GAMS

Past, Present, and Future

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GAMS Development Corporation

Workshop on Optimization/Modeling/Applications
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(c) Regional farmer employment accounting rows:

\[-RES + 3 \sum_{d \in r} \sum_{t} dFLq + \sum_{d \in r} \sum_{t} dFLt = 0, \quad \text{each } r\]

\[
\begin{align*}
\text{Regional farmer} & \quad \text{Sum over districts} \\
\text{employment} & \quad \text{and quarters of} \\
\text{activity} & \quad \text{quarterly farmer} \\
& \quad \text{employment} \\
+ \quad \text{Sum over districts} & \quad \text{Sum over districts} \\
& \quad \text{and months of} & \quad \text{and months of} \\
& \quad \text{monthly farmer employment} & \quad \text{monthly farmer employment} \\
= 0
\end{align*}
\]

(d) Total employment accounting row in man-years:

\[-12LMAN + \sum_{t} LMANt = 0\]

\[-12 \left[ \frac{\text{Total employment}}{\text{in man-years}} \right] + \begin{bmatrix} \text{Sum over months of} \\ \text{total employment} \end{bmatrix}_{\text{in man-months}} = 0\]

(e) Total monthly employment accounting rows in man-months:

\[-2.2LMANt + \sum_{d} dDLt + \sum_{d} dFLq + \sum_{d} dFLt = 0, \quad \text{each } t \text{ and } q \text{ such that } t \in q\]

\[-2.2 \left[ \frac{\text{Total}}{\text{employment in month } t} \right] + \begin{bmatrix} \text{Sum over districts of} \\ \text{day labor employment} \end{bmatrix}_{\text{in month } t} \\
+ \begin{bmatrix} \text{Sum over districts of} \\ \text{quarterly farmer employment in the} \\ \text{quarter containing month } t \end{bmatrix} + \begin{bmatrix} \text{Sum over districts of} \\ \text{monthly farmer employment} \end{bmatrix} = 0\]

17 In irrigation districts the quarterly contract device is used for farmers, but in nonirrigated districts farmers are assumed to be available on a monthly basis, so that seasonal migration to irrigated areas may occur.

18 The activities for hiring farmers and day laborers are stated in units of tens of man-days per month for quarters, and there are 22 working days per month; hence the conversion factor of 2.2 is required in the first term of this equation.
## Model Data

### Table 3
Sequence of standard operations for cotton cultivation (days of unskilled labor, machinery services, and draft animal services required per hectare by month)

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**Columns**

- **NAME**: Name of the variable
- **TYPE**: Type of the variable (PL = Positive, NL = Negative)
- **STATUS**: Status of the variable (ACTIVE, LOWER, UPPER)
- **COL ACTIVITY**: Column activity
- **OBJ COEF**: Objective coefficient
- **UPPER**: Upper bound
- **MARGINAL**: Marginal value
PLANNING PROBLEM AND OBJECTIVES INITIALLY OFTEN

UNSTRUCTURED

ILL-DEFINED

CONFLICTING

UNCERTAIN

CHANGING

EMOTIONAL

MATHEMATICAL MODEL USED TO RECOGNIZE AND FORMULATE PROBLEMS, DEFINE ISSUES AND EXPLORE SOLUTION SPACE
RESULT:  - Drain of resources (technical, time, money)
          - Essentially no documentation
MAJOR CONSTRAINTS:

COST

SKILLS

TIME

TOOLS

DOCUMENTATION

TRUST

.
RESULT:  - Limited drain of resources
  - Same representation of models for humans and machines
  - Model representation is also model documentation
DEVELOPMENT OF GAMS

Phase 1 (1978)

- The system can be used to represent and analyze any algebraic model (be it linear or nonlinear)
- The system can perform algebraic manipulations on all data
- The system can generate and solve linear programs automatically
- The system can generate reports on data and solutions via simple 'display' statements
DEVELOPMENT OF GAMS

Phase 2  (1979)

- The system can generate and solve nonlinear programs

- The system will provide links to special-purpose algorithms for econometric problems, network problems, etc.

- Appropriate extensions to the language will be made as the need arises
DEVELOPMENT OF GAMS

Phase 3 (?)

- Automatic structure recognition

- Internal generation of exact point-derivatives

- Improved data-base design with e.g. unit analysis, and links to existing data bases

- Availability of GAMS on different machines

- World-wide availability of the system so that it can be used as a market for testing models and algorithms
Basic Principles

• Separation of model and solution methods
• Models is a data base operator and/or object
• Balanced mix of declarative and procedural approaches
• Computing platform independence
• Multiple model types, solvers and platforms
# Change in Focus

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<th>Application</th>
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<td>• Problem representation is low priority</td>
<td>• Algebraic model representation</td>
<td>• Off-the-shelf graphical user interfaces</td>
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<td>• Large costly projects</td>
<td>• Smaller projects</td>
<td>• Links to other types of models</td>
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<td>• Long development times</td>
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<td>• Users left out</td>
<td>• Machine independence</td>
<td>• Users hardly aware of model</td>
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**Users involved**
Dinner Table Assignment

- ‘Couples” on the same table
- Mix backgrounds and interest (algorithms, applications, World Bank, GAMS staff and family)
- Allow for last minute changes
- Use a model to shed responsibility for ‘poor’ assignments
List of Participants

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Model Definition

Binary variables x(pp,tt) assignment guest to table
        cx(cc,tt) couple assignment
Variable gcnt(g) maximum number of guest of a group at each table
        z objective variable
Equation onep(pp) one table per guest
        onecc(cc) one table per couple
        defcouple(cc,pp,tt) couple mapping
        defmaxg(g,tt) maximum number of guest of a group at each table
        defz balance all groups
        defsize(tt) table size
;
onep(p)..      sum(t, x(p,t)) =e= 1;
onecc(c)..     sum(t, cx(c,t)) =e= 1;
defcouple(cp(c,p),t)..  x(p,t) =e= cx(c,t);
defsize(t)..     sum(p,x(p,t)) =l= 8 + over(t);
defmaxg(g,t)..     sum(gp(g,p), x(p,t)) =l= gcnt(g);
defz..     sum(g$(not xg(g)), card(p)/sum(p,gp(g,p))*gcnt(g)) =e= z;
model seat /all/;
Solve Summary

MODEL STATISTICS

BLOCES OF EQUATIONS  6  SINGLE EQUATIONS  425
BLOCES OF VARIABLES  4  SINGLE VARIABLES  825
NON ZERO ELEMENTS  2795  DISCRETE VARIABLES  819

GENERATION TIME  =  0.030 SECONDS  1.6 Mb  WIN212-136

EXECUTION TIME  =  0.040 SECONDS  1.6 Mb  WIN212-136
DGAMS Rev 136  MS Windows
Seating Model for GAMS Birthday Party
Solution Report  SOLVE seat Using MIP From line 70

SOLVE SUMMARY

MODEL  seat
TYPE  MIP
SOLVER  CPLEX

**** SOLVER STATUS  1 NORMAL COMPLETION
**** MODEL STATUS  1 OPTIMAL
**** OBJECTIVE VALUE  684.0000

RESOURCE USAGE, LIMIT  0.220  1000.000
ITERATION COUNT, LIMIT  237  10000
solve seat min z using mip;

Set rep(tt, pp, g)
Parameter rept;

rep(t, p, g) gp(g, p) = round(x.1(p, t));
rept(t, g) = sum(gp(g, p) rep(t, p, g), 1);
rept('total', g) = sum(t, rept(t, g));
rept(t, 'total') = sum(g, rept(t, g));
rept('total', 'total') = sum((t, g), rept(t, g));

option rep:0:0:1, rept:0:1:1; display rep, rept;

Parameter toxls(pp, g, cc, h);
toxls(p, g, c, h) = bd(p, g, c, h);
toxls(p, g, c, 'TableNo') = sum(rep(tt, p, g), ord(tt));

execute_unload toxls;
execute 'gdxxrw toxls.gdx o=show.xls par=toxls dim=4 rng=e3:m83 merge';
### Group Balance

#### Table

<table>
<thead>
<tr>
<th>S</th>
<th>A</th>
<th>U</th>
<th>G</th>
<th>F</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>t1</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
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<td>t2</td>
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</tr>
<tr>
<td>t4</td>
<td>2</td>
<td>3</td>
<td>1</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>t5</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>2</td>
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<tr>
<td>t6</td>
<td>2</td>
<td>3</td>
<td>1</td>
<td>2</td>
<td>1</td>
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<tr>
<td>t7</td>
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<td>3</td>
<td>1</td>
<td>1</td>
<td>1</td>
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<td>t8</td>
<td>1</td>
<td>3</td>
<td>1</td>
<td>1</td>
<td>2</td>
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<tr>
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<td>3</td>
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<td>2</td>
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</tr>
<tr>
<td>total</td>
<td>20</td>
<td>22</td>
<td>6</td>
<td>10</td>
<td>18</td>
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</table>

**EXECUTION TIME** = 2.694 SECONDS  1.5 Mb  WIN212-136
<table>
<thead>
<tr>
<th>Email</th>
<th>Organization</th>
<th>Group</th>
<th>Couples</th>
<th>Show</th>
<th>Conference</th>
<th>Dinner</th>
<th>GO</th>
<th>BBQ</th>
<th>TableNo</th>
<th>Con</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paragon</td>
<td></td>
<td>S</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carleton University</td>
<td></td>
<td>S</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>ARKI</td>
<td></td>
<td>S</td>
<td></td>
<td></td>
<td></td>
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<td></td>
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<td></td>
</tr>
<tr>
<td>UVW Madison</td>
<td></td>
<td>S</td>
<td>c1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>F</td>
<td>c1</td>
<td>1</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GAMS Software</td>
<td></td>
<td>G</td>
<td>c1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>IRG</td>
<td></td>
<td>A</td>
<td>c2</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hill and Associates</td>
<td></td>
<td>A</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>USDA</td>
<td></td>
<td>A</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stanford</td>
<td></td>
<td>S</td>
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<td></td>
<td></td>
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<td></td>
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<tr>
<td>Hill and Associates</td>
<td></td>
<td>A</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Data Connectivity

• Data Import/Export from *Standard Applications*
  – MS Office, Database, Text files, …

• Capture an *Instance* of a Model Failure
  – Reproducibility of Model/System Bugs
  – Problems: Life Database/different Platforms

• Definition of Data Interface
  – Gams Data eXchange (GDX)
  – Separation of Responsibility for Data and Model
Gams Data eXchange

- Gams Data eXchange (GDX):
  - Complements the ASCII text data input
  - Advantages:
    - Fast exchange of data
    - Syntactical check on data before model starts
    - Compile-time and Run-time Data Exchange
GDX Tools

GDX

- GDX API
- gams
- gdxxrw (MS Office)
- gdxdiff
- gdxmerge
- gdxsplit
- gdxdump

IDE

GDX Viewer
$onecho > dbf2txt.prg
use plt_data
copy to plt_data.txt type delimited fields PLT_CODE3,UTILABBR,;
  MWPLANT,GASMILES,CONGEST,LOCALE,SLUDGEMIL,MINGRIND,MINSULF,;
  HEATRATE,EPALAW_ON,EPAPIPS02,TONS_HG for MWPLANT>1000
$offecho
$call =dbase dbf2txt.prg
$if errorlevel 1 $abort 'Problems with DBASE'

* Process the delimited files from DBASE
$call cat plt_data.txt | cut -d, -f1,3- | sort | uniq > pdata.txt
$call cat plt_data.txt | cut -d, -f1 | sort | uniq > plant.txt

set p Plant Code /
$include plant.txt
/table pdata(p,*)
$ondelim
$include pdata.txt
$offdelim ;
## Data Contract in Excel

<table>
<thead>
<tr>
<th>Type</th>
<th>GAMS Name</th>
<th>Rng</th>
<th>Dim</th>
<th>Rdim</th>
</tr>
</thead>
<tbody>
<tr>
<td>PAR</td>
<td>Cdata</td>
<td>CDATA!A13</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>PAR</td>
<td>CPar</td>
<td>CPAR!A17</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>SSET</td>
<td>I</td>
<td>Exporters</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>SSET</td>
<td>J</td>
<td>Importers</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>SSET</td>
<td>K</td>
<td>Flavors</td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>
Data Contract in Excel – cont.

SETS
I Exporters
J Importers
K Flavors
L Sectors of demand
   / Met Metallurgical
       Thr Thermal /
R Contract type / 1*6 /

Parameter
Cdata (i,k,l,j,r) Contract data for first year
CPar (i,l,r) Contract distribution (fractions)

* Get data from the Excel file
$call gdxrwx ict.xls o=ictin.gdx index=ictparms

* Data include from GDX
$gdxin ictin.gdx
$load I J K Cdata CPar
GAMS/MapInfo

Increase in Ktons Per Year
- Less Than 0
- 0 - 199
- 200-1000
- 1000-3000
### Cadets With Schedule Violations

<table>
<thead>
<tr>
<th>Course</th>
<th>Total Enrollment</th>
<th>Name</th>
<th>SSN</th>
<th>Grad Yr</th>
<th>Reviewed</th>
</tr>
</thead>
<tbody>
<tr>
<td>EM362A</td>
<td></td>
<td></td>
<td></td>
<td>2002</td>
<td></td>
</tr>
<tr>
<td>PH365</td>
<td></td>
<td></td>
<td></td>
<td>2002</td>
<td></td>
</tr>
<tr>
<td>EM362A</td>
<td></td>
<td></td>
<td></td>
<td>2002</td>
<td></td>
</tr>
<tr>
<td>EM301A</td>
<td></td>
<td></td>
<td></td>
<td>2002</td>
<td></td>
</tr>
<tr>
<td>EN302</td>
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<td></td>
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<td>2002</td>
<td></td>
</tr>
<tr>
<td>EM301A</td>
<td></td>
<td></td>
<td></td>
<td>2002</td>
<td></td>
</tr>
<tr>
<td>EM362A</td>
<td></td>
<td></td>
<td></td>
<td>2002</td>
<td></td>
</tr>
<tr>
<td>EM362A</td>
<td></td>
<td></td>
<td></td>
<td>2002</td>
<td></td>
</tr>
</tbody>
</table>

**Cadets: 43**

**Free Hour Constraint Violations**: 43

**Design Group Violations**: 4

**Unbalanced Schedule Violations**: 7

---

**Course Details**

- **Eng Seq Activity Code**: CIVIL ENGINEERING
- **FOS1**: Civil Engineering Major
- **FOS2**: CSEW

**Schedule**

- **A**: PE310
- **B**: MA364
- **C**: PL300
- **D**: PL300
- **E**: EM362A
- **F**: EM362A
- **G**: SS307
- **H**: HI301
- **I**: EM364A
- **J**: EM364A
- **K**: R
- **L**:
Three Examples of GDX

- VEDA: post processing and ad-hoc information restructuring
- LOGMIP: experimental language extensions, algorithmic design studies
- Branch & Cut & Heuristic: automation of complex solver enhancements
The VErsatile Data Analyst (VEDA)

Amit Kanudia, KanORS Consulting Inc.

Gary A. Goldstein, IRG
VEDA Description

- Manages GAMS Sets, Parameters and Model Results for the purpose of dynamic viewing and re-organizing, and presentation to others.
- Allows for cross-cutting access to parameters and results according to index structure and element values.
- Supports construction of user-defined sets, definition of new tables, and manipulation of tables.
- Provides powerful filtering capabilities on both elements names and descriptions.
VEDA Description

• Employs customizable n-dimensional Data Cube component for displaying tables.
• Full-blown graphing facilities, as well as exporting to Excel, Word, PPT, HTML.
• Web-enabled, allowing model results to be made available over the web in user-friendly, reconfigurable tables.
• Convenient GDX2VEDA data definition file for identification of information to be ported from GAMS to VEDA.
### VEDA Table Form – Attribute List

<table>
<thead>
<tr>
<th>Code</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost_LMN</td>
<td>Total Annualized Cost including investment = fix + var + div</td>
</tr>
<tr>
<td>Cost_SP</td>
<td>Price/Supply Cost</td>
</tr>
<tr>
<td>Cost_TRD</td>
<td>Trade Import/Export Cost (based on average price)</td>
</tr>
<tr>
<td>Cost_JMV</td>
<td>Annualized Investment Cost</td>
</tr>
<tr>
<td>Cost_LIC</td>
<td>Lumped Investment Cost</td>
</tr>
<tr>
<td>EQ_0</td>
<td>User Defined Equation</td>
</tr>
<tr>
<td>EQ=combal</td>
<td>Commodity Cash Arrears (-Marginals)</td>
</tr>
<tr>
<td>EQ_0S</td>
<td>Paying Constant Stabil (+ Marginals)</td>
</tr>
<tr>
<td>VNCV</td>
<td>System Energy Intensity (QUAX)</td>
</tr>
<tr>
<td>VNCVbrities</td>
<td>Total discounted System Cost (OUI)</td>
</tr>
<tr>
<td>VAR_ACT</td>
<td>Producer Activity (+ Marginals)</td>
</tr>
<tr>
<td>VAR_GAP</td>
<td>Technology Capacity (+ Marginals)</td>
</tr>
<tr>
<td>VAR_E</td>
<td>Emission</td>
</tr>
<tr>
<td>VAR_FIN</td>
<td>Combustion Consumption</td>
</tr>
<tr>
<td>VAR_TRUST</td>
<td>Combustion Production</td>
</tr>
<tr>
<td>VAR_BV</td>
<td>Technology Investment (+ Marginals)</td>
</tr>
<tr>
<td>VAR_MEG</td>
<td>Elastic Trend + Div</td>
</tr>
<tr>
<td>VAR_PIC</td>
<td>Elastic Primary Con</td>
</tr>
</tbody>
</table>
VEDA Table Form – Sets (Model & User)/Elements
### VEDA Table Form – Search & Select Engine

![VEDA Table Form](image)

**Table Definition**

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Code</td>
<td>Original Description</td>
</tr>
<tr>
<td></td>
<td>CoalMining</td>
</tr>
<tr>
<td></td>
<td>CoalGasification</td>
</tr>
<tr>
<td></td>
<td>CoalFire</td>
</tr>
<tr>
<td></td>
<td>CoalGas</td>
</tr>
<tr>
<td></td>
<td>CoalRip</td>
</tr>
<tr>
<td></td>
<td>CoalRipation</td>
</tr>
<tr>
<td></td>
<td>Coal</td>
</tr>
<tr>
<td></td>
<td>CoalDust</td>
</tr>
<tr>
<td></td>
<td>CoalDustion</td>
</tr>
<tr>
<td></td>
<td>CoalExtractor</td>
</tr>
<tr>
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<td>CoalFire</td>
</tr>
<tr>
<td></td>
<td>CoalGas</td>
</tr>
<tr>
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<td>CoalRipation</td>
</tr>
<tr>
<td></td>
<td>Coal</td>
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<td>CoalFire</td>
</tr>
<tr>
<td></td>
<td>CoalGas</td>
</tr>
<tr>
<td></td>
<td>CoalRipation</td>
</tr>
</tbody>
</table>

**Select Process Element...**

- Include Where:
  - Code Not Like
  - Exact Match
- Exclude Where:
  - Code Not Like
  - Exact Match

**Show Advanced**

- Advanced (OK, Cancel)

**Global Filter Applied For:**
### ProcessSet/Process/Commodity/Scenario

![Image of a software interface showing tables and data for ProcessSet/Process/Commodity/Scenario]
VEDA Cube – Scenario/ProcessSet Totals
VEDA Cube – Analysis Graph
Characterization and Formulation of Disjunctions and their Relaxations

Aldo Vecchietti (*), Sangbum Lee(+) and Ignacio Grossmann(+)
MILP and MINLP formulations are the most accepted by academia and the industry for problems involving discrete decisions.

**Constrained Logic Programming (CLP):**
- general logic constraints, applied mainly for highly combinatoric problems

**Generalized Disjunctive Programming (GDP):**
- disjunctions and logic propositions for discrete choices
\[
\begin{align*}
\min & \quad Z = \sum_k c_k + f(x) + d^T y \\
\text{sujeto a:} & \\
& g(x) \leq 0 \\
& r(x) + Dy \leq 0 \\
& Ay \geq a \\
& \forall \begin{bmatrix} Y_{ik} \\ h_{ik}(x) \leq 0 \\ c_k = \gamma_{ik} \end{bmatrix} \quad i \in D_k, \quad k \in SD \\
& \Omega(Y) = True \\
& x \in R^n, \quad y \in \{0,1\}^q \\
& Y \in \{True, False\}^m, \quad c_k \geq 0
\end{align*}
\]

- $y$ binary variables (0-1)
- $x$ y $c_k$ continuous variables
- $Y_{ik}$ Boolean variables to establish if a disjunction term is true or false
- $f(x)$ objective function (linear or not linear)
- $d^T y$ Linear cost term
- $g(x)$ constraint (linear or not linear) independent of discrete choices
- $r(x) + Dy \leq 0$ mixed integer constraint (linear or not linear)
- $Ay \geq a$ integer constraint
- $\Omega(Y)$ propositional logic relating Boolean variables (disjunction terms)
Big-M Relaxation

**Big-M**

### Linear

\[
F = \bigvee_{i \in D} [a_i^T x \leq b_i] \quad x \in \mathbb{R}^n
\]

\[
a_i^T x \leq b_i + M_i (1 - y_i)
\]

\[
\sum_i y_i = 1
\]

\[
M_i = \max \{ a_i^T x - b_i | x^{lo} \leq x \leq x^{up} \}
\]

### Non Linear

\[
F = \bigvee_{i \in D} [h_i(x) \leq 0] \quad x \in \mathbb{R}^n
\]

\[
h_i(x) \leq M_i (1 - y_i)
\]

\[
\sum_i y_i = 1
\]

\[
M_i = \max \{ h_i(x) | x^{lo} \leq x \leq x^{up} \}
\]

**Beaumont Surrogate**

\[
\sum_i \frac{a_i^T x}{M_i} \leq \sum_i \frac{b_i}{M_i} + N - 1
\]

\[
\sum_i \frac{h_i(x)}{M_i} \leq N - 1
\]
Convex Hull Relaxation

**Linear**

\[ F = \bigvee_{i \in D} a_i^T x \leq b_i \quad x \in \mathbb{R}^n \]

\[ x - \sum_{i \in D} v_i = 0 \quad x, v_i \in \mathbb{R}^n \]

\[ a_i^T v_i - b_i y_i \leq 0 \]

\[ \sum_{i \in D} y_i = 1 \quad 0 \leq y_i \leq 1, \ i \in D \]

\[ 0 \leq v_i \leq v_i^{up} y_i \]

**Non linear**

\[ F = \bigvee_{i \in D} \left[ h_i(x) \leq 0 \right] \quad x \in \mathbb{R}^n \]

\[ x - \sum_{i \in D} v_i = 0 \quad x, v_i \in \mathbb{R}^n \]

\[ y_i h_i(v_i / y_i) \leq 0 \]

\[ \sum_{i \in D} y_i = 1 \quad 0 \leq y_i \leq 1, \ i \in D \]

\[ 0 \leq v^i \leq v_i^{up} y_i \]
Improper disjunction of special interest in Process Engineering

\[
\begin{align*}
\min Z &= (x_1 - 1.1)^2 + (x_2 - 1.1)^2 + c_1 \\
s.t.
& \begin{cases}
Y_1 \\
x_1^2 + x_2^2 \leq 1 \\
c_1 = 1
\end{cases} \lor \begin{cases}
\neg Y_1 \\
x_1 = x_2 = 0 \\
c_1 = 0
\end{cases}
\end{align*}
\]

Both relaxations have the same feasible region
Convex hull

**X – Y Space**

\[
\text{min} Z = (x_1 - 1.1)^2 + (x_2 - 1.1)^2 + y_1
\]

s.t.
\[
x_1^2 + x_2^2 \leq y_1^2
\]
\[
0 \leq x_1 \leq y_1
\]
\[
0 \leq x_2 \leq y_1
\]
\[
0 \leq y_1 \leq 1
\]

Big-M

\[
\text{min} Z = (x_1 - 1.1)^2 + (x_2 - 1.1)^2 + y_1
\]

s.t.
\[
x_1^2 + x_2^2 \leq y_1
\]
\[
0 \leq x_1, x_2 \leq 1; 0 \leq y_1 \leq 1
\]
Two Term Disjunction

\[
\begin{bmatrix}
\text{True} \\
\text{Constraint 1}
\end{bmatrix} \lor \begin{bmatrix}
\text{False} \\
\text{Constraint 2}
\end{bmatrix}
\]

Modeling two terms disjunction

IF (condition\(_1\)) THEN
Constraints to be considered when condition\(_1\) is True
ELSE
Constraints to be considered when condition\(_1\) is False
END IF
N Term Disjunction

\[
\left[ \begin{array}{c}
1 \\
Constraints 1
\end{array} \right] \lor \left[ \begin{array}{c}
2 \\
Constraints 2
\end{array} \right] \lor \ldots \lor \left[ \begin{array}{c}
N \\
Constraints N
\end{array} \right]
\]

IF (condition\(_1\)) THEN

Constraints to be considered when condition\(_1\) is True

ELSIF (condition\(_2\)) THEN

Constraints to be considered when condition\(_1\) is True

ELSIF (condition\(_3\)) THEN

... 

ELSIF (condition\(_N\)) THEN

Constraints to be considered when condition\(_1\) is True

END IF
Example

\[
\begin{align*}
\min & \quad c + 2x_1 + x_2 \\
\begin{bmatrix}
Y_1 \\
-x_1 + x_2 + 2 \leq 0
\end{bmatrix} & \lor \\
\begin{bmatrix}
Y_2 \\
2 - x_2 \leq 0
\end{bmatrix} \\
\begin{bmatrix}
Y_3 \\
x_1 - x_2 \leq 1
\end{bmatrix} & \lor \\
\begin{bmatrix}
\neg Y_3 \\
x_1 = 0
\end{bmatrix}
\end{align*}
\]

\[
Y_1 \land \neg Y_2 \Rightarrow \neg Y_3
\]

\[
\neg (Y_2 \land Y_3)
\]

0 \leq x_1 \leq 5, \ 0 \leq x_2 \leq 5, \ c \geq 0

Y_j \in \{true, false\}, \ j = 1,2,3.
$ontext
BEGIN LOGMIP

IF Y('1') THEN

  EQUAT1;
  EQUAT2;
ELSIF Y('2') THEN

  EQUAT3;
  EQUAT4;
ENDIF;

IF Y('3') THEN

  EQUAT5;
ELSE

  EQUAT6;
ENDIF;

$offtext
END LOGMIP

OPTION MIP=LOGMIPC;
MODEL PEQUE2 /ALL/;
SOLVE PEQUE2 USING MIP MINIMIZING Z;

EQUAT1.. X('2') - X('1') + 2 =L= 0;
EQUAT2.. C =E= 5;
EQUAT3.. 2 - X('2') =L= 0;
EQUAT4.. C =E= 7;
EQUAT5.. X('1') - X('2') =L= 1;
EQUAT6.. X('1') =E= 0;
INT1.. Y('1') + Y('3') =L= 1;
INT2.. Y('2') + (1 - Y('3')) =G= 1;
INT3.. Y('2') + Y('3') =L= 1;
FICT.. SUM(I, Y(I)) =G= 0;
OBJECTIVE.. Z =E= C + 2*X('1') + X('2');
X.UP(J) = 20;
C.UP = 7;
Branch-and-Cut & Heuristics in GAMS for MIP Problems

Hua (Edward) Ni
George Washington University
Branch-and-Cut (B&C)

• B&C is an established algorithm to improve the B&B search.
• Implementation facilities:
  – MIP solver callback functions (CPLEX, XPRESS, …)
  – B&C framework (ABACUS, COIN BCP, …)
• Required Knowledge for B&C
  – IT knowledge (C/C++/JAVA, Solver APIs)
  – Mathematical programming knowledge
  – Application specific knowledge
• Supply GAMS users with an easy access to B&C
Design Principle

GAMS SYSTEM

GAMS Solver Link

MIP Solver (e.g. CPLEX)

B&B Callback

User Cut Generator & Heuristics (e.g. GAMS)
A Steiner Tree Problem

- Berlin52 – from SteinLib
  - 52 nodes (1 source, n′=15 sinks), 1326 edges

- Flow formulation:

\[
\begin{align*}
\min & \sum_{(i,j) \in A} f_{ij} y_{ij}, \text{ s.t. } \sum_{(j,i) \in \delta^{-}(i)} x_{ji} - \sum_{(i,j) \in \delta^{+}(i)} x_{ij} = b_i, 0 \leq x_{ij} \leq n' y_{ij}, y \in \{0,1\} \\
\text{Dicut: } & \sum_{(i,j) \in \delta^{-}(S)} y_{ij} \geq 1 \quad \text{if } S \subseteq V \text{ and } b(S) > 0. \\
\text{Separation: } & \\
\xi = \min \left\{ \sum_{(i,j) \in A} \bar{y}_{ij} z_{j} (1 - z_{i}) : \sum_{i \in V} b_i z_i > 0, z_i \in \{0,1\} \forall i \in V \right\}
\end{align*}
\]
Set nn nodes
    arc(nn,nn) arcs; alias(nn,n,m);
Parameter demand(nn) node demand
    fcost(nn,nn) fixed cost
$gdxin NetInfo.gdx
$load nn demand fcost

Variables ybar(nn,nn) the fractional y solution
    cost
binary variables z(nn);
Equations Obj objective
    SC positive demand over the node block;
Obj.. sum(arc(m,n), ybar.l(m,n)*z(n)*(1-z(m))) =e= cost;
SC.. sum(n, demand(n)*z(n)) =g= 1;

Model Dicut /Obj, SC/;
execute_load 'CutCBSol.gdx' ybar=y;
arc(m,n)$fcost(m,n) = yes;
Solve Dicut mini cost using MINLP;
Cut Generator in GAMS II

```gams
arc(m,n)$fcost(m,n) = yes;
Solve Dicut mini cost using MINLP;

Set S(nn) Nodes in the node block: S(n) = round(z.l(n));
Set cc number of cuts generated / 1 /;

Parameter CC_y(cc,nn,nn) coefficient of the y variables in the cut
cut rhs
currence (cc) the sense of the cuts
NUMCUTS /1/;

if(cost.l>=1, NUMCUTS = 0;
else CSENSE(cc) = 3;
CRHS(cc) = 1;
CC_y(cc,arc(m,n)) = not S(m) and S(n);
);

execute_unload 'CutCBCuts.gdx' NUMCUTS, CRHS, CSENSE, CC_y;
```
Computational Results

• Overhead
  – Time spent within the callback functions minus MIP computation on cuts and heuristics.
  – 20% ~ 25%

• Performance Improvements (B&C vs. regular GAMS/CPLEX)
  – Steiner: 6 hours vs. 2+ days (unsolvable)
  – Pipeline Design: 20 minutes vs. 450 minutes
Convergence – Steiner Tree

![Graph showing convergence over computation time for different methods: B&C&Dual, B&C&H_Dual, B&C&H_Primal, B&C_Primal, CPLEX_Dual, CPLEX_Primal.](image)
Convergence – Pipeline Design

![Graph showing computation time vs. seconds for different algorithms.]

- B&C&H_Dual
- B&C&H_Primal
- CPLEX_Dual
- CPLEX_Primal
- B&C_Dual
- B&C_Primal

The graph shows the computation time (in seconds) for different algorithms over a range of 1800 seconds.
What is a Model?

• List of Equations
  – Mathematical Programming (MP) Model
• Collection of several intertwined (MP) Models
  – Data Preparation and Calibration
  – “Solution” Module
  – Reporting Module
• Categorization of Models by answering:
  – Who is the User of a Model?
Who is the *User* of a Model?

- (Academic) Researcher
  - One time use (Research Paper)
- Domain&Model Expert
  - Model Results used for Consulting
- Black Box User
  - Model integrated in (Optimization) Application
- Each Category has its own needs
  - Development & Deployment
Research Models

- 95% of Model Source is (Equation) Algebra
- Declarative Modeling
- Set of (Benchmark) Problem Instances
- Modeling Language Differences: Few
- *Taste* (Syntax, Development Environment, …)
- Platform, Model Type, *Solver*
<table>
<thead>
<tr>
<th><strong>Solver</strong></th>
<th><strong>Description</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>BARON</strong></td>
<td>Branch-And-Reduce Optimization Navigator for proven global solutions from The Optimization Firm</td>
</tr>
<tr>
<td><strong>BDMLP</strong></td>
<td>LP solver that comes with any GAMS system</td>
</tr>
<tr>
<td><strong>CONOPT</strong></td>
<td>Large scale NLP solver from ARKI Consulting and Development</td>
</tr>
<tr>
<td><strong>CPLEX</strong></td>
<td>High-performance LP/MIP solver from Ilog</td>
</tr>
<tr>
<td><strong>DECIS</strong></td>
<td>Large scale stochastic programming solver from Stanford University</td>
</tr>
<tr>
<td><strong>DICOPT</strong></td>
<td>Framework for solving MINLP models. Needs both an NLP solver and a MIP solver. From Carnegie Mellon University</td>
</tr>
<tr>
<td><strong>LGO</strong></td>
<td>Lipschitz global optimizer from Finner Consulting Services</td>
</tr>
<tr>
<td><strong>MILES</strong></td>
<td>MCP solver from University of Colorado at Boulder that comes with any GAMS system</td>
</tr>
<tr>
<td><strong>MINOS</strong></td>
<td>NLP solver from Stanford University</td>
</tr>
<tr>
<td><strong>MOSEK</strong></td>
<td>Large scale LP/MIP plus conic and convex non-linear programming system from EKA Consulting</td>
</tr>
<tr>
<td><strong>MPSGE</strong></td>
<td>Modeling Environment for CGE models from University of Colorado at Boulder</td>
</tr>
<tr>
<td><strong>OQNLP</strong></td>
<td>Multi-start method for global optimization from Optimal Methods Inc.</td>
</tr>
<tr>
<td><strong>NLPEC</strong></td>
<td>MPEC to NLP translator that uses other GAMS NLP solvers</td>
</tr>
<tr>
<td><strong>OSL</strong></td>
<td>High performance LP/MIP solver from IBM</td>
</tr>
<tr>
<td><strong>OSLSE</strong></td>
<td>OSL Stochastic Extension for solving stochastic models</td>
</tr>
<tr>
<td><strong>PATH</strong></td>
<td>Large scale MCP solver from University of Wisconsin at Madison</td>
</tr>
<tr>
<td><strong>PATHNLP</strong></td>
<td>Large scale NLP solver for convex problems from University of Wisconsin at Madison</td>
</tr>
<tr>
<td><strong>SBB</strong></td>
<td>Branch-and-Bound algorithm from ARKI Consulting and Development for solving MINLP models, requires an NLP solver</td>
</tr>
<tr>
<td><strong>SNOPT</strong></td>
<td>Large scale SQP based NLP solver from Stanford University</td>
</tr>
<tr>
<td><strong>XA</strong></td>
<td>Large scale LP/MIP system from Sunset Software</td>
</tr>
<tr>
<td><strong>XPRESS</strong></td>
<td>High performance LP/MIP solver from Dash</td>
</tr>
</tbody>
</table>
Available Solvers

- Growing number of MP Solvers (often out of Academic Labs)
- NEOS: >40 Solvers
- Impractical to have Interface to all Modeling Languages
- “Solution”: Model Translation

- Multi-solvers
- Semi-infinite Optimization
- Mixed Integer Nonlinearly Constrained Optimization
- Mixed Integer Linear Programming
- Nonlinearly Constrained Optimization
- Semidefinite & Second Order Cone Programming
- Linear Programming
- Bound Constrained Optimization
- Unconstrained Optimization
- Linear Network Optimization
- Complementarity Problems
- Nondifferentiable Optimization
- Stochastic Linear Programming
- Global Optimization
- Application-specific Optimization
- Miscellaneous
- Administration
Instructions

In order to use the GMS2XX translation service which is based on the "solver" GAMS/CONVERT you have to attach your model to an email and send it to our translation server at gms2xx@gamsworld.org. You specify the language in the subject line, for example

Subject: GAMS

At the moment we support the following languages:

- AMPL
- BARON
- CplexLP
- CplexMPS
- GAMS
- LGO
- LINGO
- MINOPT
- ALL (this creates scalar versions of all supported languages, listed above)
Consulting Models

- *Model* is Tool for Problem Analysis
- 10% of Model Source is (Equation) Algebra
- User: Domain & Modeling Expert (not necessary the same person)
- *Living* Model (changes with the problem)
  - Lifecycle: At least 10 years
  - Technology Change (Platform, Solver, …)
Hill and Associates, Inc.
Electric Generation, Coal and Emissions Forecasting System

National Power Model™
- Dispatch Economics
- 90+ Control Areas
- Seasonal/TOD Prices, Flow & Gen.

Demand Model
- GDP
- Weather
- Electric Intensity

Regional Emission Limits
- SO2, CO2, NOx

Transmission
- Bi-Directional Simultaneous Flows
- Seasonal Limits
- Time-of-Day Rates

Coal Marginal Cost Models
- Demand
- Industrial
- Commercial
- Residential

International Coal Trade Model

Utility Fuel Economics Model
- Fuel Switching
- Clean-up Equip Choices
- Allowance Trading

Plant/Area by TOD
- Generation
- Power Flows
- Marginal Prices
- Emissions

Coal Plant Costs & Emissions Forecast

Coal Plant Energy Demand

Seasonal Dispatch Costs, Emission Rates

Generation Database (all units)
- New Build
- Gas & Oil Forecast

Generation Cost Supply Models
- Unit Info
- Transp. Rates
- Compliance Costs

Coal Supply Curves
- Cash Cost by Mine
- All Regions
- By Coal Type

Demand Database (coal units)

Generation Compliance Models
- SO2
- NOx
- Particulates

Strategies for
Modeling System Requirements

- *Survive* in such a diverse Environment
- Compatibility
  - 15 year application lifecycle
- Data Connectivity/Exchange
  - Programs *and* People
- Support for Analysis/Reporting
  - Modeling System Tools and external Program
Black Box Model

• *Innocent User*

• Bulletproof Optimization Application
  – No *failures*: e.g. No Infeasible Models

• Model embedded in larger System:
  • Optimization
  • Takes Longer than one is willing to wait
  • It will eventually fail

• Application
  • Real Time
  • Always need a *Solution* to Problem
Scheduling US Military Academy West Point

“… each student’s daily activities are a carefully regimented balance of academic, military, and physical requirements.”
Modeling System Requirements

- Reliable System
- Using Third Party Software (Solver)
  - Keep Resource Usage of Solver in check
  - Solver will eventually crash
- Possibility to Implement Simple Heuristics
- Platform Choice
- Less important: Data Import/Export
  - IT does not want Modeling System to *mess* with DB
  - Simple/Thin Interfaces (text files, XML)
Future Directions

• Value Added Applications
• Solution Service Providers
• Distributed System Architectures
• New Solution Approaches
• Continued Changes in the Modeling ‘Industry’