEmbeddedCodeV Python: [arguments]
  - Same as \$onEmbeddedCode but parameter substitution is disabled (the Python code is passed on verbatim)

- \$offEmbeddedCode {output symbol}
  - Ends a section with Python code
  - The optional output symbol(s) get updated in the GAMS database
Syntax: GAMS

Execution Time:

EmbeddedCode[S|V] Python: [arguments]
  Python code
  {Python code}
endEmbeddedCode {output symbol}

• EmbeddedCode[S] Python: [arguments]
  • Starts a section with Python code
  • Parameter substitution is activated
  • The optional arguments can be accessed in the Python code

• EmbeddedCodeV Python: [arguments]
  • Same as EmbeddedCode but parameter substitution is disabled (the Python code is passed on verbatim)

• endEmbeddedCode {output symbol}
  • Ends a section with Python code
  • The optional output symbol(s) get updated in the GAMS database
Syntax: **GAMS**

**Execution Time:**

```plaintext
pauseEmbeddedCode {output symbols}
continueEmbeddedCode[S|V] [handle]: [arguments]
```

- **pauseEmbeddedCode** `{output symbol}`
  - Pauses a section with Python code
  - The optional `output` symbol(s) get updated in the GAMS database

- **continueEmbeddedCode** `[S] [handle]: [arguments]`
  - Continues a previously paused section with Python code
  - Parameter substitution is activated
  - The optional `handle` (pointing to a specific paused embedded code section) could be retrieved by the function `embeddedHandle`. If omitted, the last section paused will be continued.

- **continueEmbeddedCodeV** `[handle]: [arguments]`
  - Same as `continueEmbeddedCode` but parameter substitution is disabled (the Python code is passed on verbatim)
Syntax: Python

The Python Class `ECGamsDatabase` serves as interface between GAMS and Python. An instance of this class is automatically created when an embedded code section is entered and can be accessed using the identifier `gams`. Several methods can be used to interact with GAMS:

- `gams.get(symbolName, [...])`
  - Retrieves iterable object representing the symbol `symbolName`
  - Several optional parameters allow to modify format of the data

- `gams.set(symbolName, data[, merge][, domCheck])`
  - Sets data for the GAMS symbol `symbolName`
  - Data takes a Python list of items representing records of the symbol
  - Optional parameter `merge` specifies if data in a GAMS symbol is merged or replaced
  - Optional parameter `domCheck` specifies if Domain Checking is applied
Syntax: Python

- `gams.getUel(idx)`
  - Returns the label corresponding to the label index `idx`
- `gams.mergeUel(label)`
  - Adds `label` to the GAMS universe if it was unknown and returns the corresponding label index
  - Note: New labels cannot be added at execution time
- `gams.getUelCount()`
  - Returns the number of labels
- `gams.printLog(msg)`
  - Print `msg` to log
- `gams.arguments`
  - Contains the arguments that were passed to the Python interpreter at start-up of the embedded code section
- `gams.epsAsZero`
  - Flag to read GAMS EPS as 0 [True] or as a small number (4.94066E-300) [False]
- `gams._debug`
  - Debug flag for additional output
Some **Examples** of Python Embedded Code

- Splitting of labels (compile time)
- Permutation
- Sorting
- Calculation of quantiles
- Power set
- Matching
- Parsing of specially structured ASCII input
- TSP subtour elimination
- Benders Decomposition using **Message Passing Interface (MPI)** on **High-Performance Computing (HPC)** infrastructure
Plot example

```plaintext
Solve var1 maximize m using nlp;
Hress('con1',p)  = m.1(p);
Hress('mean',p)  = m.1;
Hress('var',p)   = v.1;
Hress('status',p) = var.lmodelstat;
ymax = v.2;

Loop (p,p1,pp)
  v.2(p) = min (v.2(p1) - (card(pp)-1)*ord(p(p))-1),ord(p(p));
  Solve var2 minimizing m using nlp;
  Hress('con1',p)  = m.1(p);
  Hress('mean',p)  = m.1;
  Hress('var',p)   = v.1;
  Hress('status',p) = var.lmodelstat;
end;
Display xres;

Parameter mean(p), var(p);
mean(p) = area('mean',p);
var(p)  = area('var',p);

embeddedCode Python:
plt.plot(gams.get('mean'), keyFormat=KeyFormat.SKIP), \
    gams.get('var'), keyFormat=KeyFormat.SKIP, \
    markersize=10)
plt.ylabel('variance')
plt.xlabel('return')
plt.show()
```

Hands-On meanvarplot
Next steps ...

• More examples
  • High Performance Libraries for specific tasks
    • FORTRAN (Factorization of matrix)
    • C/C++ (Expansion Planning Power Systems)
  • Support of other popular frameworks (compiled and interpreted)
    • C/C++
    • C#/NET, Java, R, ...
    • Connect of powerful libraries e.g. boost::graph, ...

• Provide a configurable build system that supports building the required libraries (for compiled languages) at GAMS compile time
• Provide a documented API to allow integration of individual user embedded code libraries
• Asynchronous/parallel use of embedded code

This feature is currently in beta status. Any feedback to support@gams.com is highly appreciated.
Thank You

Meet us at the GAMS booth!