GAMS — A User's Guide

Tutorial by Richard E. Rosenthal

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Introduction

1.1 Motivation

Substantial progress was made in the 1950s and 1960s with the development of algorithms and computer codes to solve large mathematical programming problems. The number of applications of these tools in the 1970s was less then expected, however, because the solution procedures formed only a small part of the overall modeling effort. A large part of the time required to develop a model involved data preparation and transformation and report preparation. Each model required many hours of analyst and programming time to organize the data and write the programs that would transform the data into the form required by the mathematical programming optimizers. Furthermore, it was difficult to detect and eliminate errors because the programs that performed the data operations were only accessible to the specialist who wrote them and not to the analysts in charge of the project.

GAMS was developed to improve on this situation by:

- ➢ Providing a high-level language for the compact representation of large and complex models
- ➢ Allowing changes to be made in model specifications simply and safely
- ➢ Allowing unambiguous statements of algebraic relationships
- ➢ Permitting model descriptions that are independent of solution algorithms

1.2 Basic Features of GAMS

1.2.1 General Principles

The design of GAMS has incorporated ideas drawn from relational database theory and mathematical programming and has attempted to merge these ideas to suit the needs of strategic modelers. Relational database theory provides a structured framework for developing general data organization and transformation capabilities. Mathematical programming provides a way of describing a problem and a variety of methods for solving it. The following principles were used in designing the system:

1. All existing algorithmic methods should be available without changing the user's model representation. Introduction of new methods, or of new implementations of existing methods, should be possible without requiring changes in existing models. Linear, nonlinear, mixed integer, mixed integer nonlinear optimizations and mixed complementarity problems can currently be accommodated.

2. The optimization problem should be expressible independently of the data it uses. This separation of logic and data allows a problem to be increased in size without causing an increase in the complexity of the representation.

3. The use of the relational data model requires that the allocation of computer resources be automated. This means that large and complex models can be constructed without the user having to worry about details such as array sizes and scratch storage.

1.2.2 Documentation

The GAMS model representation is in a form that can be easily read by people and by computers. This means that the GAMS program itself is the documentation of the model, and that the separate description required in the past (which was a burden to maintain, and which was seldom up-to-date) is no longer needed. Moreover, the design of GAMS incorporates the following features that specifically address the user's documentation needs:

- ➢ A GAMS model representation is concise, and makes full use of the elegance of the mathematical representation.
- ➢ All data transformations are specified concisely and algebraically. This means that all data can be entered in their most elemental form and that all transformations made in constructing the model and in reporting are available for inspection.
- ➢ Explanatory text can be made part of the definition of all symbols and is reproduced whenever associated values are displayed.
- ➢ All information needed to understand the model is in one document.

Of course some discipline is needed to take full advantage of these design features, but the aim is to make models more accessible, more understandable, more verifiable, and hence more credible.

1.2.3 Portability

The GAMS system is designed so that models can be solved on different types of computers with no change. A model developed on a small personal computer can later be solved on a large mainframe. One person can develop a model that is later used by others, who may be physically distant from the original developer. In contrast to previous approaches, only one document need be moved — the GAMS statement of the model. It contains all the data and logical specifications needed to solve the model.

1.2.4 User Interface

Portability concerns also have implications for the user interface. The basic GAMS system is file-oriented, and no special editor or graphical input and output routines exist. Rather than burden the user with having to learn yet another set of editing commands, GAMS offers an open architecture in which each user can use his word processor or editor of choice. This basic user interface facilitates the integration of GAMS with a variety of existing and future user environments.

1.2.5 Model Library

When architects begin to design a new building, they develop the new structure by using ideas and techniques that have been tested in previous structures. The same is true in other fields: design elements from previous projects serve as sources of ideas for new developments.

From the early stages of the development of GAMS we have collected models to be used in a library of examples. Many of these are standard textbook examples and can be used in classes on problem formulation or to illustrate points about GAMS. Others are models that have been used in policy or sector analysis and are interesting for both the methods and the data they use. All the substantive models in the library are described in the open literature. A collection of models is now included with all GAMS systems, along with a database to help users locate examples that cover countries, sectors, or topics of interest to them.

The syntax used to introduce features in the various chapters are presented using the Backus-Naur form (BNF) notation where:

`[]`	denotes that the enclosed construct is optional,
`{}`	denotes that the enclosed construct may be repeated zero or more times, and
`|`	denotes that there is an *or* operator across the arguments on both sides of the symbol.

1.3 Organization of the Book

Some introductions to software systems are like reference manuals: they describe each command in detail. Others take you step by step through a small number of examples. This book uses elements of both approaches. The text is divided into three parts. The first part (Chapters 1 and 2) is introductory. Chapter 2 is a self-contained tutorial that guides you through a single example, a small transportation model, in some detail: you can quickly investigate the flavor of GAMS by reading it.

The second part (Chapters 3 to 17) comprises the meat of the book. The components of the GAMS language are introduced 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, [TRNSPORT]). Some specialized material has deliberately been omitted in this process because the primary aim is to make GAMS accessible to the widest possible audience, especially those without extensive experience with computers or mathematical programming systems. Some familiarity with quantitative methods and mathematical representations is assumed.

The third part consists of specialized discussions of advanced topics and can be studied as needed. Users with large, complex, or expensive models will find much useful material in this part.

2

A GAMS Tutorial by Richard E. Rosenthal

2.1 Introduction

The introductory part of this book ends with a detailed example of the use of GAMS for formulating, solving, and analyzing a small and simple optimization problem. Richard E. Rosenthal of the Naval Postgraduate School in Monterey, California wrote it. The example is a quick but complete overview of GAMS and its features. Many references are made to other parts of the book, but they are only to tell you where to look for more details; the material here can be read profitably without reference to the rest of the book.

The example is an instance of the transportation problem of linear programming, which has historically served as a '*laboratory animal*' in the development of optimization technology. [See, for example, Dantzig (1963)[1].] It is a good choice for illustrating the power of algebraic modeling languages like GAMS because the transportation problem, no matter how large the instance at hand, possesses a simple, exploitable algebraic structure. You will see that almost all of the statements in the GAMS input file we are about to present would remain unchanged if a much larger transportation problem were considered.

In the familiar transportation problem, we are given the supplies at several plants and the demands at several markets for a single commodity, and we are given the unit costs of shipping the commodity from plants to markets. The economic question is: how much shipment should there be between each plant and each market so as to minimize total transport cost?

The algebraic representation of this problem is usually presented in a format similar to the following.

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 (\$/case)

Decision Variables:
  x_{ij} = amount of commodity to ship from plant i to market j (cases),
  where $x_{ij} \geq 0$, for all i, j

Constraints:

Observe supply limit at plant i:	$\sum_j x_{ij} \leq a_j$	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)

Note that this simple example reveals some modeling practices that we regard as good habits in general and that are consistent with the design of GAMS. First, all the entities of the model are identified (and grouped) by type. Second, the ordering of entities is chosen so that no symbol is referred to before it is defined. Third, the

[1]Dantzig, George B. (1963). *Linear Programming and Extensions*, Princeton University Press, Princeton N.J.

units of all entities are specified, and, fourth, the units are chosen to a scale such that the numerical values to be encountered by the optimizer have relatively small absolute orders of magnitude. (The symbol $K here means thousands of dollars.)

The names of the types of entities may differ among modelers. For example, economists use the terms *exogenous variable* and *endogenous variable* for *given data* and *decision variable*, respectively. In GAMS, the terminology adopted is as follows: indices are called `sets`, given data are called `parameters`, decision variables are called `variables`, and constraints and the objective function are called `equations`.

The GAMS representation of the transportation problem closely resembles the algebraic representation above. The most important difference, however, is that the GAMS version can be read and processed by the computer.

Plants	*Shipping Distances to Markets (1000 miles)*			*Supplies*
	New York	Chicago	Topeka	
Seattle	2.5	1.7	1.8	350
San Diego	2.5	1.8	1.4	600
Demands	325	300	275	

Table 2.1: Data for the transportation problem (adapted from Dantzig, 1963)

As an instance of the transportation problem, suppose there are two canning plants and three markets, with the data given in table 2.1. Shipping distances are in thousands of miles, and shipping costs are assumed to be $90.00 per case per thousand miles. The GAMS representation of this problem is as follows:

```
Sets
     i   canning plants   / seattle, san-diego /
     j   markets          / new-york, chicago, topeka / ;

Parameters

     a(i)  capacity of plant i in cases
       /    seattle     350
            san-diego   600  /

     b(j)  demand at market j in cases
       /    new-york    325
            chicago     300
            topeka      275  / ;

Table d(i,j)  distance in thousands of miles
                  new-york       chicago      topeka
    seattle          2.5           1.7          1.8
    san-diego        2.5           1.8          1.4  ;

Scalar f  freight in dollars per case per thousand miles  /90/ ;

Parameter c(i,j)  transport cost in thousands of dollars per case ;

          c(i,j) = f * d(i,j) / 1000 ;

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/ ;

Solve transport using lp minimizing z ;

Display x.l, x.m ;
```

If you submit a file containing the statements above as input to the GAMS program, the transportation model will be formulated and solved. Details vary on how to invoke GAMS on different of computers, but the simplest (’*no frills*’) way to call GAMS is to enter the word GAMS followed by the input file’s name. You will see a number of terse lines describing the progress GAMS is making, including the name of the file onto which the output is being written. When GAMS has finished, examine this file, and if all has gone well the optimal shipments will be displayed at the bottom as follows.

```
             new-york     chicago      topeka
seattle        50.000     300.000
san-diego     275.000                 275.000
```

You will also receive the marginal costs (simplex multipliers) below.

```
              chicago      topeka
seattle                     0.036
san-diego       0.009
```

These results indicate, for example, that it is optimal to send nothing from Seattle to Topeka, but if you insist on sending one case it will add .036 $K (or $36.00) to the optimal cost. (Can you prove that this figure is correct from the optimal shipments and the given data?)

2.2 Structure of a GAMS Model

For the remainder of the tutorial, we will discuss the basic components of a GAMS model, with reference to the example above. The basic components are listed in table 2.2.

There are optional input components, such as edit checks for bad data and requests for customized reports of results. Other optional advanced features include saving and restoring old models, and creating multiple models in a single run, but this tutorial will discuss only the basic components.

Before treating the individual components, we give a few general remarks.

1. A GAMS model is a collection of statements in the GAMS Language. The only rule governing the ordering of statements is that an entity of the model cannot be referenced before it is declared to exist.

2. GAMS statements may be laid out typographically in almost any style that is appealing to the user. Multiple lines per statement, embedded blank lines, and multiple statements per line are allowed. You will get a good idea of what is allowed from the examples in this tutorial, but precise rules of the road are given in the next Chapter.

3. When you are a beginning GAMS user, you should terminate every statement with a semicolon, as in our examples. The GAMS compiler does not distinguish between upper-and lowercase letters, so you are free to use either.

4. Documentation is crucial to the usefulness of mathematical models. It is more useful (and most likely to be accurate) if it is embedded within the model itself rather than written up separately. There are at least two ways to insert documentation within a GAMS model. First, any line that starts with an asterisk in column 1 is disregarded as a comment line by the GAMS compiler. Second, perhaps more important, documentary text can be inserted within specific GAMS statements. All the lowercase words in the transportation model are examples of the second form of documentation.

Inputs:	Outputs:
• `Sets` Declaration Assignment of members	• Echo Print
• Data (`Parameters, Tables, Scalars`) Declaration Assignment of values	• Reference Maps
• `Variables` Declaration Assignment of type	• Equation Listings
• Assignment of bounds and/or initial values (optional)	• Status Reports
• `Equations` Declaration Definition	• Results
• `Model` and `Solve` statements	
• `Display` statement (optional)	

Table 2.2: The basic components of a GAMS model

5. As you can see from the list of input components above, the creation of GAMS entities involves two steps: a declaration and an assignment or definition. *Declaration* means declaring the existence of something and giving it a name. *Assignment* or *definition* means giving something a specific value or form. In the case of equations, you must make the declaration and definition in separate GAMS statements. For all other GAMS entities, however, you have the option of making declarations and assignments in the same statement or separately.

6. The names given to the entities of the model must start with a letter and can be followed by up to thirty more letters or digits.

2.3 Sets

Sets are the basic building blocks of a GAMS model, corresponding exactly to the indices in the algebraic representations of models. The Transportation example above contains just one `Set` statement:

```
Sets
     i   canning plants   / seattle, san-diego /
     j   markets          / new-york, chicago, topeka / ;
```

The effect of this statement is probably self-evident. We declared two sets and gave them the names `i` and `j`. We also assigned members to the sets as follows:

i = {Seattle, San Diego}
j = {New York, Chicago, Topeka}.

You should note the typographical differences between the GAMS format and the usual mathematical format for listing the elements of a set. GAMS uses slashes '/' rather than curly braces '{}' to delineate the set simply because not all computer keyboards have keys for curly braces. Note also that multiword names like 'New York' are not allowed, so hyphens are inserted.

The lowercase words in the `sets` statement above are called *text*. Text is optional. It is there only for internal documentation, serving no formal purpose in the model. The GAMS compiler makes no attempt to interpret the text, but it saves the text and '*parrots*' it back to you at various times for your convenience.

It was not necessary to combine the creation of sets i and j in one statement. We could have put them into separate statements as follows:

```
Set    i   canning plants   / seattle, san-diego / ;
Set    j   markets          / new-york, chicago, topeka / ;
```

The placement of blank spaces and lines (as well as the choice of upper- or lowercase) is up to you. Each GAMS user tends to develop individual stylistic conventions. (The use of the singular `set` is also up to you. Using `set` in a statement that makes a single declaration and `sets` in one that makes several is good English, but GAMS treats the singular and plural synonymously.)

A convenient feature to use when you are assigning members to a set is the asterisk. It applies to cases when the elements follow a sequence. For example, the following are valid `set` statements in GAMS.

```
Set    t   time periods         /1991*2000/;
Set    m   machines             /mach1*mach24/;
```

Here the effect is to assign

$t \quad = \quad \{1991,1992,1993, \ldots\ldots, 2000\}$

$m \quad = \quad \{\text{mach}_1, \text{mach}_2, \ldots\ldots, \text{mach}_{24}\}$.

Note that set elements are stored as character strings, so the elements of t are not numbers.

Another convenient feature is the `alias` statement, which is used to give another name to a previously declared set. In the following example:

```
Alias (t,tp);
```

the name `tp` is like a t' in mathematical notation. It is useful in models that are concerned with the interactions of elements within the same set.

The sets `i`, `j`, `t`, and `m` in the statements above are examples of static sets, i.e., they are assigned their members directly by the user and do not change. GAMS has several capabilities for creating dynamic sets, which acquire their members through the execution of set-theoretic and logical operations. Dynamic sets are discussed in Chapter 12, page113. Another valuable advanced feature is multidimensional sets, which are discussed in Section 4.5, page 39.

2.4 Data

The GAMS model of the transportation problem demonstrates all of the three fundamentally different formats that are allowable for entering data. The three formats are:

- Lists
- Tables
- Direct assignments

The next three sub-sections will discuss each of these formats in turn.

2.4.1 Data Entry by Lists

The first format is illustrated by the first Parameters statement of the example, which is repeated below.

```
Parameters

     a(i)  capacity of plant i in cases
       /    seattle     350
            san-diego   600  /

     b(j)  demand at market j in cases
       /    new-york    325
            chicago     300
            topeka      275  / ;
```

This statement has several effects. Again, they may be self-evident, but it is worthwhile to analyze them in detail. The statement declares the existence of two parameters, gives them the names `a` and `b`, and declares their *domains* to be `i` and `j`, respectively. (A domain is the set, or tuple of sets, over which a parameter, variable, or equation is defined.) The statement also gives documentary text for each parameter and assigns values of `a(i)` and `b(j)` for each element of `i` and `j`. It is perfectly acceptable to break this one statement into two, if you prefer, as follows.

```
Parameters a(i)  capacity of plant i in cases
     / seattle     350
       san-diego   600  / ;

Parameters b(j)  demand at market j in cases
    / new-york    325
      chicago     300
      topeka      275  / ;
```

Here are some points to remember when using the list format.

1. The list of domain elements and their respective parameter values can be laid out in almost any way you like. The only rules are that the entire list must be enclosed in slashes and that the element-value pairs must be separated by commas or entered on separate lines.

2. There is no semicolon separating the element-value list from the name, domain, and text that precede it. This is because the same statement is being used for declaration and assignment when you use the list format. (An element-value list by itself is not interpretable by GAMS and will result in an error message.)

3. The GAMS compiler has an unusual feature called *domain checking*, which verifies that each domain element in the list is in fact a member of the appropriate set. For example, if you were to spell 'Seattle' correctly in the statement declaring `Set i` but misspell it as 'Seatle' in a subsequent element-value list, the GAMS compiler would give you an error message that the element 'Seatle' does not belong to the set `i`.

4. Zero is the default value for all parameters. Therefore, you only need to include the nonzero entries in the element-value list, and these can be entered in any order .

5. A scalar is regarded as a parameter that has no domain. It can be declared and assigned with a `Scalar` statement containing a *degenerate* list of only one value, as in the following statement from the transportation model.

   ```
   Scalar f freight in dollars per case per thousand miles /90/;
   ```

If a parameter's domain has two or more dimensions, it can still have its values entered by the list format. This is very useful for entering arrays that are sparse (having few non-zeros) and super-sparse (having few distinct non-zeros).

2.4.2 Data Entry by Tables

Optimization practitioners have noticed for some time that many of the input data for a large model are derived from relatively small tables of numbers. Thus, it is very useful to have the table format for data entry. An example of a two-dimensional table (or matrix) is provided the transportation model:

```
Table d(i,j)  distance in thousands of miles
                  new-york       chicago      topeka
    seattle          2.5           1.7          1.8
    san-diego        2.5           1.8          1.4  ;
```

The effect of this statement is to declare the parameter `d` and to specify its domain as the set of ordered pairs in the Cartesian product of `i` and `j`. The values of `d` are also given in this statement under the appropriate heading. If there are blank entries in the table, they are interpreted as zeroes.

As in the list format, GAMS will perform domain checking to make sure that the row and column names of the table are members of the appropriate sets. Formats for entering tables with more columns than you can fit on one line and for entering tables with more than two dimensions are given in Chapter 5, page 43.

2.4.3 Data Entry by Direct Assignment

The direct assignment method of data entry differs from the list and table methods in that it divides the tasks of parameter declaration and parameter assignment between separate statements. The transportation model contains the following example of this method.

```
Parameter c(i,j)  transport cost in thousands of dollars per case ;
          c(i,j) = f * d(i,j) / 1000 ;
```

It is important to emphasize the presence of the semicolon at the end of the first line. Without it, the GAMS compiler would attempt to interpret both lines as parts of the same statement. (GAMS would fail to discern a valid interpretation, so it would send you a terse but helpful error message.)

The effects of the first statement above are to declare the parameter `c`, to specify the domain `(i,j)`, and to provide some documentary text. The second statement assigns to `c(i,j)` the product of the values of the parameters `f` and `d(i,j)`. Naturally, this is legal in GAMS only if you have already assigned values to `f` and `d(i,j)` in previous statements.

The direct assignment above applies to all `(i,j)` pairs in the domain of `c`. If you wish to make assignments for specific elements in the domain, you enclose the element names in quotes. For example,

```
c('Seattle','New-York')  = 0.40;
```

is a valid GAMS assignment statement.

The same parameter can be assigned a value more than once. Each assignment statement takes effect immediately and overrides any previous values. (In contrast, the same parameter may not be declared more than once. This is a GAMS error check to keep you from accidentally using the same name for two different things.)

The right-hand side of an assignment statement can contain a great variety of mathematical expressions and built-in functions. If you are familiar with a scientific programming language such as FORTRAN or C, you will have no trouble in becoming comfortable writing assignment statements in GAMS. (Notice, however, that GAMS has some efficiencies shared by neither FORTRAN nor C. For example, we were able to assign `c(i,j)` values for all `(i,j)` pairs without constructing '*do loops*'.)

The GAMS standard operations and supplied functions are given later. Here are some examples of valid assignments. In all cases, assume the left-hand-side parameter has already been declared and the right-hand-side parameters have already been assigned values in previous statements.

```
csquared       = sqr(c);
```

```
e              = m*csquared;
w              = l/lamda;
eoq(i)         = sqrt( 2*demand(i)*ordcost(i)/holdcost(i));
t(i)           = min(p(i), q(i)/r(i), log(s(i)));
euclidean(i,j) = qrt(sqr(xi(i) - xi(j) + sqr(x2(i) - x2(j)));
present(j)     = future(j)*exp(-interest*time(j));
```

The summation and product operators to be introduced later can also be used in direct assignments.

2.5 Variables

The decision variables (or endogenous variables) of a GAMS-expressed model must be declared with a `Variables` statement. Each variable is given a name, a domain if appropriate, and (optionally) text. The transportation model contains the following example of a `Variables` statement.

```
Variables
    x(i,j)  shipment quantities in cases
    z       total transportation costs in thousands of dollars ;
```

This statement results in the declaration of a shipment variable for each `(i,j)` pair. (You will see in Chapter 8, page 71, how GAMS can handle the typical real-world situation in which only a subset of the `(i,j)` pairs is allowable for shipment.)

The `z` variable is declared without a domain because it is a scalar quantity. Every GAMS optimization model must contain one such variable to serve as the quantity to be minimized or maximized.

Once declared, every variable must be assigned a type. The permissible types are given in table 2.3.

Variable Type	*Allowed Range of Variable*
`free(default)`	$-\infty$ to $+\infty$
`positive`	0 to $+\infty$
`negative`	$-\infty$ to 0
`binary`	0 or 1
`integer`	$0, 1, \ldots, 100$ (default)

Table 2.3: Permissible variable types

The variable that serves as the quantity to be optimized must be a scalar and must be of the `free` type. In our transportation example, `z` is kept free by default, but `x(i,j)` is constrained to non-negativity by the following statement.

```
Positive variable x ;
```

Note that the domain of `x` should not be repeated in the type assignment. All entries in the domain automatically have the same variable type.

Section 2.10 describes how to assign lower bounds, upper bounds, and initial values to variables.

2.6 Equations

The power of algebraic modeling languages like GAMS is most apparent in the creation of the equations and inequalities that comprise the model under construction. This is because whenever a group of equations or inequalities has the same algebraic structure, all the members of the group are created simultaneously, not individually.

2.6.1 Equation Declaration

Equations must be declared and defined in separate statements. The format of the declaration is the same as for other GAMS entities. First comes the keyword, `Equations` in this case, followed by the name, domain and text of one or more groups of equations or inequalities being declared. Our transportation model contains the following equation declaration:

```
Equations
     cost        define objective function
     supply(i)   observe supply limit at plant i
     demand(j)   satisfy demand at market j ;
```

Keep in mind that the word `Equation` has a broad meaning in GAMS. It encompasses both equality and inequality relationships, and a GAMS equation with a single name can refer to one or several of these relationships. For example, `cost` has no domain so it is a single equation, but `supply` refers to a set of inequalities defined over the domain `i`.

2.6.2 GAMS Summation (and Product) Notation

Before going into equation definition we describe the summation notation in GAMS. Remember that GAMS is designed for standard keyboards and line-by-line input readers, so it is not possible (nor would it be convenient for the user) to employ the standard mathematical notation for summations.

The summation notation in GAMS can be used for simple and complex expressions. The format is based on the idea of always thinking of a summation as an operator with two arguments: `Sum(index of summation, summand)` A comma separates the two arguments, and if the first argument requires a comma then it should be in parentheses. The second argument can be any mathematical expression including another summation.

As a simple example, the transportation problem contains the expression

```
Sum(j, x(i,j))
```

that is equivalent to $\sum_j x_{ij}$.

A slightly more complex summation is used in the following example:

```
Sum((i,j), c(i,j)*x(i,j))
```

that is equivalent to $\sum_i \sum_j c_{ij} x_{ij}$.

The last expression could also have been written as a nested summation as follows:

```
Sum(i, Sum(j, c(i,j)*x(i,j)))
```

In Section 11.3, page 106, we describe how to use the *dollar* operator to impose restrictions on the summation operator so that only the elements of `i` and `j` that satisfy specified conditions are included in the summation.

Products are defined in GAMS using exactly the same format as summations, replacing `Sum` by `Prod`. For example,

```
prod(j, x(i, j))
```

is equivalent to: $\Pi_j x_{ij}$.

Summation and product operators may be used in direct assignment statements for parameters. For example,

```
scalar totsupply   total supply over all plants;
totsupply = sum(i, a(i));
```

2.6.3 Equation Definition

Equation definitions are the most complex statements in GAMS in terms of their variety. The components of an equation definition are, in order:

1. The name of the equation being defined
2. The domain
3. Domain restriction condition (optional)
4. The symbol '`..`'
5. Left-hand-side expression
6. Relational operator: `=l=`, `=e=`, or `=g=`
7. Right-hand-side expression

The transportation example contains three of these statements.

```
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) ;
```

Here are some points to remember.

➢ The power to create multiple equations with a single GAMS statement is controlled by the domain. For example, the definition for the `demand` constraint will result in the creation of one constraint for each element of the domain `j`, as shown in the following excerpt from the GAMS output.

```
DEMAND(new-york)..X(seattle,new-york) + X(san-diego,new-york)=G=325 ;
DEMAND(chicago).. X(seattle,chicago) + X(san-diego,chicago)  =G=300 ;
DEMAND(topeka)..  X(seattle,topeka) + X(san-diego,topeka)    =G=275 ;
```

➢ The key idea here is that the definition of the demand constraints is exactly the same whether we are solving the toy-sized example above or a 20,000-node real-world problem. In either case, the user enters just one generic equation algebraically, and GAMS creates the specific equations that are appropriate for the model instance at hand. (Using some other optimization packages, something like the extract above would be part of the input, not the output.)

➢ In many real-world problems, some of the members of an equation domain need to be omitted or differentiated from the pattern of the others because of an exception of some kind. GAMS can readily accommodate this loss of structure using a powerful feature known as the *dollar* or '*such-that*' operator, which is not illustrated here. The domain restriction feature can be absolutely essential for keeping the size of a real-world model within the range of solvability.

➢ The relational operators have the following meanings:

`=l=`	less than or equal to
`=g=`	greater than or equal to
`=e=`	equal to

➢ It is important to understand the difference between the symbols '`=`' and '`=e=`'. The '`=`' symbol is used only in direct assignments, and the '`=e=`' symbol is used only in equation definitions. These two contexts are very different. A direct assignment gives a desired value to a parameter before the solver is called. An equation definition also describes a desired relationship, but it cannot be satisfied until after the solver is called. It follows that equation definitions must contain variables and direct assignments must not.

- ➢ Variables can appear on the left or right-hand side of an equation or both. The same variable can appear in an equation more than once. The GAMS processor will automatically convert the equation to its equivalent standard form (variables on the left, no duplicate appearances) before calling the solver.
- ➢ An equation definition can appear anywhere in the GAMS input, provided the equation and all variables and parameters to which it refers are previously declared. (Note that it is permissible for a parameter appearing in the equation to be assigned or reassigned a value after the definition. This is useful when doing multiple model runs with one GAMS input.) The equations need not be defined in the same order in which they are declared.

2.7 Objective Function

This is just a reminder that GAMS has no explicit entity called the *objective function*. To specify the function to be optimized, you must create a variable, which is free (unconstrained in sign) and scalar-valued (has no domain) and which appears in an equation definition that equates it to the objective function.

2.8 Model and Solve Statements

The word `model` has a very precise meaning in GAMS. It is simply a collection of equations. Like other GAMS entities, it must be given a name in a declaration. The format of the declaration is the keyword `model` followed by the name of the model, followed by a list of equation names enclosed in slashes. If all previously defined equations are to be included, you can enter `/all/` in place of the explicit list. In our example, there is one Model statement:

```
model transport  /all/  ;
```

This statement may seem superfluous, but it is useful to advanced users who may create several models in one GAMS run. If we were to use the explicit list rather than the shortcut `/all/`, the statement would be written as

```
model transport / cost, supply, demand / ;
```

The domains are omitted from the list since they are not part of the equation name. The list option is used when only a subset of the existing equations comprises a specific model (or sub-model) being generated.

Once a model has been declared and assigned equations, we are ready to call the solver. This is done with a solve statement, which in our example is written as

```
solve transport using lp minimizing z ;
```

The format of the solve statement is as follows:

1. The key word `solve`
2. The name of the model to be solved
3. The key word `using`
4. An available solution procedure. The complete list is

`lp`	for linear programming
`qcp`	for quadratic constraint programming
`nlp`	for nonlinear programming
`dnlp`	for nonlinear programming with discontinuous derivatives
`mip`	for mixed integer programming
`rmip`	for relaxed mixed integer programming
`miqcp`	for mixed integer quadratic constraint programming

`minlp`	for mixed integer nonlinear programming
`rmiqcp`	for relaxed mixed integer quadratic constraint programming
`rminlp`	for relaxed mixed integer nonlinear programming
`mcp`	for mixed complementarity problems
`mpec`	for mathematical programs with equilibrium constraints
`cns`	for constrained nonlinear systems

5. The keyword '`minimizing`' or '`maximizing`'
6. The name of the variable to be optimized

2.9 Display Statements

The `solve` statement will cause several things to happen when executed. The specific instance of interest of the model will be generated, the appropriate data structures for inputting this problem to the solver will be created, the solver will be invoked, and the output from the solver will be printed to a file. To get the optimal values of the primal and/or dual variables, we can look at the solver output, or, if we wish, we can request a display of these results from GAMS. Our example contains the following statement:

```
display x.l, x.m ;
```

that calls for a printout of the final levels, `x.l`, and marginal (or reduced costs), `x.m`, of the shipment variables, `x(i,j)`. GAMS will automatically format this printout in to dimensional tables with appropriate headings.

2.10 The '.lo, .l, .up, .m' Database

GAMS was designed with a small database system in which records are maintained for the variables and equations. The most important fields in each record are:

`.lo`	lower bound
`.l`	level or primal value
`.up`	upper bound
`.m`	marginal or dual value

The format for referencing these quantities is the variable or equation's name followed by the field's name, followed (if necessary) by the domain (or an element of the domain).

GAMS allows the user complete read-and write-access to the database. This may not seem remarkable to you now, but it can become a greatly appreciated feature in advanced use. Some examples of use of the database follow.

2.10.1 Assignment of Variable Bounds and/or Initial Values

The lower and upper bounds of a variable are set automatically according to the variable's type (`free, positive, negative, binary`, or `integer`), but these bounds can be overwritten by the GAMS user. Some examples follow.

```
x.up(i,j)    =  capacity(i,j)  ;
x.lo(i,j)    =  10.0  ;
x.up('seattle','new-york') = 1.2*capacity(seattle','new-york') ;
```

It is assumed in the first and third examples that `capacity(i,j)` is a parameter that was previously declared and assigned values. These statements must appear after the variable declaration and before the `Solve` statement. All the mathematical expressions available for direct assignments are usable on the right-hand side.

In nonlinear programming it is very important for the modeler to help the solver by specifying as narrow a range as possible between lower and upper bound. It is also very helpful to specify an initial solution from which the solver can start searching for the optimum. For example, in a constrained inventory model, the variables are `quantity(i)`, and it is known that the optimal solution to the unconstrained version of the problem is a parameter called `eoq(i)`. As a guess for the optimum of the constrained problem we enter

```
quantity.l(i)  =  0.5*eoq(i)  ;
```

(The default initial level is zero unless zero is not within the bounded range, in which case it is the bound closest to zero.)

It is important to understand that the `.lo` and `.up` fields are entirely under the control of the GAMS user. The `.l` and `.m` fields, in contrast, can be initialized by the user but are then controlled by the solver.

2.10.2 Transformation and Display of Optimal Values

(This section can be skipped on first reading if desired.)

After the optimizer is called via the `solve` statement, the values it computes for the primal and dual variables are placed in the database in the `.l` and `.m` fields. We can then read these results and transform and display them with GAMS statements.

For example, in the transportation problem, suppose we wish to know the percentage of each market's demand that is filled by each plant. After the solve statement, we would enter

```
parameter pctx(i,j)  perc of market j's demand filled by plant i;
pctx(i,j) =  100.0*x.l(i,j)/b(j) ;
display pctx ;
```

Appending these commands to the original transportation problem input results in the following output:

```
pctx    percent of market j's demand filled by plant I
          new-york   chicago   topeka
seattle     15.385   100.000
san-diego   84.615             100.000
```

For an example involving marginal, we briefly consider the *ratio constraints* that commonly appear in blending and refining problems. These linear programming models are concerned with determining the optimal amount of each of several available raw materials to put into each of several desired finished products. Let `y(i,j)` be the variable for the number of tons of raw material *i* put into finished product `j`. Suppose the *ratio constraint* is that no product can consist of more than 25 percent of one ingredient, that is,

```
y(i,j)/q(j) =l=   .25 ;
```

for all `i`, `j`. To keep the model linear, the constraint is written as

```
ratio(i,j).. y(i,j) - .25*q(j)  =l=  0.0  ;
```

rather than explicitly as a ratio.

The problem here is that `ratio.m(i,j)`, the marginal value associated with the linear form of the constraint, has no intrinsic meaning. At optimality, it tells us by at most how much we can benefit from relaxing the linear constraint to

```
y(i,j) - .25*q(j)  =l=  1.0 ;
```

Unfortunately, this relaxed constraint has no realistic significance. The constraint we are interested in relaxing (or tightening) is the nonlinear form of the ration constraint. For example, we would like to know the marginal benefit arising from changing the ratio constraint to

```
y(i,j)/q(j)  =l=  .26  ;
```

We can in fact obtain the desired marginals by entering the following transformation on the undesired marginals:

```
parameter  amr(i,j)  appropriate marginal for ratio constraint ;
amr(i,j)  =  ratio.m(i,j)*0.01*q.l(j) ;
display amr ;
```

Notice that the assignment statement for `amr` accesses both `.m` and `.l` records from the database. The idea behind the transformation is to notice that

```
y(i,j)/q(j)  =l=  .26  ;
```

is equivalent to

```
y(i,j) - .25*q(j)  =l=  0.01*q(j)  ;
```

2.11 GAMS Output

The default output of a GAMS run is extensive and informative. For a complete discussion, see Chapter 10, page 85. This tutorial discusses output partially as follows:

Echo Print
Reference Maps
Status Reports
Error Messages
Model Statistics
Solution Reports

A great deal of unnecessary anxiety has been caused by textbooks and users' manuals that give the reader the false impression that flawless use of advanced software should be easy for anyone with a positive pulse rate. GAMS is designed with the understanding that even the most experienced users will make errors. GAMS attempts to catch the errors as soon as possible and to minimize their consequences.

2.11.1 Echo Prints

Whether or not errors prevent your optimization problem from being solved, the first section of output from a GAMS run is an echo, or copy, of your input file. For the sake of future reference, GAMS puts line numbers on the left-hand side of the echo. For our transportation example, which luckily contained no errors, the echo print is as follows:

```
   3   Sets
   4        i   canning plants   / seattle, san-diego /
   5        j   markets          / new-york, chicago, topeka / ;
   6
   7   Parameters
   8
   9        a(i)  capacity of plant i in cases
  10          /    seattle     350
  11               san-diego   600  /
  12
  13        b(j)  demand at market j in cases
  14          /    new-york    325
  15               chicago     300
  16               topeka      275  / ;
  17
  18   Table d(i,j)  distance in thousands of miles
  19                     new-york       chicago      topeka
  20       seattle          2.5           1.7          1.8
```

```
21        san-diego        2.5          1.8         1.4  ;
22
23    Scalar f  freight in dollars per case per thousand miles  /90/ ;
24
25   Parameter c(i,j) transport cost in thousands of dollars per case;
26
27              c(i,j) = f * d(i,j) / 1000 ;
28
29    Variables
30         x(i,j) shipment quantities in cases
31         z      total transportation costs in thousands of dollars ;
32
33    Positive Variable x ;
34
35    Equations
36         cost        define objective function
37         supply(i)   observe supply limit at plant i
38         demand(j)   satisfy demand at market j ;
39
40    cost ..        z  =e=  sum((i,j), c(i,j)*x(i,j)) ;
41
42    supply(i) ..   sum(j, x(i,j))  =l=  a(i) ;
43
44    demand(j) ..   sum(i, x(i,j))  =g=  b(j) ;
45
46    Model transport /all/ ;
47
48    Solve transport using lp minimizing z ;
49
50    Display x.l, x.m ;
51
```

The reason this echo print starts with line number 3 rather than line number 1 is because the input file contains two *dollar-print-control* statements. This type of instruction controls the output printing, but since it has nothing to do with defining the optimization model, it is omitted from the echo. The dollar print controls must start in column 1.

```
$title a transportation model
$offuppper
```

The `$title` statement causes the subsequent text to be printed at the top of each page of output. The `$offupper` statement is needed for the echo to contain mixed upper- and lowercase. Other available instructions are given in Appendix D, page 193.

2.11.2 Error Messages

When the GAMS compiler encounters an error in the input file, it inserts a coded error message inside the echo print on the line immediately following the scene of the offense. These messages always start with `****` and contain a '$' directly below the point at which the compiler thinks the error occurred. The $ is followed by a numerical error code, which is explained after the echo print. Several examples follow.

Example 1: Entering the statement

```
set  q  quarterly time periods  / spring, sum, fall, wtr / ;
```

results in the echo

```
   1   set q quarterly time periods / spring, sum, fall, wtr  / ;
****                                        $160
```

In this case, the GAMS compiler indicates that something is wrong with the set element sum. At the bottom of the echo print, we see the interpretation of error code 160:

```
Error Message
160  UNIQUE ELEMENT EXPECTED
```

The problem is that `sum` is a reserved word denoting summation, so our set element must have a unique name like `'summer'`. This is a common beginner's error. The complete list of reserved words is shown in the next chapter.

Example 2: Another common error is the omission of a semicolon preceding a direct assignment or equation definition. In our transportation example, suppose we omit the semicolon prior to the assignment of `c(i,j)`, as follows.

```
parameter c(i,j)  transport cost in 1000s of dollars per case
c(i,j)  = f * d(i,j)  /  1000  ;
```

Here is the resulting output.

```
  16   parameter c(i,j) transport cost in 1000s of dollars per case
  17             c(i,j)  = f*d(i,j)/1000
****                 $97    $195$96$194$1
Error Message
  1   REAL NUMBER EXPECTED
 96   BLANK NEEDED BETWEEN IDENTIFIER AND TEXT
      (-OR-ILLEGAL CHARACTER IN IDENTIFIER)
      (-OR-CHECK FOR MISSING ';' ON PREVIOUS LINE)
 97   EXPLANATORY TEXT CAN NOT START WITH '$', '=', or '..'
      (-OR-CHECK FOR MISSING ';' ON PREVIOUS LINE)
194   SYMBOL REDEFINED
195   SYMBOL REDEFINED WITH A DIFFERENT TYPE
```

It is not uncommon for one little offense like our missing semicolon to generate five intimidating error messages. The lesson here is: concentrate on fixing the first error and ignore the other! The first error detected (in line 17), code 97, indicate that GAMS thinks the symbols in line 17 are a continuation of the documentary text at the end of line 16 rather than a direct assignment as we intended. The error message also appropriately advises us to check the preceding line for a missing semicolon.

Unfortunately, you cannot always expect error messages to be so accurate in their advice. The compiler cannot read your mind. It will at times fail to comprehend your intentions, so learn to detect the causes of errors by picking up the clues that abound in the GAMS output. For example, the missing semicolon could have been detected by looking up the c entry in the cross-reference list (to be explained in the next section) and noticing that it was never assigned.

```
SYMBOL       TYPE      REFERENCES
C            PARAM     DECLARED     15   REF   17
```

Example 3: Many errors are caused merely by spelling mistakes and are caught before they can be damaging. For example, with '`Seattle`' spelled in the table differently from the way it was introduced in the set declaration, we get the following error message.

```
   4   sets
   5          i   canning plants  /seattle, san-diego /
   6          j   markets  /new-york, chicago, topeka /  ;
   7
   8   table d(i,j)  distance in thousand of miles
   9           new-york   chicago   topeka
  10      seatle       2.5      1.7       1.8
****         $170
  11      san-diego    2.5      1.8           1.4   ;
Error Message
170 DOMAIN VIOLATION FOR ELEMENT
```

Example 4: Similarly, if we mistakenly enter `dem(j)` instead of `b(j)` as the right-hand side of the demand constraint, the result is

```
   45   demand(j)  ..   sum(i,  x(i,j)  )   =g=  dem(j)  ;
****                                             $140
    Error Message
    140 UNKNOWN SYMBOL, ENTERED AS PARAMETER
```

Example 5: The next example is a mathematical error, which is sometimes committed by novice modelers and which GAMS is adept at catching. The following is mathematically inconsistent and, hence, is not an interpretable statement.

$$\text{For all } i, \quad \sum_i x_{ij} = 100$$

There are two errors in this equation, both having to do with the control of indices. Index i is over-controlled and index j is under-controlled.

You should see that index i is getting conflicting orders. By appearing in the quantifier '*for all i*', it is supposed to remain fixed for each instance of the equation. Yet, by appearing as an index of summation, it is supposed to vary. It can't do both. On the other hand, index j is not controlled in any way, so we have no way of knowing which of its possible values to use.

If we enter this meaningless equation into GAMS, both errors are correctly diagnosed.

```
   meaninglss(i)  ..    sum(i, x(i,j))   =e=    100 ;
****                        $125   $149
ERROR MESSAGES
125  SET IS UNDER CONTROL ALREADY          [This refers to set i]
149  uncontrolled set entered as constant  [This refers to set j]
```

A great deal more information about error reporting is given in Section 10.6, page 98. Comprehensive error detection and well-designed error messages are a big help in getting models implemented quickly and correctly.

2.11.3 Reference Maps

The next section of output, which is the last if errors have been detected, is a pair of *reference maps* that contain summaries and analyses of the input file for the purposes of debugging and documentation.

The first reference map is a *cross-reference map* such as one finds in most modern compilers. It is an alphabetical, cross-referenced list of all the entities (sets, parameters, variables, and equations) of the model. The list shows the type of each entity and a coded reference for each appearance of the entity in the input. The cross-reference map for our transportation example is as follows (we do not display all tables).

```
SYMBOL      TYPE   REFERENCES
A           PARAM  DECLARED        9  DEFINED       10      REF       42
B           PARAM  DECLARED       13  DEFINED       14      REF       44
C           PARAM  DECLARED       25 ASSIGNED       27      REF       40
COST        EQU    DECLARED       36  DEFINED       40 IMPL-ASN       48
                       REF        46
D           PARAM  DECLARED       18  DEFINED       18      REF       27
DEMAND      EQU    DECLARED       38  DEFINED       44 IMPL-ASN       48
                       REF        46
F           PARAM  DECLARED       23  DEFINED       23      REF       27
           SET    DECLARED        4  DEFINED       4      REF        9
                        18        25        27      30       37     2*40
                      2*42        44  CONTROL       27       40       42
                        44
J           SET    DECLARED        5  DEFINED        5      REF       13
                        18        25        27      30       38     2*40
                        42      2*44  CONTROL       27       40       42
                        44
SUPPLY      EQU    DECLARED       37  DEFINED       42 IMPL-ASN       48
                       REF        46
TRANSPORT   MODEL  DECLARED       46  DEFINED       46 IMPL-ASN       48
                       REF        48
X           VAR    DECLARED       30 IMPL-ASN       48      REF       33
                        40        42        44    2*50
```

```
Z           VAR    DECLARED       31 IMPL-ASN       48       REF       40
                         48
```

For example, the cross-reference list tells us that the symbol A is a parameter that was declared in line 10, defined (assigned value) in line 11, and referenced in line 43. The symbol I has a more complicated entry in the cross-reference list. It is shown to be a set that was declared and defined in line 5. It is referenced once in lines 10, 19, 26, 28, 31, 38, 45 and referenced twice in lines 41 and 43. Set I is also used as a controlling index in a summation, equation definition or direct parameter assignment in lines 28, 41, 43 and 45.

For the GAMS novice, the detailed analysis of the cross-reference list may not be important. Perhaps the most likely benefit he or she will get from the reference maps will be the discovery of an unwanted entity that mistakenly entered the model owing to a punctuation or syntax error.

The second part of the reference map is a list of model entities grouped by type and listed with their associated documentary text. For example, this list is as follows.

```
sets
i           canning plants
j           markets

parameters
a           capacity of plant i in cases
b           demand at market j in cases
c           transport cost in 1000s of dollars per case
d           distance in thousands of miles
f           freight in dollars per case per thousand miles

variables
x           shipment quantities in cases
z           total transportation costs in 1000s of dollars

equations
cost        define objective function
demand      satisfy demand at market j
supply      observe supply limit at plant i

models
transport
```

2.11.4 Equation Listings

Once you succeed in building an input file devoid of compilation errors, GAMS is able to generate a model. The question remains, and only you can answer it, does GAMS generate the model you intended?

The equation listing is probably the best device for studying this extremely important question.

A product of the solve command, the equation listing shows the specific instance of the model that is created when the current values of the sets and parameters are plugged into the general algebraic form of the model. For example, the generic demand constraint given in the input file for the transportation model is

```
demand(j)  ..   sum(i, x(i,j))  =g=  b(j)  ;
```

while the equation listing of specific constraints is

```
--------demand   =g=   satisfy demand at market  j
demand(new-york)..  x(seattle, new-york) +x(san-diego, new-york)  =g=  325  ;
demand(chicago)..  x(seattle, chicago) +x(san-diego, chicago )  =g=  300  ;
demand(topeka)..  x(seattle, topeka) +x(san-diego, topeka)  =g=  275 ;
```

The default output is a maximum of three specific equations for each generic equation. To change the default, insert an input statement prior to the solve statement:

```
option limrow  =  r ;
```

where `r` is the desired number.

The default output also contains a section called the column listing, analogous to the equation listing, which shows the coefficients of three specific variables for each generic variable. This listing would be particularly useful for verifying a GAMS model that was previously implemented in MPS format. To change the default number of specific column printouts per generic variable, the above command can be extended:

```
option limrow  =  r,  limcol  = c ;
```

where `c` is the desired number of columns. (Setting `limrow` and `limcol` to 0 is a good way to save paper after your model has been debugged.)

In nonlinear models, the GAMS equation listing shows first-order Taylor approximations of the nonlinear equations. The approximations are taken at the starting values of the variables.

2.11.5 Model Statistics

The last section of output that GAMS produces before invoking the solver is a group of statistics about the model's size, as shown below for the transportation example.

```
MODEL STATISTICS

BLOCKS OF EQUATIONS       3     SINGLE EQUATIONS        6
BLOCKS OF VARIABLES       2     SINGLE VARIABLES        7
NON ZERO ELEMENTS        19
```

The `BLOCK` counts refer to the number of generic equations and variables. The `SINGLE` counts refer to individual rows and columns in the specific model instance being generated. For nonlinear models, some other statistics are given to describe the degree of non-linearity in the problem.

2.11.6 Status Reports

After the solver executes, GAMS prints out a brief *solve summary* whose two most important entries are `SOLVER STATUS` and the `MODEL STATUS`. For our transportation problem the solve summary is as follows:

```
               S O L V E     S U M M A R Y

     MODEL   TRANSPORT           OBJECTIVE  Z
     TYPE    LP                  DIRECTION  MINIMIZE
     SOLVER  BDMLP               FROM LINE  49

**** SOLVER STATUS     1 NORMAL COMPLETION
**** MODEL STATUS      1 OPTIMAL

**** OBJECTIVE VALUE             153.6750

RESOURCE USAGE, LIMIT         0.110     1000.000
ITERATION COUNT, LIMIT        5         1000
```

The status reports are preceded by the same `****` string as an error message, so you should probably develop the habit of searching for all occurrences of this string whenever you look at an output file for the first time. The desired solver status is `1 NORMAL COMPLETION`, but there are other possibilities, documented in Section 10.5, page 91, which relate to various types of errors and mishaps.

There are eleven possible model status's, including the usual linear programming termination states (`1 OPTIMAL, 3 UNBOUNDED, 4 INFEASIBLE`), and others relating to nonlinear and integer programming. In nonlinear programming, the status to look for is `2 LOCALLY OPTIMAL`. The most the software can guarantee for nonlinear programming is a local optimum. The user is responsible for analyzing the convexity of the problem to determine whether local optimality is sufficient for global optimality.

In integer programming, the status to look for is `8 INTEGER SOLUTION`. This means that a feasible integer solution has been found. More detail follows as to whether the solution meets the relative and absolute optimality tolerances that the user specifies.

2.11.7 Solution Reports

If the solver status and model status are acceptable, then you will be interested in examining the results of the optimization. The results are first presented in as standard mathematical programming output format, with the added feature that rows and columns are grouped and labeled according to names that are appropriate for the specific model just solved. In this format, there is a line of printout for each row and column giving the lower limit, level, upper limit, and marginal. Generic equation block and the column output group the row output by generic variable block. Set element names are embedded in the output for easy reading. In the transportation example, the solver outputs for `supply(i)`, `demand(j)`, and `x(i,j)` are as follows:

```
---- EQU SUPPLY      observe supply limit at plant i

             LOWER     LEVEL     UPPER    MARGINAL

seattle       -INF    350.000   350.000      EPS
san-diego     -INF    550.000   600.000       .

---- EQU DEMAND      satisfy demand at market j

            LOWER     LEVEL     UPPER    MARGINAL

new-york   325.000   325.000     +INF      0.225
chicago    300.000   300.000     +INF      0.153
topeka     275.000   275.000     +INF      0.126

---- VAR X           shipment quantities in cases

                      LOWER     LEVEL     UPPER    MARGINAL

seattle  .new-york      .       50.000     +INF       .
seattle  .chicago       .      300.000     +INF       .
seattle  .topeka        .         .        +INF      0.036
san-diego.new-york      .      275.000     +INF       .
san-diego.chicago       .         .        +INF      0.009
san-diego.topeka        .      275.000     +INF       .
```

The single dots '`.`' in the output represent zeroes. The entry `EPS`, which stands for *epsilon*, mean very small but nonzero. In this case, `EPS` indicates degeneracy. (The slack variable for the Seattle supply constraint is in the basis at zero level. The marginal is marked with `EPS` rather than zero to facilitate restarting the optimizer from the old basis.)

If the solvers results contain either infeasibilities or marginal costs of the wrong sign, then the offending entries are marked with `INFES` or `NOPT`, respectively. If the problem terminates unbounded, then the rows and columns corresponding to extreme rays are marked `UNBND`.

At the end of the solvers solution report is a very important *report summary*, which gives a tally of the total number of non-optimal, infeasible, and unbounded rows and columns. For our example, the report summary shows all zero tallies as desired.

```
**** REPORT SUMMARY :        0     NONOPT
                             0 INFEASIBLE
                             0  UNBOUNDED
```

After the solver's report is written, control is returned from the solver back to GAMS. All the levels and marginals obtained by the solver are entered into the GAMS database in the `.l` and `.m` fields. These values can then be transformed and displayed in any desired report. As noted earlier, the user merely lists the quantities to be displayed, and GAMS automatically formats and labels an appropriate array. For example, the input statement.

```
display x.l, x.m  ;
```

results in the following output.

```
----     50 VARIABLE  X.L           shipment quantities in cases

             new-york     chicago      topeka

seattle        50.000     300.000
san-diego     275.000                 275.000

----     50 VARIABLE  X.M           shipment quantities in cases

              chicago      topeka

seattle                     0.036
san-diego       0.009
```

As seen in reference maps, equation listings, solution reports, and optional displays, GAMS saves the documentary text and '*parrots*' it back throughout the output to help keep the model well documented.

2.12 Summary

This tutorial has demonstrated several of the design features of GAMS that enable you to build practical optimization models quickly and effectively. The following discussion summarizes the advantages of using an algebraic modeling language such as GAMS versus a matrix generator or conversational solver.

- By using an algebra-based notation, you can describe an optimization model to a computer nearly as easily as you can describe it to another mathematically trained person.
- Because an algebraic description of a problem has generality, most of the statements in a GAMS model are reusable when new instances of the same or related problems arise. This is especially important in environments where models are constantly changing.
- You save time and reduce generation errors by creating whole sets of closely related constraints in one statement.
- You can save time and reduce input errors by providing formulae for calculating the data rather than entering them explicitly.
- The model is self-documenting. Since the tasks of model development and model documentation can be done simultaneously, the modeler is much more likely to be conscientious about keeping the documentation accurate and up to date.
- The output of GAMS is easy to read and use. The solution report from the solver is automatically reformatted so that related equations and variables are grouped together and appropriately labeled. Also, the `display` command allows you to modify and tabulate results very easily.
- If you are teaching or learning modeling, you can benefit from the insistence of the GAMS compiler that every equation be mathematically consistent. Even if you are an experienced modeler, the hundreds of ways in which errors are detected should greatly reduce development time.
- By using the *dollar* operator and other advanced features not covered in this tutorial, one can efficiently implement large-scale models. Specific applications of the dollar operator include the following:
  1. It can enforce logical restrictions on the allowable combinations of indices for the variables and equations to be included in the model. You can thereby screen out unnecessary rows and columns and keep the size of the problem within the range of solvability.
  2. It can be used to build complex summations and products, which can then be used in equations or customized reports.
  3. It can be used for issuing warning messages or for terminating prematurely conditioned upon context-specific data edits.

3

GAMS Programs

3.1 Introduction

This chapter provides a look at the structure of the GAMS language and its components. It should be emphasized again that GAMS is a programming language, and that programs must be written in the language to use it. A GAMS program is contained in a disk file, which is normally constructed with a text editor of choice. When GAMS is 'run', the file containing the program (the input file) is submitted to be processed. After this processing has finished the results, which are in the output file(s), can be inspected with a text editor. On many machines a few terse lines appear on the screen while GAMS runs, keeping the user informed about progress and error detection. But it is the responsibility of the user to inspect the output file carefully to see the results and to diagnose any errors.

The first time or casual reader can skip this chapter: the discussion of specific parts of the language in the next Chapters does not assume an understanding of this chapter.

3.2 The Structure of GAMS Programs

GAMS programs consist of one or more statements (sentences) that define data structures, initial values, data modifications, and symbolic relationships (equations). While there is no fixed order in which statements have to be arranged, the order in which data modifications are carried out is important. Symbols must be declared as to type before they are used, and must have values assigned before they can be referenced in assignment statements. Each statement is followed by a semicolon except the last statement, where a semicolon is optional.

3.2.1 Format of GAMS Input

GAMS input is free format. A statement can be placed anywhere on a line, multiple statements can appear on a line, or a statement can be continued over any number of lines as follows:

```
statement;
statement;
statement; statement; statement;
the words that you are now reading is an example of a very
long statement which is stretched over two lines;
```

Blanks and end-of-lines can generally be used freely between individual symbols or words. GAMS is not case sensitive, meaning that lower and upper case letters can be mixed freely but are treated identically. Up to 255 characters can be placed on a line and completely blank lines can be inserted for easier reading.

Not all lines are a part of the GAMS language. Two special symbols, the asterisk '`*`' and the dollar symbol '`$`' can be used in the first position on a line to indicate a non-language input line. An asterisk in column one means that the line will not be processed, but treated as a comment. A dollar symbol in the same position indicates that compiler options are contained in the rest of the line.

Multiple files can be used as input through the use of the `$include` facility described in Appendix D. In short, the statement,

```
$include file1
```

inserts the contents of the specified file (file1 in this case) at the location of the call. A more complex versions of this is the `$batinclude` which is described in Appendix D.

3.2.2 Classification of GAMS Statements

Each statement in GAMS is classified into one of two groups:

- ➢ declaration and definition statements; or
- ➢ execution statements

A declaration statement describes the class of symbol. Often initial values are provided in a declaration, and then it may be called a definition. The specification of symbolic relationships for an equation is a definition. The declaration and definition statements are:

`acronym`	`parameter`	`equation declaration`
`set`	`scalar`	`equation definition`
`alias`	`table`	`model`
	`variable`	

Execution statements are instructions to carry out actions such as data transformation, model solution, and report generation. The execution statements are:

`option`	`display`	`solve`
`assignment`	`abort`	`loop`
`for`	`while`	`repeat`
	`execute`	

Although there is great freedom about the order in which statements can be placed in a GAMS program, certain orders are commonly used. The two most common arrangements are discussed in the next sub-section.

3.2.3 Organization of GAMS Programs

The two most common ways of organizing GAMS programs are shown in table 3.1. The first style places the data first, followed by the model and then the solution statements. In this style of organization, the sets are placed first. Then the data are specified with parameter, scalar, and table statements. Next the model is defined with the variable, equation declaration, equation definition, and model statement. Finally the model is solved and the results are displayed.

A second style emphasizes the model by placing it before the data. This is a particularly useful order when the model may be solved repeatedly with different data sets. There is a separation between declaration and definition.

For example, sets and parameters may be declared first with the statements

```
set  c  "crops" ;
parameter yield  "crop yield" ;
```

and then defined later with a statement:

```
set  c         / wheat, clover, beans/ ;
parameter yield / wheat     1.5
                  clover    6.5
                  beans     1.0  / ;
```

Style 1	Style 2
Data:	Model:
Set declarations and definitions	Set declarations
Parameter declarations and definitions	Parameter declarations
Assignments	Variable declarations
Displays	Equation declaration
Model:	Equation definition
Variable declarations	Model definition
Equation declaration	Data:
Equation definition	Set definitions
Model definition	Parameter definitions
Solution:	Assignments
Solve	Displays
Displays	Solution:
	Solve
	Displays

Table 3.1: Organization of GAMS programs

The first statement declares that the identifier `c` is a set and the second defines the elements in the set

☞ *Sets and parameters used in the equations must be declared before the equations are specified; they can be* defined, *however, after the equation specifications but before a specific equation is used in a solve statement. This gives GAMS programs substantial organizational flexibility.*

3.3 Data Types and Definitions

There are five basic GAMS data types and each symbol or identifier must be declared to belong to one of the following groups:

`acronyms`	`models`	`sets`
`equations`	`parameters`	`variables`

`Scalars` and `tables` are not separate data types but are a shorthand way to declare a symbol to be a `parameter`, and to use a particular format for initializing the numeric data.

Definitions have common characteristics, for example:

`parameter`	`a`	`(i,j)`	`input-output matrix`
data-type-keyword	identifier	domain list	text

The domain list and the text are always optional characteristics. Other examples are:

```
set         time     time periods;
model       turkey   turkish fertilizer model ;
variables   x,y,z  ;
```

In the last example a number of identifiers (separated by commas) are declared in one statement.

3.4 Language Items

Before proceeding with more language details, a few basic symbols need to be defined and the rules for recognizing and writing them in GAMS established. These basic symbols are often called lexical elements and form the building blocks of the language. They are:

characters	delimiters	labels	reserved words and tokens
comments	text	numbers	identifiers (indents)

Each of these items are discussed in detail in the following sub-sections.

☞ *As noted previously, we can use any mix of lower and upper case. GAMS makes no distinction between upper and lower case.*

3.4.1 Characters

A few characters are not allowed in a GAMS program because they are illegal or ambiguous on some machines. Generally all unprintable and control characters are illegal. The only place where any character is legal is in an '$ontext-$offtext' block as illustrated in the section on comments below. For completeness the full set of legal characters are listed in table 3.2. Most of the uncommon punctuation characters are not part of the language, but can be used freely in text or comments.

A to Z	alphabet	a to z	alphabet	0 to 9	numerals
&	ampersand	"	double quote	#	pound sign
*	asterisk	=	equals	?	question mark
@	at	>	greater than	;	semicolon
\	back slash	<	less than	'	single quote
:	colon	–	minus	/	slash
,	comma	( )	parenthesis		space
$	dollar	[ ]	square brackets	_	underscore
.	dot	{ }	braces	!	exclamation mark
+	plus	%	percent	^	circumflex

Table 3.2: Legal characters

3.4.2 Reserved Words

GAMS, like computer languages such as C and Pascal, uses reserved words (often also called keywords) that have predefined meanings. It is not permitted to use any of these for one's own definitions, either as identifiers or labels. The complete list of reserved words are listed in table 3.3. In addition, a small number of symbols constructed from non-alphanumeric characters have a meaning in GAMS.

abort	eps	integer	not	sameas	sum
acronym	eq	le	option	scalar	system
acronyms	equation	loop	options	scalars	table
alias	equations	lt	or	semicont	then
all	file	maximizing	ord	semiint	until
and	files	minimizing	parameter	set	using
assign	for	model	parameters	sets	variable
binary	free	models	positive	smax	variables
card	ge	na	prod	smin	while
diag	gt	ne	putpage	solve	xor
display	if	negative	puttl	sos1	yes
else	inf	no	repeat	sos2	

The reserved non-alphanumeric symbols are:

..	=l=	=g=	=e=	=n=	=x=	=c=	--	++	**

Table 3.3: Reserved words and symbols

3.4.3 Identifiers

Identifiers are the names given to sets, parameters, variables, models, etc. GAMS requires an identifier to start with a letter followed by more letters or digits. The length of an identifier is currently limited to 63 characters.

Identifiers can only contain alphanumeric characters (letters or numbers). Examples of legal identifiers are:

```
a   a15   revenue   x0051
```

whereas the following identifiers are incorrect:

```
15   $casg      milk&meat
```

☞ *A name used for one data type cannot be reused for another.*

3.4.4 Labels

Labels are set elements. They may be up to 63 characters long and can be used in quoted or unquoted form.

The unquoted form is simpler to use but places restrictions on characters used, in that any unquoted label must start with a letter or digit and can only be followed by letters, digits, or the sign characters + and -. Examples of unquoted labels are:

```
Phos-Acid      1986      1952-53   A
September      H2S04      Line-1
```

In quoted labels, quotes are used to delimit the label, which may begin with and/or include any legal character. Either single or double quotes can be used but the closing quote has to match the opening one. A label quoted with double quotes can contain a single quote (and vice versa). Most experienced users avoid quoted labels because they can be tedious to enter and confusing to read. There are a couple of special circumstances. If one wants to make a label stand out, then one can, for instance, put asterisks in it and indent it. A more subtle example is that GAMS keywords can be used as labels if they are quoted. If one needs to use labels like no, ne or sum then they will have to be quoted. Examples of quoted labels are:

```
'*TOTAL*'   'MATCH'   '10%INCR'   '12"/FOOT'   'LINE 1'
```

☞ *Labels do not have a value. The label '1986' does not have the numerical value 1986 and the label '01' is different from the label '1'.*

The rules for constructing identifiers and labels are shown in table 3.4.

	Identifiers	*Unquoted Labels*	*Quoted Labels*
Number of Characters	63	63	63
Must Begin With	A letter	A letter or a number	Any character
Permitted Special Characters	None	+ or − characters	Any but the starting quote

Table 3.4: Rules for constructing identifiers and labels

3.4.5 Text

Identifiers and simple labels can also be associated with a line of descriptive text. This text is more than a comment: it is retained by GAMS and is displayed whenever results are written for the identifier.

Text can be quoted or unquoted. Quoted text can contain any character except the quote character used. Single or double quotes can be used but must match. Text has to fit on one line and cannot exceed 80 characters in length. Text used in unquoted form must follow a number of mild restrictions. Unquoted text cannot start with a reserved word, '..' or '=' and must not include semicolon ';', commas ',', or slashes '/'. End of lines terminate a text. These restrictions are a direct consequence of the GAMS syntax and are usually followed naturally by the user. Some examples are:

```
this is text
final product shipment (tpy)
"quoted text containing otherwise illegal characters ; /,"
'use single quotes to put a "double" quote in text'
```

3.4.6 Numbers

Numeric values are entered in a style similar to that used in other computer languages

☞ *Blanks can not be used in a number: GAMS treats a blank as a separator.*

☞ *The common distinction between real and integer data types does not exist in GAMS. If a number is used without a decimal point it is still stored as a real number.*

In addition, GAMS uses an extended range arithmetic that contains special symbols for infinity (`INF`), negative infinity (`-INF`), undefined (`UNDF`), epsilon (`EPS`), and not available (`NA`). One cannot enter `UNDF`; it is only produced by an operation that does not have a proper result, such as division by zero. All the other special symbols can be entered and used as if they were ordinary numbers.

The following example shows various legal ways of entering numbers:

```
     0        156.70          -135          .095         1.
  2e10         2e+10       15.e+10        .314e5       +1.7
   0.0            .0            0.           INF       -INF
   EPS            NA
```

The letter `e` denotes the well-known scientific notation allowing convenient representation of very large or small numbers.

For example:

$$\texttt{1e-5} = 1 * 10^{-5} = 0.00001 \qquad \texttt{3.56e6} = 3.56 * 10^{6} = 3,560,000$$

☞ *GAMS uses a smaller range of numbers than many computers are able to handle. This has been done to ensure that GAMS programs will behave in the same way on a wide variety of machines, including personal computers. A good general rule is to avoid using or creating numbers with absolute values greater than `1.0e+20`.*

☞ *A number can be entered with up to ten significant digits on all machines, and more on some.*

3.4.7 Delimiters

As mentioned before, statements are separated by a semicolon '`;`'. However, if the next statement begins with a reserved word (often called keyword in succeeding chapters), then GAMS does not require that the semicolon be used.

The characters comma '`,`' and slash '`/`' are used as delimiters in data lists, to be introduced later. The comma terminates a data element (as does an end-of-line) and the slash terminates a data list.

3.4.8 Comments

A comment is an explanatory text that is not processed or retained by the computer. There are three ways to include comments in a GAMS program.

The first, already mentioned above, is to start a line with an asterisk '`*`' in the first character position. The remaining characters on the line are ignored but printed on the output file.

The second is to use special 'block' delimiters that cause GAMS to ignore an entire section of the program. The `$` symbol must be in the first character position. The choice between the two ways is a matter of individual taste or utility. The example below illustrates the use of the block comment.

```
$ontext
Following a $ontext directive in column 1 all lines are ignored by GAMS but
printed on the output file until the matching $offtext is encountered, also
in column 1. This facility is often used to logically remove parts of programs
that are not used every time, such as statements producing voluminous reports.
Every $ontext must have a matching $offtext in the same file
$offtext
```

The third style of comment allows embedding a comment within a line. It must be enabled with the compiler option `$inlinecom` or `$eolcom` as in the following example.

```
$eolcom #
$inlinecom {}
x = 1 ;   # this is a comment
y = 2 ;   { this is also a comment }  z = 3 ;
```

3.5 Summary

This completes the discussion of the components of the GAMS language. Many unfamiliar terms used in this chapter have been further explained in the Glossary.

4

Set Definitions

4.1 Introduction

Sets are fundamental building blocks in any GAMS model. They allow the model to be succinctly stated and easily read. In this chapter we will discuss how sets are declared and initialized. There are some more advanced set concepts, such as assignments to sets as well as lag and lead operations, but these are not introduced until much later in the book. However the topics covered in this chapter will be enough to provide a good start on most models.

4.2 Simple Sets

A set S that contains the elements a, b and c is written, using normal mathematical notation, as:

$$S = \{a, b, c\}$$

In GAMS notation, because of character set limitations, the same set must be written as

```
set   S   /a, b, c/
```

The `set` statement begins with the keyword `set` (or `sets`). `S` is the name of the set, and its members are `a`, `b`, and `c`. They are labels, but are often referred to as elements or members.

4.2.1 The Syntax

In general, the syntax in GAMS for simple sets is as follows:

```
set set_name ["text"] [/element ["text"] {,element ["text"]} /]
  {,set_name ["text"] [/element ["text"] {,element ["text"]} /] } ;
```

`set_name` is the internal name of the set (also called an identifier) in GAMS. The accompanying text is used to describe the set or element immediately preceding it.

4.2.2 Set Names

The name of the set is an identifier. An identifier has to start with a letter followed by more letters or digits. It can only contain alphanumeric characters, and can be up to 63 characters long. This is enough to construct meaningful names, and explanatory text can be used to provide more details.

Examples of legal identifiers are

```
i   i15   countries   s0051
```

whereas the following identifiers are incorrect:

```
25   $currency   food&drink
```

4.2.3 Set Elements

The name of each set element can be up to 63 characters long, and can be used in quoted or unquoted form. The unquoted form is simpler to use but places restrictions on characters used, in that any unquoted label must start with a letter or digit and can only be followed by letters, digits, or the sign characters `+` and `-`. Examples of legal unquoted labels are:

```
Phos-Acid      1986      1952-53   A
September      H2S04      Line-1
```

In quoted labels, quotes are used to delimit the label, which may begin with and/or include any legal character. Either single or double quotes can be used but the closing quote has to match the opening one. A label quoted with double quotes can contain a single quote (and vice versa). Most experienced users avoid quoted labels because they can be tedious to enter and confusing to read. There are a couple of special circumstances. If one wants to make a label stand out, then to put asterisks in it and indent it, as below, is common. A more subtle example is that it is possible to use GAMS keywords as labels if they are quoted. If one need to use labels like `no`, `ne` or `sum` then they will have to be quoted.

Examples of quoted labels are:

```
'*TOTAL*'    'Match'   '10%incr'   '12"/foot'   'Line 1'
```

☞ *Labels do not have a value. The label '`1986`' does not have the numerical value 1986 and the label '`01`' is different from the label '`1`'.*

Each element in a set must be separated from other elements by a comma or by an end-of-line. In contrast, each element is separated from any associated text by a blank.

Consider the following example from the Egyptian fertilizer model [FERTS], where the set of fertilizer nutrients could be written as

```
set  cq   "nutrients"  / N, P205 / ;
```

or as

```
set  cq   "nutrients"  / N
                         P205  / ;
```

The order in which the set members are listed is normally not important. However, if the members represent, for example, time periods, then it may be useful to refer to *next* or *previous* member. There are special operations to do this, and they will be discussed in Chapter 13. For now, it is enough to remember that the order in which set elements are specified is not relevant, unless and until some operation implying order is used. At that time, the rules change, and the set becomes what we will later call an ordered set.

4.2.4 Associated Text

It is also possible to associate text with each set member or element. Explanatory text must not exceed 254 characters and must all be contained on the same line as the identifier or label it describes.

For example, label text for the set of final products in [SHALE] contains details of the units of measurement.

```
Set   f         "final products"
/yncrude         "refined crude (million barrels)"
 lpg                "liquified petroleum gas(million barrels)"
 ammonia          "ammonia (million tons)"
 coke       "coke (million tons)"
 sulfur          "sulfur (million tons)"
/;
```

Notice that text may have embedded blanks, and may include special characters such as parentheses. There are, however, restrictions on special characters in text. Include slashes, commas or semicolons only if the text is enclosed in quotes. A set definition like

```
set  prices   prices of commodities in dollars/ounce
      / gold-price, sil-price / ;
```

will cause errors since the slash between dollars and ounce will signal the beginning of the set declaration, and the GAMS compiler will treat ounce as the name of the first element. Further, the slash before gold-price will be treated as the end of the set definition, and gold-price will be treated as a new set. However, by enclosing the explanatory text in quotes, this problem is avoided. The following text is valid:

```
set  prices   "prices of commodities in dollars/ounce"
```

4.2.5 Sequences as Set Elements

The asterisk '`*`' plays a special role in set definitions. It is used to relieve the tedium of typing a sequence of elements for a set, and to make intent clearer. For example in a simulation model there might be ten annual time periods from 1991 to 2000. Instead of typing ten years, the elements of this set can be written as

```
set  t   "time"  /1991 * 2000 /;
```

which means that the set includes the ten elements `1991`, `1992`,...,`2000`. GAMS builds up these label lists by looking at the differences between the two labels. If the only characters that differ are digits, and if the number (say `L`) formed by these digits in the left one is less than that from the right one (`R`), then a label is constructed for every integer in the sequence `L` to `R`. Any non-numeric differences or other inconsistencies cause errors.

The following example illustrates the most general form of the '*asterisked*' definition:

```
set  g  / a1bc * a20bc /;
```

Note that this is not the same as

```
set  g  / a01bc * a20bc /;
```

although the sets, which have 20 members each, have 11 members in common. As a last example, the following are all illegal because they are not consistent with the rule given above for making lists:

```
set  illegal1  / a20bc * a10bc /
     illegal2  / a1x1 * a9x9 /
     illegal3  / a1 * b9 /;
```

Note one last time that set elements (often referred to as labels) can contain the sign characters '`-`' and '`+`' as well as letters and numbers.

4.2.6 Declarations for Multiple Sets

The keyword `set` (if you prefer, say `sets` instead: the two are equivalent) does not need to be used for each set, rather only at the beginning of a group of sets. It is often convenient to put a group of set declarations together at the beginning of the program. When this is done the set keyword need only be used once. If you prefer to intermingle set declarations with other statements, you will have to use a new `set` statement for each additional group of sets.

The following example below shows how two sets can be declared together. Note that the semicolon is used only after the last set is declared.

```
sets
       s   "Sector"    /  manuf
                          agri
                          services
                          government  /
        r   "regions"  /  north
                          eastcoast
                          midwest
                          sunbelt    / ;
```

4.3 The Alias Statement: Multiple Names for a Set

It is sometimes necessary to have more than one name for the same set. In input-output models, for example, each commodity may be used in the production of all other commodities and it is necessary to have two names for the set of commodities to specify the problem without ambiguity. In the general equilibrium model [ORANI], the set of commodities is written

```
set  c   "commodities"  / food, clothing /  ;
```

and a second name for the set `c` is established with either of the following statements

```
alias (c, cp) ;
alias (cp, c) ;
```

where `cp` is the new set that can be used instead of the original set `c`.

☞ *The newly introduced set can be used as an alternative name for the original set, and will always contain only the same elements as the original set.*

The alias statement can be used to introduce more than one new name for the original set.

```
alias (c,cp, cpp, cppp);
```

where the new sets `cp`, `cpp`, `cppp` are all new names for the original set `c`.

☞ *The order of the sets in the alias statement does not matter. The only restriction set by GAMS is that exactly one of the sets in the statement be defined earlier. All the other sets are introduced by the alias statement.*

We will not demonstrate the use of set aliases until later. Just remember they are used for cases when a set has to be referred to by more than one name.

4.4 Subsets and Domain Checking

It is often necessary to define sets whose members must all be members of some larger set. The syntax is:

```
set set_ident1 (set_ident2) ;
```

where `set_ident1` is a subset of the larger set `set_ident2`.

For instance, we may wish to define the sectors in an economic model following the style in [CHENERY].

```
set
  i    "all sectors" / light-ind, food+agr, heavy-ind, services /
  t(i) "traded sectors" / light-ind, food+agr, heavy-ind /
  nt   "non-traded sectors" / services /  ;
```

Some types of economic activity, for example exporting and importing, may be logically restricted to a subset of all sectors. In order to model the trade balance, for example, we need to know which sectors are traded, and one obvious way is to list them explicitly, as in the definition of the set `t` above. The specification `t(i)` means that each member of the set `t` must also be a member of the set `i`. GAMS will enforce this relationship, which is called domain checking. Obviously the order of declaration is important: the membership of `i` must be known before `t` is declared for checking to be done. There will be much more on this topic in succeeding chapters. For now it is important to note that domain checking will find any spelling errors that might be made in establishing the members of the set `t`. These would cause errors in the model if they went undetected.

It is legal but unwise to define a subset without reference to the larger set, as is done above for the set `nt`. If services were misspelled no error would be marked, but the model would give incorrect results. So we urge you to use domain checking whenever possible. It catches errors and allows you to write models that are conceptually cleaner because logical relationships are made explicit.

This completes the discussion of sets in which the elements are simple. This is sufficient for most GAMS applications; however, there are a variety of problems for which it is useful to have sets that are defined in terms of two or more other sets.

4.5 Multi-dimensional Sets

It is often necessary to provide mappings between elements of different sets. For this purpose, GAMS allows the use of multi-dimensional sets.

☞ *GAMS allows sets with up to 20 dimensions.*

The next two sub-sections explain how to express one-to-one and many-to-many mappings between sets.

4.5.1 One-to-one Mapping

Consider a set whose elements are pairs: $A = \{(b,d),\ (a,c),\ (c,e)\}$.

In this set there are three elements and each element consists of a pair of letters. This kind of set is useful in many types of modeling. As an illustrative example, consider the world aluminum model [ALUM], where it is necessary to associate, with each bauxite-supplying country, a port that is near to the bauxite mines. The set of countries is

```
set  c   "countries"
       /  jamaica
          haiti
          guyana
          brazil  / ;
```

and the set of ports is

```
set    p   "ports"
/  kingston
   s-domingo
   georgetown
   belem  / ;
```

Then a set can be created to associate each port with its country, viz.,

```
set  ptoc(p, c)   "port to country relationship"
```

```
                / kingston    .jamaica
                  s-domingo   .haiti
                  georgetown  .guyana
                  belem       .brazil  /;
```

The dot between `kingston` and `jamaica` is used to create one such pair. Blanks may be used freely around the dot for readability. The set `ptoc` has four elements, and each element consists of a port-country pair. The notation `(p,c)` after the set name `ptoc` indicates that the first member of each pair must be a member of the set `p` of ports, and that the second must be in the set `c` of countries. This is a second example of domain checking. GAMS will check the set elements to ensure that all members belong to the appropriate sets.

4.5.2 Many-to-many Mapping

A many-to-many mapping is needed in certain cases. Consider the following set

```
set  i  / a, b /
     j  / c, d, e /
     ij1(i,j) /a.c, a.d/
     ij2(i,j) /a.c, b.c/
     ij3(i,j) /a.c, b.c, a.d, b.d/ ;
```

`ij1`	represents a one-to-many mapping where one element of `i` maps onto many elements of `j`.
`ij2`	represents a many-to-one mapping where many elements of `i` map onto one element of `j`.
`ij3`	is the most general case where many elements of `i` map on to many elements of `j`.

These sets can be written compactly as

```
set  i  / a, b /
     j  / c, d, e /
     ij1(i,j) /a.(c,d)/
     ij2(i,j) /(a,b).c/
     ij3(I,j) /(a,b).(c,d)/ ;
```

The parenthesis provides a list of elements that can be expanded when creating pairs.

☞ *When complex sets like this are created, it is important to check that the desired set has been obtained. The checking can be done by using a display statement.*

The concepts may be generalized to set with more than two labels per set element. Mathematically these are called 3-tuples, 4-tuples, or more generally, n-tuples.

This section ends with some examples to illustrate definitions of multi-label set elements. Some examples of the compact representation of sets of n-tuples using combinations of dots, parentheses and commas are shown in table 4.1.

Construct	*Result*
`(a,b).c.d`	`a.c.d, b.c.d`
`(a,b).(c,d) .e`	`a.c.e, b.c.e, a.d.e, b.d.e`
`(a.1*3).c`	`(a.1, a.2, a.3).c` or `a.1.c, a.2.c, a.3.c`
`1*3.  1*3.  1*3`	`1.1.1, 1.1.2, 1.1.3, ..., 3.3.3`

Table 4.1: Examples of the compact representation of sets

Note that the asterisk can also be used in conjunction with the dot. Recall that the elements of the list `1*4` are $\{1, 2, 3, 4\}$ when examining the examples in table 4.1.

4.6 Summary

In GAMS, a simple `set` consists of a set name and the elements of the set. Both the name and the elements may have associated text that explains the name or the elements in more detail. More complex sets have elements that are pairs or even n-tuples. These sets with pairs and n-tuples are ideal for establishing relationships between the elements in different sets. GAMS also uses a domain checking capability to help catch labeling inconsistencies and typographical errors made during the definition of related sets.

The discussion here has been limited to sets whose members are all specified as the set is being declared. For many models this is all you need to know about sets. Later we will discuss more complicated concepts, such as sets whose membership changes in different parts of the model (assignment to sets) and other set operations such as unions, complements and intersections.

5

Data Entry: Parameters, Scalars & Tables

5.1 Introduction

One of the basic design paradigms of the GAMS language has been to use data in its most basic form, which may be scalar, list oriented, or tables of two or more dimensions. Based on this criterion, three data types are introduced in this chapter.

`Scalar`	Single (scalar) data entry.
`Parameter`	List oriented data.
`Table`	Table oriented data. Must involve two or more dimensions.

Each of these data types will be explained in detail in the following sections.

☞ *Initialization of data can only be done once for parameters; thereafter data must be modified with assignment statements.*

5.2 Scalars

The `scalar` statement is used to declare and (optionally) initialize a GAMS parameter of dimensionality zero. That means there are no associated sets, and that there is therefore exactly one number associated with the parameter.

5.2.1 The Syntax

In general, the syntax in GAMS for a `scalar` declaration is:

```
scalar[s] scalar_name [text] [/signed_num/]
       {  scalar_name [text] [/signed_num/]} ;
```

`Scalar_name` is the internal name of the scalar (also called an identifier) in GAMS. The accompanying text is used to describe the element immediately preceding it. `Signed_num` is a signed number and is assigned to be the value of `scalar_name`.

As with all identifiers, `scalar_name` has to start with a letter followed by more letters or digits. It can only contain alphanumeric characters, and can be up to 63 characters long. Explanatory text must not exceed 254 characters and must all be contained on the same line as the identifier or label it describes.

5.2.2 An Illustrative Example

An example of a `scalar` definition in GAMS is shown below.

```
Scalars   rho  "discount rate"  / .15 /
          irr  "internal rate of return"
          life "financial lifetime of productive units"  /20/;
```

The statement above initializes `rho` and `life`, but not `irr`. Later on another `scalar` statement can be used to initialize `irr`, or, (looking ahead to a notion that will be developed later), an assignment statement could be used to provide the value:

```
irr  =  0.07;
```

5.3 Parameters

While `parameter` is a data type that encompasses `scalars` and `tables`, the discussion in this chapter will focus on the use of `parameters` in data entry. List oriented data can be read into GAMS using the `parameter` statement.

5.3.1 The Syntax

In general, the syntax in GAMS for a `parameter` declaration is:

```
parameter[s] param_name [text] [/ element [=] signed_num
                                {,element [=] signed num} /]
           {,param_name [text] [/ element [=] signed_num
                                {,element [=] signed num} /]} ;
```

`Param_name` is the internal name of the parameter (also called an identifier) in GAMS. The accompanying text is used to describe the parameter immediately preceding it. `Signed_num` is a signed number and is declared to be the value of the entry associated with the corresponding element.

As with all identifiers, `param_name` has to start with a letter followed by more letters or digits. It can only contain alphanumeric characters, and can be up to 63 long. Explanatory text must not exceed 254 characters and must all be contained on the same line as the identifier or label it describes.

A parameter may be indexed over one or more sets (the maximum number being 20). The elements in the data should belong to the set that the parameter is indexed over.

☞ *The default value of a* `parameter` *is 0.*

Parameter initialization requires a list of data elements, each consisting of a label and a value. Slashes must be used at the beginning and end of the list, and commas must separate data elements entered more than one to a line. An equals sign or a blank may be used to separate the label-tuple from its associated value. A parameter can be defined in a similar syntax to that used for a set.

5.3.2 An Illustrative Examples

The fragment below is adapted from [MEXSS]. We also show the set definitions because they make the example clearer.

```
Set  i   "steel plants"   / hylsa     "monterrey"
                            hylsap    "puebla"  /
     j   "markets"        / mexico-df, monterrey, guadalaja / ;

parameter  dd(j)    distribution of demand
                         /  mexico-df   55,
                            guadalaja   15 / ;
```

The domain checking specification for dd means that there will be a vector of data associated with it, one number corresponding to every member of the set j listed. The numbers are specified along with the declaration in a format very reminiscent of the way we specified sets: in this simple case a label followed by a blank separator and then a value. Any of the legal number entry formats are allowable for the value. The default data value is zero. Since monterrey has been left out of the data list, then the value associated with dd('monterrey'), the market share in monterrey, would be zero.

We can also put several data elements on a line, separated by commas:

```
parameter  a(i)  / seattle  =  350,  san-diego  =  600 /
           b(i)  / seattle    2000,  san-diego    4500 / ;
```

As with sets, commas are optional at end-of-line.

5.3.3 Parameter Data for Higher Dimensions

A parameter can have up to 20 dimensions. The list oriented data initialization through the parameter statement can be easily extended to data of higher dimensionality. The label that appears on each line in the one-dimensional case is replaced by a label-tuple for higher dimensions. The elements in the n-tuple are separated by dots (.) just like in the case of multi-dimensional sets.

The following example illustrates the use of parameter data for higher dimensions:

```
parameter  salaries(employee,manager,department)
             /anderson  .murphy  .toy          = 6000
              hendry    .smith   .toy          = 9000
              hoffman   .morgan  .cosmetics    = 8000 /  ;
```

All the mechanisms using asterisks and parenthesized lists that we introduced in our discussion of sets are available here as well. Below is an artificial example, in which a very small fraction of the total data points are initialized. GAMS will mark an error if the same label combination (or label-tuple) appears more than once in a data list.

```
Set  row  / row1*row10 /
     col  / col1*col10 / ;
parameter  a(row, col)
         /  (row1,row4) . cl2*col7     12
              row10 . col10            17
              row1*row7 . col10        33  / ;
```

In this example, the twelve elements row1.col2 to row1.col7 and row4.col2 to row4.col7 are all initialized at 12, the single element row10.col10 at 17, and the seven elements rows1.col10 to row7.col10 at 33. The other 80 elements (out of a total of 100) remain at their default value, which is 0. This example shows the ability of GAMS to provide a concise initialization, or definition, for a sparse data structure.

5.4 Tables

Tabular data can be declared and initialized in GAMS using a table statement. For 2- and higher-dimensional parameters this provides a more concise and easier method of data entry than the list based approach, since each label appears only once (at least in small tables).

5.4.1 The Syntax

In general, the syntax in GAMS for a table declaration is:

```
table table_name [text] EOL
            element    { element }
            element    signed_num { signed_num} EOL
            {element   signed_num { signed_num} EOL} ;
```

`Table_name` is the internal name of the table (also called an identifier) in GAMS. The accompanying text is used to describe the parameter immediately preceding it. `Signed_num` is a signed number and is declared to be the value of the entry associated with the corresponding element.

☞ *The table statement is the only statement in the GAMS language that is not free format.*

The following rules apply:

- ➢ The relative positions of all entries in a table are significant. This is the only statement where end of line (EOL) has meaning. The character positions of the numeric table entries must overlap the character positions of the column headings.
- ➢ The column section has to fit on one line.
- ➢ The sequence of signed numbers forming a row must be on the same line.
- ➢ The element definition of a row can span more than one line.
- ➢ A specific column can appear only once in the entire table.

The rules for forming simple tables are straightforward. The components of the header line are the by now familiar `keyword-identifier-domain_list-text sequence`, the `domain-list` and text being optional. Labels are used on the top and the left to map out a rectangular grid that contains the data values. The order of labels is unimportant, but if domain checking has been specified each label must match one in the associated set. Labels must not be repeated, but can be left out if the corresponding numbers are all zero or not needed. At least one blank must separate all labels and data entries. Blank entries imply that the default value (zero) will be associated with that label combination.

☞ *Notice also that, in contrast to the* `set`*,* `scalar`*, and* `parameter` *statements, only one identifier can be declared and initialized in a table statement.*

5.4.2 An Illustrative Example

The example below, adapted from [KORPET], is preceded by the appropriate set definitions,

```
sets  i   "plants"
       /  inchon,ulsan,yosu /
      m   "productive units"
              atmos-dist         "atmospheric distillation unit"
              steam-cr           "steam cracker"
              aromatics          "aromatics unit"
              hydrodeal          "hydrodealkylator"  /  ;

table ka(m,i) "initial cap. of productive units (100 tons per yr)"
                 inchon      ulsan      yosu
atmos-dist         3702      12910      9875
steam-cr                       517      1207
aromatics                      181       148
hydrodeal                      180          ;
```

In the example above, the row labels are drawn from the set m, and those on the column from the set `i`. Note that the data for each row is aligned under the corresponding column headings.

☞ *If there is any uncertainty about which data column a number goes with, GAMS will protest with an error message and mark the ambiguous entry.*

5.4.3 Continued Tables

If a table has too many columns to fit nicely on a single line, then the columns that don't fit can be continued on additional lines. We use the same example to illustrate:

```
table ka(m,i)  initial cap. of productive units (100 tons per yr)
               inchon    ulsan
atmos-dist     3702      12910
steam-cr                   517
aromatics                  181
hydrodeal                  180

    +          yosu
atmos-dist     9875
steam-cr       1207
aromatics       148  ;
```

The crucial item is the plus '+' sign above the row labels and to the left of the column labels in the continued part of the table. The row labels have been duplicated, except that `hydroreal` has been left out, not having associated data. Tables can be continued as many times as necessary.

5.4.4 Tables with more than Two Dimensions

A table can have up to 20 dimensions. Dots are again used to separate adjacent labels, and can be used in the row or column position. The label on the left of the row corresponds to the first set in the domain list, and that on the right of each column header to the last. Obviously there must be the same number of labels associated with each number in the table, as there are sets in the domain list.

The actual layout chosen will depend on the size of the controlling sets and the amount of data, and the ideal choice should be the one that provides the most intuitively satisfactory way of organizing and inspecting the data. Most people can more easily look down a column of numbers than across a row, but to put extra labels on the row leads to a greater density of information.

The following example, adapted from [MARCO], illustrates the use of tables with more than two dimensions.

```
Sets  ci   "commodities :   intermediate"
       / naphtha    "naphtha"
         dist       "distillate"
         gas-oil    "gas-oil"  /
      cr   "commodities :   crude oils"
       / mid-c       "mid-continent"
         w-tex       "west-texas"  /
      q   "attributes of intermediate products"
       / density, sulfur /  ;

table attrib(ci, cr, q)    blending attributes
                       density    sulfur
naphtha. mid-c          272        .283
naphtha. w-tex          272       1.48
dist   . mid-c          292        .526
dist   . w-tex          297         2.83
gas-oil. mid-c          295        .98
gas-oil. w-tex          303       5.05   ;
```

The table `attrib` could also be laid out as shown below:

```
table attrib (ci,cr,q)   blending attributes
        w-tex.density  mid-c.density  w-tex.sulfur  mid-c.sulfur
naphtha      272            272         1.48      .283
dist         297            297         2.83      .526
gas-oil      303            303         5.05      .98   ;
```

5.4.5 Condensing Tables

All the mechanisms using asterisks and parenthesized lists that were introduced in the discussion of sets are available here as well. The following example shows how repeated columns or rows can be condensed with asterisks and lists in parentheses follows. The set membership is not shown, but can easily be inferred.

```
table upgrade(strat,size,tech)
            small.tech1  small.tech2  medium.tech1  medium.tech2
strategy-1       .05          .05           .05           .05
strategy-2       .2           .2             .2           .2
strategy-3       .2           .2             .2           .2
strategy-4                                   .2           .2

table upgradex(strat,size,tech) alternative way of writing table
                                     tech1*tech2
strategy-1.(small,medium)                 .05
strategy-2*strategy-3.(small,medium)      .2
trategy-4.medium                          .2;

display attrib, attribx;
```

Here we encounter the `display` statement again. It causes the data associated with `upgrade` and `upgradex` to be listed on the output file.

5.4.6 Handling Long Row Labels

It is possible to continue the row labels in a table on a second, or even third, line in order to accommodate a reasonable number of columns. The break must come after a dot, and the rest of each line containing an incomplete row label-tuple must be blank.

The following example, adapted from [INDUS], is used to illustrate. As written, this table actually has nine columns and many rows: we have just reproduced a small part to show continued row label-tuples.

```
table yield (c,t,s,w,z)      crop yield (metric tons per acre)
                                                   nwfp     pmw
wheat.(bullock, semi-mech).la-plant.
                                 (heavy, january)   .385     .338
wheat.(bullock, semi-mech).la-plant.light           .506     .446
wheat.(bullock, semi-mech).la-plant. standard       .592     .524
wheat.(bullock, semi-mech).(qk-harv, standard).
                                 (heavy, january) .439       .387
```

5.5 Acronyms

An acronym is a special data type that allows the use of strings as values.

5.5.1 The Syntax

The declaration for an acronymis similar to a set or parameter declaration in that several of them can be declared in one statement.

```
Acronym[s]  acronym_name {,acronym_name}
```

`Acronym_name` is an identifier and follows the same naming convention as other identifiers like names of sets, parameters, or tables.

5.5.2 Illustrative Example

Consider the following example,

```
set machines /m-1*m-5/ ; acronyms monday, tuesday, wednesday, thursday, friday ;
parameter shutdown(machines) /
   m-1  tuesday
```

```
m-2  wednesday
m-3  friday
m-4  monday
m-5  thursday
/ ;
```

In the example above, data entries are in the form of strings like 'monday' and 'tuesday'. By declaring each of those character strings as acronyms, this kind of data entry can be used by GAMS. Sections 6.2.7 and 11.2.5 will explain the further use of acronyms once entered in this form.

5.6 Summary

In this chapter, the declaration and initialization of parameters with the parameter, scalar and the table statement have been discussed. The next chapter will describe how this data can be changed with assignment statements.

6

Data Manipulations with Parameters

6.1 Introduction

Data once initialized may require manipulation in order to bring it to the form required in the model. The first part of this chapter will deal explicitly with parameter manipulation. The rest of the chapter will be devoted to explaining the ramifications: indexed assignment functions, index operations.

6.2 The Assignment Statement

The assignment statement is the fundamental data manipulation statement in GAMS. It may be used to define or alter values associated with any sets, parameters, variables or equations.

A simple assignment is written in the style associated with many other computer languages. GAMS uses the traditional symbols for addition (+), subtraction (-), multiplication (*) and division (/). We will use them in the examples that follow, and give more details in Section 6.3, page 53.

6.2.1 Scalar Assignments

Consider the following artificial sequence:

```
scalar x  / 1.5/ ;
x = 1.2;
x = x + 2;
```

The scalar `x` is initialized to be 1.5. The second statement changes the value to 1.2, and the third changes it to 3.2. The second and third statement assignments have the effect of replacing the previous value of `x`, if any, with a new one.

Note that the same symbol can be used on the left and right of the = sign. The new value is not available until the calculation is complete, and the operation gives the expected result.

☞ *An assignment cannot start with a reserved word. A semicolon is therefore required as a delimiter before all assignments.*

6.2.2 Indexed Assignments

The syntax in GAMS for performing indexed assignments is extremely powerful. This operation offers what may be thought of as simultaneous or parallel assignment and it provides a concise way of specifying large amounts of data. Consider the mathematical statement, $DJ_d = 2.75 DA_d$ for all d.

This means that for every member of the set *d*, a value is assigned to *DJ*. This can be written in GAMS as follows,

```
dj(d) = 2.75*da(d) ;
```

This assignment is known technically as an indexed assignment and set `d` will be referred to as the controlling index or controlling set.

☞ *The index sets on the left hand side of the assignment are together called the controlling domain of the assignment*

The extension to two or more controlling indices should be obvious. There will be an assignment made for each label combination that can be constructed using the indices inside the parenthesis. Consider the following example of an assignment to all 100 data elements of `a`.

```
Set   row        / r-1*r-10 /
      col        / c-1*c-10 /
      sro(row)   / r-7*r-10 / ;
parameters  a(row,col),
a(row,col)  =  13.2 + r(row)*c(col)  ;
```

The calculation in the last statement is carried out for each of the 100 unique two-label combinations that can be formed from the elements of `row` and col. The first of these is, explicitly,

```
a('r-1','c-1') = 13.2 + r('r-1')*c('c-1').
```

6.2.3 Using Labels Explicitly in Assignments

It is often necessary to use labels explicitly in assignments. This can be done as discussed earlier with parameters - by using quotes around the label. Consider the following assignment,

```
a('r-7','c-4') = -2.36 ;
```

This statement assigns a constant value to one element of `a`. All other elements of `a` remain unchanged. Either single or double quotes can be used around the labels.

6.2.4 Assignments Over Subsets

In general, wherever a set name can occur in an indexed assignment, a subset (or even a label) can be used instead if you need to make the assignment over a subset instead of the whole domain.

Consider the following example,

```
a(sro,'col-10')  =  2.44 -33*r(sro) ;
```

where `sro` has already been established to be a proper subset of `row`.

6.2.5 Issues with Controlling Indices

☞ *The number of controlling indices on the left of the* = *sign should be at least as many as the number of indices on the right. There should be no index on the right hand side of the assignment that is not present on the left unless it is operated on by an indexed operator*

Consider the following statement,

```
a(row,'col-2')  = 22 - c(col)   1;
```

GAMS will flag this statement as an error since `col` is an index on the right hand side of the equation but not on the left.

☞ *Each set is counted only once to determine the number of controlling indices. If the same set appears more than once within the controlling domain, the second and higher occurrences of the set should be* `aliases` *of the original set in order for the number of controlling indices to be equal to the number of indices.*

Consider the following statement as an illustration,

```
b(row,row)  =  7.7 - r(row) ;
```

This statement has only one controlling index (`row`). If one steps through the elements of `row` one at a time assignments will be made only to the diagonal entries in `b`. This will assign exactly 10 values! None of the off-diagonal elements of `b` will be filled.

If an additional name is provided for `row` and used in the second index position, then there will be two controlling indices and GAMS will make assignments over the full Cartesian product, all 100 values. Consider the following example,

```
alias(row,rowp)  ;
b(row,rowp)  = 7.7 - r(row) + r(rowp) ;
```

6.2.6 Extended Range Identifiers in Assignments

The GAMS *extended range* identifiers can also be used in assignment statements, as in

```
a(row,'col-10')  =  inf ;  a(row,'col-1')  =  -inf ;
```

Extended range arithmetic will be discussed later in this Section. The values most often used are `NA` in incomplete tables, and `INF` for variable bounds.

6.2.7 Acronyms in Assignments

Acronyms can also be used in assignment statements, as in

```
acronym monday, tuesday, wednesday, thursday, friday ;
parameter dayofweek ;
dayofweek = wednesday ;
```

☞ *Acronyms contain no numeric value, and are treated as character strings* only.

6.3 Expressions

An expression is an arbitrarily complicated specification for a calculation, with parentheses nested as needed for clarity and intent. In this section, the discussion of parameter assignments will continue by showing in more detail the expressions that can be used on the right of the `=` sign. All numerical facilities available in both standard and *extended* arithmetic will be covered.

6.3.1 Standard Arithmetic Operations

The standard arithmetic symbols and operations are

`**`	exponentiation

`*,/`	multiplication and division
`+,-`	addition and subtraction (unary and binary)

They are listed above in precedence order, which determines the order of evaluation in an expression without parentheses.

Consider, for example:

```
x = 5 + 4*3**2 :
```

For clarity, this could have been written:

```
x = 5 + (4*(3**2)) ;
```

In both cases the result is 41.

☞ *It is better to use parentheses than to rely on the precedence of operators, since it prevents errors and clarifies intentions.*

☞ *Expressions may be freely continued over many lines: an end-of-line is permissible at any point where a blank may be used. Blanks may be used for readability around identifiers, parentheses and operator symbols. Blanks are not allowed within identifiers or numbers, and are significant inside the quote marks used to delimit labels.*

☞ *`x**n` is calculated inside GAMS as `exp[n*log(x)]`. This operation is not defined if `x` has a negative value, and an error will result. If the possibility of negative values for `x` is to be admitted* and *the exponent is known to be an integer, then a function call, `power(x,n)`, is available.*

Three additional capabilities are available to add power and flexibility of expression calculations. They are indexed operations, functions and extended range arithmetic.

6.3.2 Indexed Operations

In addition to the simple operations explained before, GAMS also provides the following four indexed operations.

`sum`	Summation over controlling index
`prod`	Product over controlling index
`smin`	Minimum value over controlling index
`smax`	Maximum value over controlling index

These four operations are performed over one or more controlling indices. The syntax in GAMS for these operations is,

```
indexed_op( (controlling_indices), expression)
```

If there is only one controlling index, the parentheses around it can be removed. The most common of these is `sum`, which is used to calculate totals over the domain of a set. Consider the following simple example adapted from [ANDEAN] for illustration.

```
sets i   plants  / cartagena, callao, moron /
     m   product / nitr-acid, sulf-acid, amm-sulf /;

parameter capacity(i,m) capacity in tons per day
          totcap(m)     total capacity by process ;

totcap(m) = sum(i, capacity(i,m));
```

This would be written, using normal mathematical representation, as $totC_m = \sum_i C_{im}$.

The index over which the summation is done, `i`, is separated from the reserved word `sum` by a left parenthesis and from the data term `capacity(i,m)` by a comma. `i` is again called the controlling index for this operation. The scope of the control is the pair of parentheses `()` that starts immediately after the sum. It is not likely to be useful to have two independent index operations controlled by the same index.

It is also possible to sum simultaneously over the domain of two or more sets, in which case more parentheses are needed. Also, of course, an arithmetic expression may be used instead of an identifier;

```
count = sum((i,j), a(i,j)) ;
emp = sum(t, l(t)*m(t)) ;
```

The equivalent mathematical forms are:

$$\texttt{count} = \sum_i \sum_j A_{ij} \quad \text{and} \quad \texttt{emp} = \sum_t L_t M_t$$

The `smin` and `smax` operations are used to find the largest and smallest values over the domain of the index set or sets. The index for the `smin` and `smax` operators is specified in the same manner as in the index for the `sum` operator. Consider the following example to find the largest capacity,

```
lrgunit = smax((i,m),capacity(i,m));
```

6.3.3 Functions

Functions play an important part in the GAMS language, especially for non-linear models. Similar to other programming languages, GAMS provides a number of built-in (intrinsic) functions. However, GAMS is used in an extremely diverse set of application areas and this creates frequent requests for the addition of new and often sophisticated and specialized functions. There is a trade-off between satisfying these requests and avoiding complexity not needed by most users. The GAMS Function Library Facility (6.3.3) provides the means for managing that trade-off.

Intrinsic Functions

GAMS provides commonly used standard functions such as exponentiation, and logarithmic, and trigonometric functions. The complete list of available functions is given in table 6.1. There are cautions to be taken when functions appear in equations; these are dealt with in Section 8.4, page 74.

In table 6.1, the Endogenous Classification (second column) specifies in which models the function can legally appear with endogenous (non-constant) arguments. In order of least to most restrictive, the choices are *any*, *NLP*, *DNLP* or *none* (see Section 9.2.2 for details).

The following conventions are used for the function arguments. Lower case indicates that an endogenous variable is allowed. Upper case indicates that a constant argument is required. The arguments in square brackets can be omitted and default values will be used. Those default values are specified in the function description provided in the last column.

Function	*Endogenous Classification*	*Description*
Mathematical functions		
`abs(x)`	DNLP	returns the absolute value of an expression or term x
`arccos(x)`	NLP	returns the inverse cosine of the argument x where x is a real number between -1 and 1 and the output is in radians, see MathWorld

`arcsin(x)`	NLP	returns the inverse sine of the argument x where x is a real number between -1 and 1 and the output is in radians, see MathWorld
`arctan(x)`	NLP	returns the inverse tangent of the argument x where x is a real number and the output is in radians, see MathWorld
`arctan2(y,x)`	NLP	four-quadrant arctan function yielding arctangent(y/x) which is the angle the vector (x,y) makes with (1,0) in radians
`Beta(x,y)`	DNLP	beta function: $B(x,y) = \frac{\gamma(x)\gamma(y)}{\gamma(x+y)}$, see MathWorld
`betaReg(x,y,z)`	NLP	regularized beta function, see MathWorld
`binomial(n,k)`	NLP	returns the (generalized) binomial coefficient for $n,k \geq 0$
`ceil(x)`	DNLP	returns the smallest integer number greater than or equal to x
`centropy(x,y[,Z])`	NLP	Centropy: $x \cdot \ln(\frac{x+Z}{y+Z})$, default setting: $Z = 0$
`cos(x)`	NLP	returns the cosine of the argument x where x must be in radians, see MathWorld
`cosh(x)`	NLP	returns the hyperbolic cosine of x where x must be in radians, see MathWorld
`cvPower(X,y)`	NLP	returns X^y for $X \geq 0$, another possible command is '`X**y`'
`div(dividend,divisor)`	NLP	returns $\frac{dividend}{divisor}$, undefined for $divisor = 0$
`div0(dividend,divisor)`	NLP	returns $\frac{dividend}{divisor}$, returns 1^{299} for $divisor = 0$
`eDist(x1[,x2,x3,x4,x5,x6])`	NLP	Euclidean or L-2 Norm: $\sqrt{x_1^2 + x_2^2 + ...}$, default setting: $x_2, x_3, x_4, x_5, x_6 = 0$
`entropy(x)`	NLP	Entropy: $-x \cdot \ln(x)$
`errorf(x)`	NLP	calculates the integral of the standard normal distribution from negative infinity to x, $errorf(x) = \frac{1}{\sqrt{2\pi}} \int\limits_{-\infty}^{x} e^{\frac{-t^2}{2}} dt$
`execSeed`	none	reads or writes the seed for the random number generator
`exp(x)`	NLP	returns the exponential function e^x of an expression or term x, see MathWorld
`fact(X)`	any	returns the factorial of X where X is an integer
`floor(x)`	DNLP	returns the greatest integer number less than or equal to x
`frac(x)`	DNLP	returns the fractional part of x
`gamma(x)`	DNLP	gamma function: $\gamma(x) = \int\limits_{0}^{\infty} t^{x-1} e^{-t} dt$, see MathWorld
`gammaReg(x,a)`	NLP	regularized gamma function, see MathWorld
`log(x)`	NLP	returns the natural logarithm, logarithm base e, see MathWorld
`logBeta(x,y)`	NLP	log beta function: $\log(B(x,y))$
`log10(x)`	NLP	returns the common logarithm, logarithm base 10, see MathWorld
`log2(x)`	NLP	returns the binary logarithm, logarithm base 2, see MathWorld
`max(x1,x2,x3,...)`	DNLP	returns the maximum of a set of expressions or terms, the number of arguments is not limited
`min(x1,x2,x3,...)`	DNLP	returns the minimum of a set of expressions or terms, the number of arguments is not limited
`mod(x,y)`	DNLP	returns the remainder of x divided by y
`ncpCM(x,y,Z)`	NLP	function that computes a Chen-Mangasarian smoothing equaling: $x - Z \cdot \ln(1 + e^{\frac{x-y}{Z}})$

`ncpF(x,y[,Z])`	NLP	function that computes a Fisher smoothing equaling: $\sqrt{(x^2+y^2+2\cdot Z)}-x-y, \qquad Z \geq 0$, default setting: $Z=0$
`ncpVUpow(r,s[,MU])`	NLP	NCP Veelken-Ulbrich: smoothed min $\text{ncpVUpow} = \begin{cases} \frac{(r+s-\lvert t\rvert)}{2} & \text{if } \lvert t\rvert \geq \mu \\ \frac{(r+s-\frac{\mu}{8}\cdot(-(\frac{t}{\mu})^4+6(\frac{t}{\mu})^2+3))}{2} & \text{otherwise} \end{cases}$ where $t=r-s$, default setting: $MU=0$
`ncpVUsin(r,s[,MU])`	NLP	NCP Veelken-Ulbrich: smoothed min $\text{ncpVUsin} = \begin{cases} \frac{(r+s-\lvert t\rvert)}{2} & \text{if } \lvert t\rvert \geq \mu \\ \frac{(r+s-(\frac{2\mu}{\pi}\sin(\frac{\pi\cdot}{2\mu}+\frac{3\pi}{2})+\mu))}{2} & \text{otherwise} \end{cases}$ where $t=r-s$, default setting: $MU=0$
`normal(MEAN,STDDEV)`	none	generates a random number with normal distribution with mean MEAN and standard deviation STDDEV, see MathWorld
`pi`	any	value of $\pi = 3.141593...$
`poly(x,A0,A1,A2[,A3,A4])`	NLP	computes a polynomial over scalar x where result $= A_0+A_1x+A_2x^2+A_3x^3+...$ - this has a maximum of 6 arguments, default setting: $A_3, A_4 = 0$
`power(x,Y)`	NLP	returns x^Y where Y must be an integer, another possible command is 'x**Y'
`randBinomial(N,P)`	none	generates a random number with binomial distribution where n is the number of trials and p the probability of success for each trial, see MathWorld
`randLinear(LOW,SLOPE,HIGH)`	none	generates a random number between LOW and HIGH with linear distribution, SLOPE must be greater than $\frac{2}{\text{HIGH}-\text{LOW}}$
`randTriangle(LOW,MID,HIGH)`	none	generates a random number between LOW and HIGH with triangular distribution, MID is the most probable number, see MathWorld
`round(x[,DECPL])`	DNLP	rounding x, DECPL declares the number of decimal places, default setting: DECPL = 0
`rPower(x,y)`	NLP	returns x^y for $x, y \geq 0$, another possible command is '`x**y`'
`sigmoid(x)`	NLP	Sigmoid calculation: $\frac{1}{1+e^{-x}}$, see MathWorld
`sign(x)`	DNLP	sign of x, returns 1 if $x>0$, -1 if $x<0$, and 0 if $x=0$
`signPower(x,Y)`	NLP	signed power, another possible command is 'sign(x)*abs(x)**Y', where Y must be greater than 0
`sin(x)`	NLP	returns the sine of the argument x where x must be in radians, see MathWorld
`sinh(x)`	NLP	returns the hyperbolic sine of x where x must be in radians, see MathWorld
`slexp(x[,SP])`	NLP	smooth (linear) exponential function, SP means smoothing parameter, default setting: $SP=150$
`sllog10(x[,SP])`	NLP	smooth (linear) logarithm base 10, SP means smoothing parameter, default setting: $SP=10^{-150}$
`slrec(x[,SP])`	NLP	smooth (linear) reciprocal, SP means smoothing parameter, default setting: $SP=10^{-10}$
`sqexp(x[,SP])`	NLP	smooth (quadratic) exponential funtion, SP means smoothing parameter, default setting: $SP=150$

`sqlog10(x[,SP])`	NLP	smooth (quadratic) logarithm base 10, SP means smoothing parameter, default setting: $SP = 10^{-150}$
`sqr(x)`	NLP	returns the square of an expression or term x
`sqrec(x[,SP])`	NLP	smooth (quadratic) reciprocal, SP means smoothing parameter, default setting: $SP = 10^{-10}$
`sqrt(x)`	NLP	returns the squareroot of x, see MathWorld
`tan(x)`	NLP	returns the tangent of the argument x where x must be in radians, see MathWorld
`tanh(x)`	NLP	returns the hyperbolic tangent of x where x must be in radians, see MathWorld
`trunc(x)`	DNLP	truncation, removes decimals from x
`uniform(LOW,HIGH)`	none	generates a random number between LOW and HIGH with uniform distribution, see MathWorld
`vcPower(x,Y)`	NLP	returns x^Y for $x \geq 0$, another possible command is '`x**Y`'

Logical functions

`bool_and(x,y)`	DNLP	boolean and: returns 0 if $x = 0 \quad \vee \quad y = 0$, else returns 1, another possible command is '`x and y`'
`bool_eqv(x,y)`	DNLP	boolean equivalence: returns 0 if exactly one argument is 0, else returns 1, another possible command is '`x eqv y`'
`bool_imp(x,y)`	DNLP	boolean implication: returns 1 if $x = 0 \vee y \neq 0$, else returns 0, another possible command is '`x imp y`'
`bool_not(x)`	DNLP	boolean not: returns 1 if $x = 0$, else returns 0, another possible command is '`not x`'
`bool_or(x,y)`	DNLP	boolean or: returns 0 if $x = y = 0$, else returns 1, another possible command is '`x or y`'
`bool_xor(x,y)`	DNLP	boolean xor: returns 1 if exactly one argument is 0, else returns 0, another possible command is '`x xor y`'
`ifThen(cond,iftrue,else)`	DNLP	first argument contains a condition (e.g. $x > y$). If the condition is true, the function returns `iftrue` else it returns `else`.
`rel_eq(x,y)`	DNLP	relation 'equal': returns 1 if $x = y$, else returns 0, another possible command is '`x eq y`'
`rel_ge(x,y)`	DNLP	relation 'greater equal': returns 1 if $x \geq y$, else returns 0, another possible command is '`x ge y`'
`rel_gt(x,y)`	DNLP	relation 'greater than': returns 1 if $x > y$, else returns 0, another possible command is '`x gt y`'
`rel_le(x,y)`	DNLP	relation 'less equal': returns 1 if $x \leq y$, else returns 0, another possible command is '`x le y`'
`rel_lt(x,y)`	DNLP	relation 'less than': returns 1 if $x < y$, else returns 0, another possible command is '`x lt y`'
`rel_ne(x,y)`	DNLP	relation 'not equal': returns 1 if $x \neq y$, else returns 0, another possible command is '`x ne y`'

Time and Calendar functions

`gday(SDAY)`	any	returns Gregorian day from a serial day number date.time, where Jan 1, 1900 is day 1
`gdow(SDAY)`	any	returns Gregorian day of week from a serial day number date.time, where Jan 1, 1900 is day 1

`ghourSDAY)`	any	returns Gregorian hour of day from a serial day number date.time, where Jan 1, 1900 is day 1
`gleap(SDAY)`	any	returns 1 if the year that corresponds to a serial day number date.time, where Jan 1, 1900 is day 1, is a leap year, else returns 0
`gmillisec(SDAY)`	any	returns Gregorian milli second from a serial day number date.time, where Jan 1, 1900 is day 1
`gminute(SDAY)`	any	returns Gregorian minute of hour from a serial day number date.time, where Jan 1, 1900 is day 1
`gmonth(SDAY)`	any	returns Gregorian month from a serial day number date.time, where Jan 1, 1900 is day 1
`gsecond(SDAY)`	any	returns Gregorian second of minute from a serial day number date.time, where Jan 1, 1900 is day 1
`gyear(SDAY)`	any	returns Gregorian year from a serial day number date.time, where Jan 1, 1900 is day 1
`jdate(YEAR,MONTH,DAY)`	any	returns a serial day number, starting with Jan 1, 1900 as day 1
`jnow`	none	returns the current time as a serial day number, starting with Jan 1, 1900 as day 1
`jstart`	none	returns the time of the start of the GAMS job as a serial day number, starting with Jan 1, 1900 as day 1
`jtime(HOUR,MIN,SEC)`	any	returns fraction of a day that corresponds to hour, minute and second
GAMS utility and performance functions		
`errorLevel`	none	error code of the most recently used command
`execError`	none	number of execution errors, may either be read or assigned to
`gamsRelease`	none	returns the version number of the current GAMS release, for example 23.8
`gamsVersion`	none	returns the current gams version, for example 238
`handleCollect(HANDLE)`	none	tests if the solve of the problem identified by the calling argument HANDLE is done and if so loads the solution into GAMS. In particular it returns: • 0: if the model associated with HANDLE had not yet finished solution or could not be loaded • 1: if the solution has been loaded
`handleDelete(HANDLE)`	none	deletes the grid computing problem identified by the HANDLE calling argument and returns a numerical indicator of the status of the deletion as follows: • 0: if the the model instance has been removed • 1: if the argument HANDLE is not a legal handle • 2: if the model instance is not known to the system • 3: if the deletion of the model instance encountered errors A nonzero return indicates a failure in the deletion and causes an execution error.

`handleStatus(HANDLE)`	none	tests if the solve of the problem identified by the calling argument HANDLE is done and if so loads the solution into a GDX file. A numerical indication of the result is returned as follows: • 0: if a model associated with HANDLE is not known to the system • 1: the model associaed with HANDLE exists but the solution process is incomplete • 2: the solution process has terminated and the solution is ready for retrieval • 3: the solution process signaled completion but the solution cannot be retrieved An execution error is triggered if GAMS cannot retrieve the status of the handle.
`handleSubmit(HANDLE)`	none	resubmits a previously created instance of the model identified by the HANDLE for solution. A numerical indication of the result is returned as follows: • 0: the model instance has been resubmitted for solution • 1: if the argument HANDLE is not a legal handle • 2: if a model associated with the HANDLE is not known to the system • 3: the completion signal could not be removed • 4: the resubmit procedure could not be found • 5: the resubmit process could not be started In case of a nonzero return an execution error is triggered.
`heapFree`	none	allocated memory which is no more in use but not freed yet
`heapLimit`	none	interrogates the current heap limit (maximum allowable memory use) in Mb and allows it to be reset
`heapSize`	none	returns the current heap size in Mb
`jobHandle`	none	returns the Process ID (PID) of the last job started
`jobKill(PID)`	none	sends a kill signal to the running job with Process ID PID, the return value is one if this was succesful, otherwise it is zero
`jobStatus(PID)`	none	checks for the status of the job with the Process ID PID, possible return values are: • 0: error (input is not a valid PID or access is denied) • 1: process is still running • 2: process is finished with return code which could be accessed by errorlevel • 3: process not running anymore or was never running, no return code available
`jobTerminate(PID)`	none	sends an interrupt signal to the running job with Process ID PID, the return value is one if this was succesful, otherwise it is zero
`licenseLevel`	any	returns an indicator of type of license: • 0: demo license, limited to small models • 1: full unlimited developer license • 2: run time license, no new variables or equations can be introduced besides those inherited in a work file • 3: application license, only works with a specific work file which is locked to the license file
`licenseStatus`	any	returns a non zero when a license error is incurred

`maxExecError`	none	maximum number of execution errors, may either be read or assigned to
`sleep(SEC)`	none	execution pauses for SEC seconds
`timeClose`	none	returns the model closing time
`timeComp`	none	returns the compilation time in seconds
`timeElapsed`	none	returns the elapsed time in seconds since the start of a GAMS run
`timeExec`	none	returns the execution time in seconds
`timeStart`	none	returns the model start time since last restart

Table 6.1: GAMS functions

Consider the following example of a function used as an expression in an assignment statement,

```
x(j) = log(y(j))  ;
```

which replaces the current value of `x` with the natural logarithm of `y` over the domain of the index set `j`.

Extrinsic Functions

Using the GAMS Function Library Facility, functions can be imported from an external library into a GAMS model. Apart from the import syntax, the imported functions can be used in the same way as intrinsic functions. In particular, they can be used in equation definitions. Some function libraries are included with the standard GAMS software distribution but GAMS users can also create their own libraries using an open programming interface. Simple examples in the programming languages C, Delphi and Fortran come with every GAMS system. Contact support@gams.com for detailed instructions.

Using Function Libraries

Function libraries are made available to a model using a compiler directive:

```
$FuncLibIn <InternalLibName> <ExternalLibName>
```

Note that the Function Library Facility gives you complete control over naming so that potential name conflicts between libraries can be avoided. The `<InternalLibName>` will be used to refer to the library inside your model source code. The `<ExternalLibName>` is the one given the library when it was created. To access libraries included with your GAMS distribution you use the library's name with no path. GAMS will look for the library in a standard place within the GAMS installation. To access a library that is not part of the standard GAMS distribution the external name must include the absolute path of the library's location. When processing the `$FuncLibIn` directive, GAMS will validate the library, make the included functions available for use, and add a table of the included functions to the listing file.

Before using individual functions you must declare them:

```
Function <InternalFuncName> /<InternalLibName>.<FuncName>/;
```

Note that the syntax is similar to that used for declaring Sets, Parameters, Variables and so forth and that the control over potential naming conflicts extends to the names of the individual functions. The `<InternalFuncName>` is the one that you will use in the rest of your model code. The `<InternalLibName>` is the one that you created with the `$FuncLibIn` directive and `<FuncName>` is the name given the function when the library was created. Once functions have been declared with the `Function` statement they may be used exactly like intrinsic functions in the remainder of your model code.

Example

Here is an example that adds some concrete detail.

```
$eolcom //

$FuncLibIn trilib tridclib    // Make the library available.
                              // trilib is the internal name being created now.
                              // tridclib is the external name.
                              // With no path, GAMS will look for tridclib in
                              // the standard GAMS installation.

* Declare each of the functions that will be used.
* myCos, mySin and MyPi are names being declared now for use in this model.
* Cosine, Sine and Pi are the function names from the library.
* Note the use of the internal library name.

Function  myCos  /trilib.Cosine/
          mySin  /trilib.Sine/
          myPi   /trilib.Pi/;

scalar i, grad, rad, intrinsic;

for (i=1 to 360,
    intrinsic = cos(i/180*pi);
    grad = mycos(i,1);
    abort$round(abs(intrinsic-grad),4) 'cos', i, intrinsic, grad;
    rad  = mycos(i/180*pi);
    abort$round(abs(intrinsic-rad) ,4) 'cos', i, intrinsic, rad;);

variable x;
equation e;

e..   sqr(mysin(x)) + sqr(mycos(x)) =e= 1;
model m /e/;
x.lo = 0; x.l=3*mypi
solve m min x using nlp;
```

The following lines from the listing file describe the library loaded.

```
FUNCLIBIN  trilib tridclib
Function Library trilib
Mod. Function                      Description
Type
NLP  Cosine(x[,MODE])              Cosine: mode=0 (default) -> rad, mode=1 -> grad
NLP  Sine(x[,MODE])                Sine  : mode=0 (default) -> rad, mode=1 -> grad
any  Pi                            Pi
```

A description of the libraries included in the GAMS sytem can be found in Appendix J.

6.3.4 Extended Range Arithmetic and Error Handling

GAMS uses an *extended range* arithmetic to handle missing data, the results of undefined operations, and the representation of bounds that solver systems regard as *infinite*. The special symbols are listed in table 6.2, with the brief explanation of the meaning of each.

GAMS has defined the results of all arithmetic operations and all function values using these special values.

The results can be inspected by running the model library problem [CRAZY] . As one would expect, `1+INF` evaluates to `INF`, and `1-EPS` to `1`.

☞ *The `mapval` function should be used in comparisons involving extended range arithmetic. Only the extended range arithmetic shown in the table above give non-zero values for `mapval`. For example, `mapval(a)` takes a value of `6` if `a` is `inf`. All regular numbers result in a `mapval` of `0`.*

Special symbol	*mapval*	*Description*
`inf`	6	Plus infinity. A very large positive number
`-inf`	7	Minus infinity. A very large negative number
`na`	5	Not available. Used for missing data. Any Operation that uses the value `NA` will produce the result `NA`
`undf`	4	Undefined. The result of an undefined or illegal operation. A user cannot directly set a value to `UNDF`
`eps`	8	Very close to zero, but different from zero.

Table 6.2: Special symbols for extended arithmetic

Value		*Operations*		
a	*b*	*a**b*	*power(a,b)*	*a/b*
2	2	4	4	1
-2	2	undf	4	-1
2	2.1	4.28	undf	.952
na	2.5	na	na	na
3	0	1	1	undf
inf	2	inf	inf	inf
2	inf	undf	undf	0

Table 6.3: Exponentiation and Division

The following table shows a selection of results for exponentiation and division for a variety of input parameters.

☞ *One should avoid creating or using numbers with absolute values larger than `1.0E20`. If a number is too large, it may be treated by GAMS as undefined (`UNDF`), and all values derived from it in a model may be unusable. Always use `INF` (or `-INF`) explicitly for arbitrarily large numbers*

When an attempted arithmetic operation is illegal or has undefined results because of the value of arguments (division by zero is the normal example), an error is reported and the result is set to undefined (`UNDF`).

From there on, `UNDF` is treated as a proper data value and does not trigger additional error messages.

☞ *GAMS will not solve a model if an error has been detected, but will terminate with an error condition.*

It is thus always necessary to anticipate conditions that will cause errors, such as divide by zero. This is most easily done with the dollar control, and will be discussed in the next section.

6.4 Summary

GAMS provides powerful facilities for data manipulation with parallel assignment statements, built-in functions and extended range arithmetic.

7

Variables

7.1 Introduction

This chapter covers the declaration and manipulation of GAMS `variables`. Many of the concepts covered in the previous Chapters are directly applicable here.

A `variable` is the GAMS name for what are called *endogenous variables* by economists, *columns* or *activities* by linear programming experts, and *decision variables* by industrial Operations Research practitioners. They are the entities whose values are generally unknown until after a model has been solved. A crucial difference between GAMS variables and columns in traditional mathematical programming terminology is that one GAMS variable is likely to be associated with many columns in the traditional formulation.

7.2 Variable Declarations

A GAMS variable, like all other identifiers, must be declared before it is referenced.

7.2.1 The Syntax

The declaration of a `variable` is similar to a `set` or `parameter` declaration, in that domain lists and explanatory text are allowed and recommended, and several variables can be declared in one statement.

```
   [var-type] variable[s] var_name [text] {, var_name [text]}
```

`Var_type` is the optional variable type that is explained in detail later. `Var_name` is the internal name of the variable (also called an identifier) in GAMS. An identifier has to start with a letter followed by more letters or digits. It can only contain alphanumeric characters, and can be up to 63 characters long. The accompanying text is used to describe the set or element immediately preceding it. This must not exceed 254 characters and must all be contained on the same line as the identifier it describes.

One important difference between variable and parameter declarations is that values *cannot* be initialized in a variable declaration.

A typical `variable` statement, adapted from [RAMSEY], is shown below for illustration:

```
   variables   k(t)      capital stock (trillion rupees)
               c(t)      consumption (trillion rupees per year)
               i(t)      investment (trillion rupees per year)
               utility   utility measure   ;
```

The declaration of `k` above implies, as usual, that references to `k` are restricted to the domain of the set `t`. A model that includes `k` will probably have several corresponding variables in the associated mathematical programming problem: most likely one for each member of `t`. In this way, very large models can be constructed using a small number of variables. (It is quite unusual for a model to have as many as 50 distinct variables.) It is still unclear from the declaration whether `utility` is not domain checked or whether it is a scalar variable, i.e., one without associated sets. Later references will be used to settle the issue.

It is important that variable declarations include explanatory text and that this be as descriptive as possible, since the text is used to annotate the solution output. Note the use of '`per`' instead of '`/`' in the text above: slashes are illegal in all unquoted text.

7.2.2 Variable Types

There are five basic types of variables that may be used in variable statements. These are shown in table 7.1.

Keyword	*Default Lower Bound*	*Default Upper Bound*	*Description*
`free` (default)	`-inf`	`+inf`	No bounds on variable. Both bounds can be changed from the default values by the user
`positive`	`0`	`+inf`	No negative values are allowed for variable. The user can change the upper bound from the default value.
`negative`	`-inf`	`0`	No positive values are allowed for variables. The user can change the lower bound from the default value.
`binary`	`0`	`1`	Discrete variable that can only take values of 0 or 1
`integer`	`0`	`100`	Discrete variable that can only take integer values between the bounds. The user can change bounds from the default value.

Table 7.1: Variable types and default bounds

The default type is `free`, which means that if the type of the variable is not specified, it will not be bounded at all. The most frequently used types are `free` and `positive`, for descriptions of variables for which negative values are meaningless, such as capacities, quantities or prices.

Four additional, although more exotic, variable types - `sos1`, `sos2`, `semicont` and `semiint` are available in GAMS. These are explained in Section 17.2.1.

7.2.3 Styles for Variable Declaration

Two styles are commonly used to declare variable types. The first is to list all variables with domain specifications and explanatory text as a group, and later to group them separately as to type. The example shown below is adapted from [MEXSS]. The default type is `free`, so `phi`, `phipsi`, etc. will be `free` variables in the example below. Note the use of variable names derived from the original mathematical representation.

```
variables
   u(c,i)  "purchase of domestic materials (mill units per yr)"
   v(c.j)  "imports            (mill tpy)"
   e(c,i)  "exports            (mill tpy)"
   phi     "total cost         (mill us$)"
   phipsi  "raw material cost  (mill us$)"  ;
positive variables  u, v, e  ;
```

The commas in the list of positive variables are required separators.

☞ *It is possible to declare an identifier more than once, but that the second and any subsequent declarations should only add new information that does not contradict what has already been entered.*

The second popular way of declaring variables is to list them in groups by type. We rewrite the example above using this second method:

```
free variables
   phi     "total cost         (mill us$)"
   phipsi  "raw material cost  (mill us$)"

positive variables
   u(c,i)  "purchase of domestic materials (mill units per yr)"
   v(c,j)  "imports   (mill typ)"
   e(c,i)  "exports   (mill typ)"  ;
```

The choice between the two approaches is best based on clarity.

7.3 Variable Attributes

Another important difference between parameters and variables is that an additional set of keywords can be used to specify various attributes of variables. A GAMS parameter has one number associated with each unique label combination. A variable, on the other hand, has seven. They represent:

`.lo`	The lower bound for the variable. Set by the user either explicitly or through default values.
`.up`	The upper bound for the variable. Set by the user either explicitly or through default values.
`.fx`	The fixed value for the variable.
`.l`	The activity level for the variable. This is also equivalent to the current value of the variable. Receives new values when a model is solved.
`.m`	The marginal value (also called dual value) for the variable. Receives new values when a model is solved.
`.scale`	This is the scaling factor on the variable. This is normally an issue with nonlinear programming problems and is discussed in detail in Section 17.3.
`.prior`	This is the branching priority value of a variable. This parameter is used in mixed integer programming models only, and is discussed in detail later.

The user distinguishes between these suffix numbers when necessary by appending a suffix to the variable name.

7.3.1 Bounds on Variables

All default bounds set at declaration time can be changed using assignment statements.

☞ *For binary and integer variable types, the consequences of the type declaration cannot be completely undone.*

Bounds on variables are the responsibility of the user. After variables have been declared, default bounds have already been assigned: for many purposes, especially in linear models, the default bounds are sufficient. In nonlinear models, on the other hand, bounds play a far more important role. It may be necessary to provide bounds to prevent undefined operations, such as division by zero.

It is also often necessary to define a '*reasonable*' solution space that will help to make the nonlinear programming problem be solved more efficiently.

☞ *The lower bound cannot be greater than the upper: if you happen to impose such a condition, GAMS will exit with an error condition.*

7.3.2 Fixing Variables

GAMS allows the user to set variables through the `.fx` variable suffix. This is equivalent to the lower bound and upper bound being equal to the fixed value. Fixed variables can subsequently be freed by changing the lower and upper bounds.

7.3.3 Activity Levels of Variables

GAMS allows the user to fix the activity levels of variables through the `.l` variable suffix. These activity levels of the variables prior to the solve statement serve as initial values for the solver. This is particularly important for nonlinear programming problems.

7.4 Variables in Display and Assignment Statements

GAMS allows the modeler to use the values associated with the various attributes of each variable in assignment and display statements. The next two sub-sections explain the use of variables in the left and right hand sides of assignment statements respectively. Later we will explain the use of variables in display statements.

7.4.1 Assigning Values to Variable Attributes

Assignment statements operate on one variable attribute at a time, and require the suffix to specify which attribute is being used. Any index list comes after the suffix.

The following example illustrates the use of assignment statements to set upper bounds for variables.

```
x.up(c,i,j)  =  1000 ;  phi.lo  =  inf  ;
p.fx('pellets', 'ahmsa', 'mexico-df')  = 200  ;
c.l(t)   =  4*cinit(t)  ;
```

Note that, in the first statement, the index set covering the domain of `x` appears after the suffix. The first assignment puts an upper bound on all variables associated with the identifier `x`. The statement on the second line bounds one particular entry. The statement on the last line sets the level values of the variables in `c` to four times the values in the parameter `cinit`.

Remember that the order is important in assignments, and notice that the two pairs of statements below produce very different results. In the first case, the lower bound for `c('1985')` will be 0.01, but in the second, the lower bound is 1.

```
c.fx('1985') =  1;       c.lo(t)      =   0.01 ;
c.lo(t)   =  0.01 ;    c.fx ('1985')= 1 ;
```

Everything works as described in the previous chapter, including the various mechanisms described there of indexed operations, dollar operations, subset assignments and so on.

7.4.2 Variable Attributes in Assignments

Using variable attributes on the right hand side of assignment statements is important for a variety of reasons. Two common uses are for generating reports, and for generating initial values for some variables based on the values of other variables.

The following examples, adapted from [CHENERY], illustrate the use of variable attributes on the right hand side of assignment statements:

```
scalar      cva   "total value added at current prices"
      rva   "real value added"
      cli   "cost of living index"  ;

cva  =  sum (i, v.l(i)*x.l(i))  ;
cli  =  sum(i, p.l(i)*ynot(i))/sum(i, ynot(i))  ;
rva  =  cva/cli  ;

display cli, cva, rva ;
```

As with parameters, a `variable` must have some non-default data values associated with it before one can use it in a display statement or on the right hand side of an assignment statement. After a solve statement (to be discussed later) has been processed or if non-default values have been set with an assignment statement, this condition is satisfied.

☞ *The `.fx` suffix is really just a shorthand for `.lo` and `.up` and can therefore only be used only on the left-hand side of an assignment statement.*

7.4.3 Displaying Variable Attributes

When variables are used in `display` statements you must specify which of the six value fields should be displayed. Appending the appropriate suffix to the variable name does this. As before, no domain specification can appear. As an example we show how to `display` the level of `phi` and the level and the marginal values of `v` from [MEXSS]:

```
display phi.l, v.l, v.m;
```

The output looks similar, except that (of course) the listing shows which of the values is being displayed. Because zeroes, and especially all zero rows or columns, are suppressed, the patterns seen in the level and marginal displays will be quite different, since non-zero marginal values are often associated with activity levels of zero.

```
Mexico Steel - Small Static   (MEXSS,SEQ=15)
E x e c u t i o n

----    203 VARIABLE  PHI.L                =      538.811 total cost
                                                          (mill us$)
----    203 VARIABLE  V.L           imports
                                    (mill tpy)
                    ( ALL       0.000 )

----    203 VARIABLE  V.M           imports
                                    (mill tpy)
        mexico-df   monterrey   guadalaja
steel       7.018      18.822       6.606
```

We should mention here a clarification of our previous discussion of displays. It is actually the default values that are suppressed on display output. For parameters and variable levels, the default is zero, and so zero entries are not shown. For bounds, however, the defaults can be non-zero. The default value for the upper bound of a positive variable is `+INF`, and if above you also would display `v.up`, for example, you will see:

```
----    203 VARIABLE  V.UP          imports
                                    (mill tpy)
                    ( ALL        +INF )
```

If any of the bounds have been changed from the default value, then only the entries for the changed elements will be shown. This sounds confusing, but since few users display bounds it has not proved troublesome in practice.

7.5 Summary

Remember that wherever a parameter can appear in a display or an assignment statement, a variable can also appear - provided that it is qualified with one of the four suffixes. The only places where a variable name can appear without a suffix is in a variable declaration, as shown here, or in an equation definition, which is discussed in the next chapter.

8

Equations

8.1 Introduction

`Equations` are the GAMS names for the symbolic algebraic relationships that will be used to generate the constraints in the model. As with `variables`, one GAMS equation will map into arbitrarily many individual constraints, depending on the membership of the defining sets.

8.2 Equation Declarations

A GAMS `equation`, like all identifiers, must be declared before it can be used.

8.2.1 The Syntax

The declaration of an `equation` is similar to a `set` or `parameter` declaration, in that domain lists and explanatory text are allowed and recommended, and several equations can be declared in one statement.

```
Equation[s] eqn_name [text] {, eqn_name [text]} ;
```

`Eqn_name` is the internal name of the `equation` (an identifier) in GAMS. An identifier has to start with a letter followed by more letters or digits. It can only contain alphanumeric characters, and can be up to 63 characters long. The accompanying text is used to describe the set or element immediately preceding it. This must not exceed 254 characters and must all be contained on the same line as the identifier it describes.

There are no modifying keywords as there are with variables, and no initializing data list as there may be with parameters or sets.

8.2.2 An Illustrative Example

The example is adapted from [PRODSCH] , an inventory and production management problem. The relevant set definitions are also shown.

```
sets  q          'quarters'  / summer,fall,winter,spring /
      s          'shifts'    / first,second /;

equations
      cost      'total cost definition'
      invb(q)   'inventory balance'
      sbal(q,s) 'shift employment balance'   ;
```

The declaration of the first equation follows the keyword `equations`. This declaration begins with the name of the equation, in this case `cost`, and is followed by the text, namely '`Total cost definition`'. The equation `cost` above is a scalar equation, which will produce at most one equation in the associated optimization problem.

By contrast, the equation `sbal` is declared over the sets `q` (4 members) and `s` (2 members), and is thus likely to produce eight individual equations, one for each unique combination of labels. The circumstances under which less than eight equations might be produced will be discussed in later chapters. It is certainly true, however, that no more than eight equations will be produced.

8.3 Equation Definitions

The definitions are the mathematical specification of the equations in the GAMS language. The next sub-section explain the syntax for an equation definition and this is followed by an illustrative example. The rest of this section is devoted to discussions about some of the key components of equation definitions.

8.3.1 The Syntax

The syntax in GAMS for defining an equation is as follows,

```
eqn_name(domain_list).. expression eqn_type expression ;
```

`Eqn_name` is the name of the equation as in the equation declaration. The two dots '`..`' are always required between the equation name and start of the algebra. The expressions in the equation definition can be of the forms discussed in the Chapters before, but can involve variables as well. `Eqn_type` refers to the symbol between the two expressions that form the equation, and can be of the following types,

`=e=`	Equality: rhs must equal lhs
`=g=`	Greater than: lhs must be greater than or equal to rhs
`=l=`	Less than: lhs must be less than or equal to rhs
`=n=`	No relationships enforced between lhs and rhs. This equation type is rarely used.
`=x=`	External equation. Only supported by selected solvers.
`=c=`	Coaen constraint. Only supported by selected solvers.

☞ *As with the assignment statement, equation definitions can be carried over as many lines of input as needed. Blanks can be inserted to improve readability, and expressions can be arbitrarily complicated.*

☞ *An equation, once defined, can not be altered or re-defined. If one needs to change the logic, a new equation with a new name will have to be defined. It is possible, however, to change the meaning of an equation by changing the data it uses, or by using exception handling mechanisms (dollar operations) built into the definition*

8.3.2 An Illustrative Example

Consider the following example, adapted from [MEXSS]. The associated declarations are also included.

```
Variables  phi, phipsi, philam, phipi, phieps ;
equations  obj ;
obj.. phi  =e=  phipsi + philam + phipi - phieps ;
```

`Obj` is the name of the equation being defined. The `=e=` symbol means that this is an equality. Any of the following forms of the equation are mathematically equivalent,

```
obj..  phipsi + philam + phipi - phieps =e= phi  ;
obj..  phieps - phipsi  =e=  philam - phi + phipi  ;
obj..  phi - phieps - phipsi - philam - phipi  =e=  0 ;
obj..  0 =e= phi - phieps - phipsi - philam - phipi  ;
```

☞ *The arrangement of the terms in the equation is a matter of choice, but often a particular one is chosen because it makes the model easier to understand.*

8.3.3 Scalar Equations

A scalar equation will produce at most one equation in the associated optimization problem. The equation defined in the last Section is an example of a scalar equation, which contains only scalar variables. Note that in general, scalar equations may contain indexed variables operated on by index operators. Consider the following example from [CHENERY]

```
dty..  td =e= sum(i, y(i)) ;
```

8.3.4 Indexed Equations

All the set references in scalar equations are within the scope of index operations - many references can therefore be included in one equation. However, GAMS allows for equations to be defined over a domain, thereby developing a compact representation for constraints. The index sets to the left of the '`..`' are called the *domain of definition* of the equation.

☞ *Domain checking ensures that the domain over which an equation is defined must be the set or a subset of the set over which the equation is declared.*

Consider the following example of a singly indexed equation, meaning one that produces a separate constraint for each member of the driving (or controlling) set.

```
dg(t)..  g(t)  =e= mew(t) + xsi(t)*m(t)  ;
```

As `t` has three members, three constraints will be generated , each one specifying separately for each member of `t`, the dependence of `g` on `m`. `Mew` and `xsi` are parameters: the data associated with them are used in building up the individual constraints. These data do not have to be known when the equation is defined, but do have to be when a model containing the equation is solved.

The extension to two or more index positions on the left of the '`..`' should be obvious. There will be one constraint generated for each label combination that can constructed using the indices inside the parenthesis. Here are two examples from [AIRCRAFT], a scheduling model.

```
bd(j,h)..  b(j,h)  =e=  dd(j,h) - y(j,h) ;
yd(j,h)..  y(j,h)  =l=  sum(i, p(i,j)*x(i,j)) ;
```

The domain of definition of both equations is the Cartesian product of `j` and `h`: constraints will be generated for every label pair that can be constructed from the membership of the two sets.

8.3.5 Using Labels Explicitly in Equations

It is often necessary to use labels explicitly in equations. This can be done as with parameters - by using quotes around the label. Consider the following example,

```
dz.. tz  =e=  y('jan') + y('feb') + y('mar') + y('apr')  ;
```

8.4 Expressions in Equation Definitions

The arithmetic operators and functions that were described in Section 6.3, page 53, can be used inside equations as well.

8.4.1 Arithmetic Operators in Equation Definitions

☞ *All the mechanisms that may be used to evaluate expressions in assignments are also available in equations.*

Consider the following example adapted from [CHENERY] showing parentheses and exponentiation,

```
dem(i) .. y(i)  =e= ynot(i)*(pd*p(i))**thet(i)  ;
```

8.4.2 Functions in Equation Definitions

Function references in equation definitions can be classified into two types based on the type of the arguments,

Exogenous arguments: The arguments(s) are known. Parameters and variable attributes (for example, `.l` and `.m` attributes) are used as arguments. The expression is evaluated once when the model is being set up, and all functions except the random distribution functions uniform and normal are allowed.

Endogenous arguments: The arguments are variables and therefore unknown. The function will be evaluated many times at intermediate points while the model is being solved.

☞ *The occurrence of any function with endogenous arguments implies that the model is not linear.*

☞ *It is forbidden to use the* `uniform` *and* `normal` *functions in an equation definition.*

Functions with endogenous arguments can be further classified into types listed in table 8.1.

Type	*Function*	*Derivative*	*Examples*
Smooth	Continuous	Continuous	`exp`, `sin`, `log`
Non-Smooth	Continuous	Discontinuous	`max`, `min`, `abs`
Discontinuous	Discontinuous	Discontinuous	`ceil`, `sign`

Table 8.1: Classification of functions with endogenous arguments

Smooth functions can be used routinely in nonlinear models, but non-smooth ones may cause numerical problems and should be used only if unavoidable, and only in a special model type called `dnlp`. However, the use of the `dnlp` model type is strongly discouraged and the use of binary variables is recommended to model non-smooth functions. Discontinuous functions are not allowed at all with variable arguments.

A fuller discussion is given in Chapter 9, page 77. For convenience, all the available functions are classified in table 6.1.

8.4.3 Preventing Undefined Operations in Equations

Certain operations can be undefined at particular values for the arguments. For example, the `log`-function is undefined when the argument is 0. Division by 0 is another example. While this can easily be determined for exogenous functions and expressions, it is a lot more difficult when the operands are variables. The expression may be evaluated many times when the problem is being solved. One way of preventing an expression from becoming undefined at all intermediate points is by adding bounds to the variable concerned. Consider the following function reference from [RAMSEY], preceded by the bounding of the variables:

```
c.lo(t)   = 0.01 ;
util ..     utility  =e= sum(t, beta(t)*log(c(t))) ;
```

The bounding on `c(t)` away from 0 prevents the log function from being undefined.

8.5 Data Handling Aspects of Equations

The previous section dealt with the algebraic nature of equations. This section deals with the other aspect of an equation - it also serves as data. As with variables, four data values are associated with each unique *label-tuple* (unique label combination) of every equation. In practice these are used mainly for reporting purposes after a solve, and so the discussion will be brief. The suffixes associated with the four values are `.l`, `.m`, `.lo` and `.up`, as with variables. They may be assigned values in assignments (this is rare), or referenced in expressions or displayed, which is more common, especially for the marginal, `.m`. The meanings of the attributes `.lo`, `.l` and `.up` will be described with respect to an individual constraint rather than the symbolic equation.

After a solution has been obtained, there is a value associated with the unknown terms on the left, and this is by definition `.l`. The meaning of `.lo` and `.up` are shown in table 8.2 in terms of the constant right-hand-side (rhs) and the variable left-hand-side (`.l`) for each of the equation types. The relationship between rhs and `.l` is satisfied only if the constraint is feasible at the solution point.

Type	*.lo*	*.up*	*.l*
`=e=`	rhs	rhs	rhs
`=l=`	`-inf`	rhs	rhs
`=g=`	rhs	`inf`	rhs
`=n=`	`-inf`	`inf`	any

Table 8.2: Subfield definitions for `equations`

The meaning of the marginal value (`.m`) in terms of the objective value is discussed in detail in most texts on mathematical programming. The crude but useful definition is that it is the amount by which the objective function would change if the equation level were moved one unit.

9

Model and Solve Statements

9.1 Introduction

This chapter brings together all the concepts discussed in previous chapters by explaining how to specify a model and solve it.

9.2 The Model Statement

The model statement is used to collect equations into groups and to label them so that they can be solved. The simplest form of the `model` statement uses the keyword `all`: the model consists of all equations declared before the model statement is entered. For most simple applications this is all you need to know about the model statement.

9.2.1 The Syntax

In general, the syntax in GAMS for a model declaration is:

```
model[s] model_name [text] [/ all | eqn_name {, eqn_name} /]
       {,model_name [text] [/ all | eqn_name {, eqn_name} /]} ;
```

`Model_name` is the internal name of the model (also called an identifier) in GAMS. The accompanying text is used to describe the set or element immediately preceding it. `Eqn_name` is the name of an equation that has been declared prior to the model statement.

As with all identifiers, `model_name` has to start with a letter followed by more letters or digits. It can only contain alphanumeric characters, and can be up to 63 characters long. Explanatory text must not exceed 80 characters and must all be contained on the same line as the identifier or label it describes.

An example of a model definition in GAMS is shown below.

```
Model   transport   "a transportation model"   / all /  ;
```

The model is called `transport` and the keyword `all` is a shorthand for all known (declared) equations.

Several models can be declared (and defined) in one `model` statement. This is useful when experimenting with different ways of writing a model, or if one has different models that draw on the same data. Consider the following example, adapted from [PROLOG], in which different groups of the equations are used in alternative versions of the problem. Three versions are solved – the linear, nonlinear, and 'expenditure' versions. The model statement to define all three is

```
 model  nortonl   "linear version"      / cb,rc,dfl,bc,obj /
        nortonn   "nolinear version"    / cb,rc,dfn,bc,obj /
        nortone   "expenditure version  / cb,rc,dfe,bc,obj /  ;
```

where `cb`, `rc`, etc. are the names of the equations. We will describe below how to obtain the solution to each of the three models.

9.2.2 Classification of Models

Various types of problems can be solved with GAMS. The type of the model must be known before it is solved. The model types are briefly discussed in this section. GAMS checks that the model is in fact the type the user thinks it is, and issues explanatory error messages if it discovers a mismatch - for instance, that a supposedly linear model contains nonlinear terms. This is because some problems can be solved in more than one way, and the user has to choose which way to go. For instance, if there are binary or integer variables in the model, it can be solved either as a `MIP` or as a `RMIP`.

The problem types and their identifiers, which are needed in the a solve statement, are listed below.

`LP`	Linear programming. There are no nonlinear terms or discrete (binary or integer) variables in your model.
`QCP`	Quadratic constraint programming. There are linear and quadratic terms but no general nonlinear term or discrete (binary or integer) variables in your model.
`NLP`	Nonlinear programming. There are general nonlinear terms involving only *smooth* functions in the model, but no discrete variables. The functions were classified as to smoothness in the previous chapter.
`DNLP`	Nonlinear programming with discontinuous derivatives. This is the same as `NLP`, except that *non-smooth* functions can appear as well. These are more difficult to solve than normal `NLP` problems. The user is strongly recommended not to use this model type.
`RMIP`	Relaxed mixed integer programming. The model can contain discrete variables but the discrete requirements are relaxed, meaning that the integer and binary variables can assume any values between their bounds.
`MIP`	Mixed integer programming. Like `RMIP` but the discrete requirements are enforced: the discrete variables must assume integer values between their bounds.
`RMIQCP`	Relaxed mixed integer quadratic constraint programming. The model can contain both discrete variables and quadratic terms. The discrete requirements are relaxed. This class of problem is the same as `QCP` in terms of difficulty of solution.
`RMINLP`	Relaxed mixed integer nonlinear programming. The model can contain both discrete variables and general nonlinear terms. The discrete requirements are relaxed. This class of problem is the same as `NLP` in terms of difficulty of solution.
`MIQCP`	Mixed integer quadratic constraint programming. Characteristics are the same as for `RMIQCP`, but the discrete requirements are enforced.
`MINLP`	Mixed integer nonlinear programming. Characteristics are the same as for `RMINLP`, but the discrete requirements are enforced.
`MPEC`	Mathematical Programs with Equilibrium Constraints.
`MCP`	Mixed Complementarity Problem.
`CNS`	Constrained Nonlinear System.

Each of these model types will be discussed in detail in later chapters.

9.2.3 Model Attributes

Various model attributes can be set and accessed by the user through a list of model suffixes. The complete list of model suffixes is shown below.

Attributes Controlled by the User

`bratio`	basis acceptance test
`domlim`	maximum number of domain violations
`holdfixed`	substitution of fixed variables.
`iterlim`	iteration limit
`limcol`	number of columns displayed for each block of variables
`limrow`	number of rows displayed for each block of equations
`optca`	absolute termination criterion for MIP
`optcr`	relative termination criterion for MIP
`optfile`	option file usage
`reslim`	time limit for solver. Usually in CPU seconds
`scaleopt`	scale option (cf. Section 17.3)
`solprint`	solution print option
`solveopt`	merge or replace option for solution data
`sysout`	subsystem print option
`workspace`	size of work array (in MB)

Attributes Controlled by the Solver

`domusd`	number of domain violations
`iterusd`	number of iterations used
`modelstat`	model status (cf. Section 10.5.4)
`numequ`	number of single equations generated
`numinfes`	number of infeasibilities
`numnopt`	number of non-optimalities
`numnz`	number of non-zero entries in the coefficient matrix
`numvar`	number of single variables generated
`resusd`	resource units (in CPU seconds) used to solve model
`solvestat`	solver status (cf. Section 10.5.4)

The following example illustrates the use of model suffixes.

```
Model transport /all/ ;
transport.reslim = 60 ;
```

This sets the solver an upper limit of 60 seconds to attempt to solve the problem to optimality.

9.3 The Solve Statement

Once the model has been put together through the model statement, one can now attempt to solve it using the solve statement. On seeing this statement, GAMS calls one of the available solvers for the particular model type.

☞ *It is important to remember that GAMS itself does not solve your problem, but passes the problem definition to one of a number of separate solver programs.*

The next few sub-sections discuss the solve statement in detail.

9.3.1 The Syntax

In general, the syntax in GAMS for a model declaration is:

```
solve model_name using model_type maximizing|minimizing var_name|;
solve model_name maximizing|minimizing var_name using model_type ;
```

`Model_name` is the name of the model as defined by a `model` statement. `Var_name` is the name of the objective variable that is being optimized. `Model_type` is one of the model types described before. An example of a solve statement in GAMS is shown below.

```
Solve transport using lp minimizing cost ;
```

`Solve` and `using` are reserved words. `Transport` is the name of the model, `lp` is the model type, `minimizing` is the direction of optimization, and `cost` is the objective variable. The opposite of `minimizing` is `maximizing`, both reserved words. Note that an objective variable is used instead of an objective row or function

☞ *The objective variable must be scalar and type free, and must appear in the least one of the equations in the model.*

The next two sub-sections will describe briefly below what happens when a solve statement is processed, and more details on how the resulting output is to be interpreted will be given in the next chapter. After that sequences of solve statements will be discussed. The final section will describe options that are important in controlling solve statements.

9.3.2 Requirements for a Valid Solve Statement

When GAMS encounters a solve statement, the following are verified:

1. All symbolic equations have been defined and the objective variable is used in at least one of the equations
2. The objective variable is scalar and of type free
3. Each equation fits into the specified problem class (linearity for `lp`, continuous derivatives for `nlp`, as we outlined above)
4. All sets and parameters in the equations have values assigned.

9.3.3 Actions Triggered by the Solve Statement

The solve statement triggers a sequence of steps that are as follows:

1. The model is translated into the representation required by the solution system to be used.
2. Debugging and comprehension aids are produced and written to the output file (`EQUATION LISTING`, etc).
3. GAMS verifies that there are no inconsistent bounds or unacceptable values (for example `NA` or `UNDF`) in the problem.
4. Any errors detected at this stage cause termination with as much explanation as possible, using the GAMS names for the identifiers causing the trouble.
5. GAMS passes control to the solution subsystem and waits while the problem is solved.

6. GAMS reports on the status of the solution process and loads solution values back into the GAMS database. This causes new values to be assigned to the `.l` and `.m` fields for all individual equations and variables in the model. A row by row and column by column listing of the solution is provided by default. Any apparent difficulty with the solution process will cause explanatory messages to be displayed. Errors caused by forbidden nonlinear operations are reported at this stage.

The outputs from these steps, including any possible error messages, are discussed in detail in the next chapter.

9.4 Programs with Several Solve Statements

Several `solve` statements can be processed in the same program. If you have to solve sequences of expensive or difficult models, you should read the chapter on workfiles to find out how to interrupt and continue program execution. The next few sub-sections discuss various instances where several solve statements may be needed in the same file.

9.4.1 Several Models

If there are different models then the solves may be sequential, as below. Each of the models in [PROLOG] consists of a different set of equations, but the data are identical, so the three solves appear in sequence with no intervening assignments:

```
solve nortonl using nlp maximizing  z;
solve nortonn using nlp maximizing  z;
solve nortone using nlp maximizing  z;
```

When there is more than one `solve` statement in your program, GAMS uses as much information as possible form the previous solution to provide a starting point in the search for the next solution.

9.4.2 Sensitivity or Scenario Analysis

Multiple `solve` statements can be used not only to solve different models, but also to conduct sensitivity tests, or to perform case (or scenario) analysis of models by changing data or bounds and then solving the same model again. While some commercial LP systems allow access to sensitivity analysis through GAMS, it is possible to be far more general and not restrict the analysis to either solver or model type. This facility is even more useful for studying many scenarios since no commercial solver will provide this information.

An example of sensitivity testing is in the simple oil-refining model [MARCO]. Because of pollution control, one of the key parameters in oil refinery models is an upper bound on the sulfur content of the fuel oil produced by the refinery. In this example, the upper bound on the sulfur content of the fuel oil produced in the refinery. In this example, the upper bound on the sulfur content of fuel oil was set at 3.5 percent in the original data for the problem. First the model is solved with this value. Next a slightly lower value of 3.4 percent is used and the model is solved again. Finally, the considerably higher value of 5 percent is used and the model is solved for the last time. After each solve, key solution values (the activity levels are associated with `z`, the process levels by process `p` and by crude oil type `cr`) are saved for later reporting. This is necessary because a following solve replaces any existing values. The complete sequence is :

```
parameter report(*,*,*)  "process level report" ;

qs('upper','fuel-oil','sulfur')  =  3.5  ;
solve oil using lp maximizing phi;
report(cr,p,'base')  =  z.l(cr,p) ;

report('sulfur','limit','base') = qs('upper','fuel-oil','sulfur');
qs ('upper','fuel-oil','sulfur')  =  3.4  ;
solve oil using lp maximizing phi ;
report(cr,p,'one')  =  z.l(cr,p) ;
report('sulfur','limit','one') = qs ('upper','fuel-oil','sulfur');

qs('upper','fuel-oil','sulfur')  =  5.0  ;
solve oil using lp maximizing phi ;
report(cr,p,'two')  =  z.l(cr,p) ;
report('sulfur','limit','two') = qs('upper','fuel-oil','sulfur');

display report ;
```

This example shows not only how simply sensitivity analysis can be done, but also how the associated multi-case reporting can be handled. The parameter `qs` is used to set the upper bound on the `sulfur` content in the `fuel oil`, and the value is retrieved for the report.

The output from the display is shown below. Notice that there is no production at all if the permissible sulfur content is lowered. The *case attributes* have been listed in the row `SULFUR.LIMIT`. The *wild card* domain is useful when generating reports: otherwise it would be necessary to provide special sets containing the labels used in the report. Any mistakes made in spelling labels used only in the report should be immediately apparent, and their effects should be limited to the report. Section 14.5.1, page 130, contains more detail on how to arrange reports in a variety of ways.

```
-----   205   PARAMETER REPORT      PROCESS LEVEL REPORT

                           BASE      ONE        TWO
MID-C   .A-DIST            89.718               35.139
MID-C   .N-REFORM          20.000                6.772
MID-C   .CC-DIST           7.805                 3.057
W-TEX   .CC-GAS-OIL                              5.902
W-TEX   .A-DIST                                 64.861
W-TEX   .N-REFORM                               12.713
W-TEX   .CC-DIST                                 4.735
W-TEX   .HYDRO                                  28.733
SULFUR.LIMIT               3.500     3.400       5.000
```

9.4.3 Iterative Implementation of Non-Standard Algorithms

Another use of multiple solve statements is to permit iterative solution of different blocks of equations, solution values from the first are used as data in the next. These decomposition methods are useful for certain classes of problems because the sub-problems being solved are smaller, and therefore more tractable. One of the most common examples of such a method is the Generalized Bender's Decomposition method.

An example of a problem that is solved in this way is an input-output system with endogenous prices, described in Henaff (1980)[1]. The model consists of two groups of equations. The first group uses a given final demand vector to determine the output level in each sector. The second group uses some exogenous process and input-output data to compute sectoral price levels. Then the resulting prices are used to compute a new vector of final demands, and the two block of equations are solved again. This iterative procedure is repeated until satisfactory convergence is obtained. Henaff has used GAMS statements to perform this kind of calculation. The statements that solve the system for the first time and the next iteration are shown below:

```
model  usaio        / mb, output /;
model dualmodel   / dual, totp /;

solve usaio using lp maximizing  total ;
solve dualmodel using lp maximizing totprice;

pbar(ta)  =  (sum(ipd.l(i,ta))/4.);
d(i,t)  =  (db(i)*g(t))/(pd.l(i,t)/pbar(t))  ;

solve usaio using lp maximizing total;
solve dualmodel using lp maximizing totprice;
```

[1] Henaff, Patrick (1980). *An Input-Output Model of the French Economy*, Master's Thesis, Department of Economics, University of Maryland.

`Mb` is a set of material balance (input-output) equations, and `output` is a total output equation. `Dual` is a group of price equations, and `totp` is an equation that sums all the sectoral prices. The domestic prices `pd` used in the calculation of the average price `pbar` are divided by four because there are four sectors in this example. Also the `.l` is appended to `pd` to indicate that this is the level of the variable in the solution of the model namely in dualmodel. Thus the iterative procedure uses solution values from one iteration to obtain parameter values for the next one. In particular, both `pbar` and `pd` are used to compute the demand `d` for the `i-th` product in time period `t, d(i,t)`. Also, the base year demand `db` and the growth factor `g` are used in that calculation. Then when the new final demand vector `d` is calculated, the two blocks of equations are solved again.

9.5 Making New Solvers Available with GAMS

This short section is to encourage those of you who have a favorite solver not available through GAMS. Linking a solver program with GAMS is a straightforward task, and we can provide documents that describe what is necessary and provide the source code that has been used for existing links. The benefits of a link with GAMS to the developer of a solver are several. They include:

- ➢ Immediate access to a wide variety of test problems.
- ➢ An easy way of making performance comparisons between solvers.
- ➢ The guarantee that a user has not somehow provided an illegal input specification.
- ➢ Elaborate documentation, particularly of input formats, is not needed.
- ➢ Access to the existing community of GAMS users, for marketing or testing.

This completes the discussion of the model and solve statements. In the next chapter the various components of GAMS output are described in some detail.

10

GAMS Output

10.1 Introduction

The output from GAMS contains many aids for checking and comprehending a model. In this chapter the contents of the output file are discussed. Ways by which the amount of diagnostic output produced can be controlled will also be discussed, although complete lists of all these controls are not given until later. A small nonlinear model, [ALAN] by Alan S. Manne, is used to illustrate the output file, and list it piece by piece as we discuss the various components. The possibilities for extension to large models with voluminous output (which is when the diagnostics are really useful) should be apparent.

The output from a GAMS run is produced on one file, which can be read using any text editor. The default name of this output file depends on the operating system, but Appendix C describes how this default can be changed. The display statement, described in detail in Chapter 14, can be used to export information from the GAMS program to the listing file.

10.2 The Illustrative Model

[ALAN] is a portfolio selection model whose object is to choose a portfolio of investments whose expected return meets a target while minimizing the variance. We will discuss a simplified version of this model. The input file is listed for reference.

```
$Title A Quadratic Programming Model for Portfolio Analysis ALAN,SEQ=124a)
$onsymlist onsymxref onuellist onuelxref
$Ontext
This is a mini mean-variance portfolio selection problem described in
'GAMS/MINOS:Three examples' by Alan S. Manne, Department of Operations
 Research, Stanford University, May 1986.

$Offtext
* This model has been modified for use in the documentation

 Set i  securities   /hardware, software, show-biz, t-bills/; alias (i,j);

 Scalar target     target mean annual return on portfolio % /10/,
        lowyield   yield of lowest yielding security,
        highrisk   variance of highest security risk ;

 Parameters  mean(i)  mean annual returns on individual securities (%)
      / hardware   8
        software   9
        show-biz  12
        t-bills    7 /

 Table v(i,j)  variance-covariance array (%-squared annual return)
```

```
                 hardware  software  show-biz  t-bills
      hardware      4         3        -1        0
      software      3         6         1        0
      show-biz     -1         1        10        0
      t-bills       0         0         0        0 ;

   lowyield = smin(i, mean(i)) ;
   highrisk = smax(i, v(i,i)) ;
   display lowyield, highrisk ;

   Variables  x(i)       fraction of portfolio invested in asset i
              variance   variance of portfolio

   Positive Variable x;

   Equations  fsum    fractions must add to 1.0
              dmean   definition of mean return on portfolio
              dvar    definition of variance;

   fsum..     sum(i, x(i))                     =e=  1.0  ;
   dmean..    sum(i, mean(i)*x(i))             =e=  target;
   dvar..     sum(i, x(i)*sum(j,v(i,j)*x(j)))  =e=  variance;

   Model portfolio  / fsum, dmean, dvar / ;
   Solve portfolio using nlp minimizing variance;
```

10.3 Compilation Output

This is the output produced during the initial check of the program, often referred to as compilation. It contains two or three parts: the echo print of the program, an explanation of any errors detected, and the maps. The next four sub-sections will discuss each of these in detail.

10.3.1 Echo Print of the Input File

The *Echo Print* of the program is always the first part of the output file. It is just a listing of the input with the lines numbers added. The `$offlisting` directive would turn off the listing of the input file.

```
A Quadratic Programming Model for Portfolio Analysis (ALAN,SEQ=124a)


This is a mini mean-variance portfolio selection problem described in
'GAMS/MINOS: Three examples' by Alan S. Manne, Department of Operations
Research, Stanford University, May 1986.

   9  * This model has been modified for use in the documentation
```

Note that the first line number shown is 9. If the lines on the input are counted, it can be seen that this comment line shown above appears after 8 lines of dollar directives and comments.

The line starting `$title` has caused text of the users choice to be put on the page header, replacing the default tile, which just announces GAMS. The following `$-` directives are used to display more information in the output file and we be discussed. The text within the `$ontext-$offtext` pair is listed without line numbers, whereas comments starting with asterisks have line numbers shown. Line numbers always refer to the physical line number in your input file.

☞ *Dollar control directives are only listed if a directive to list them is enabled, or if they contain errors.*

Here is the rest of the echo print:

```
  10
  11 Set i securities /hardware,software,show-biz,t-bills/; alias (i,j);
  12
  13   Scalar target     target mean annual return on portfolio % /10/,
  14          lowyield   yield of lowest yielding security,
  15          highrisk   variance of highest security risk ;
  16
  17 Parameters mean(i) mean annual returns on individual securities (%)
  18
  19       / hardware   8
  20         software   9
  21         show-biz  12
  22         t-bills    7 /
  23
  24   Table v(i,j)  variance-covariance array (%-squared annual return)
  25
  26                    hardware  software  show-biz  t-bills
  27
  28         hardware      4         3         -1        0
  29         software      3         6          1        0
  30         show-biz     -1         1         10        0
  31         t-bills       0         0          0        0 ;
  32
  33   lowyield = smin(i, mean(i)) ;
  34   highrisk = smax(i, v(i,i)) ;
  35   display lowyield, highrisk ;
  36
  37   Variables  x(i)       fraction of portfolio invested in asset i
  38              variance   variance of portfolio
  39
  40   Positive Variable x;
  41
  42   Equations  fsum    fractions must add to 1.0
  43              dmean   definition of mean return on portfolio
  44              dvar    definition of variance;
  45
  46   fsum..     sum(i, x(i))                     =e=  1.0  ;
  47   dmean..    sum(i, mean(i)*x(i))             =e=  target;
  48   dvar..     sum(i, x(i)*sum(j,v(i,j)*x(j)))  =e=  variance;
  49
  50   Model portfolio  / fsum, dmean, dvar / ;
  51
  52   Solve portfolio using nlp minimizing variance;
```

That is the end of the echo of the input file. If errors had been detected, the explanatory messages would be found in this section of the listing file. All discussion of error messages have been grouped in the section 10.6, page 98.

10.3.2 The Symbol Reference Map

The maps are extremely useful if one is looking into a model written by someone else, or if trying to make some changes in one's own model after spending time away from it.

The first map is the *Symbol Cross Reference*, which lists the identifiers (symbols) from the model in alphabetical order, identifies them as to type, shows the line numbers where the symbols appear, and classifies each appearance. The symbol reference map can be turned on by entering a line containing `$onsymxref` at the beginning of the program. The map that resulted from [ALAN] is shown.

```
Symbol Listing


SYMBOL      TYPE   REFERENCES

DMEAN       EQU    DECLARED       43  DEFINED       47 IMPL-ASN       52
                          REF       50
DVAR        EQU    DECLARED       44  DEFINED       48 IMPL-ASN       52
                          REF       50
FSUM        EQU    DECLARED       42  DEFINED       46 IMPL-ASN       52
```

```
                      REF       50
HIGHRISK    PARAM  DECLARED       15 ASSIGNED       34      REF       35
I           SET    DECLARED       11  DEFINED       11      REF       11
                         17       24       33     2*34       37       46
                       2*47     2*48  CONTROL       33       34       46
                         47       48
J           SET    DECLARED       11      REF       24     2*48
                    CONTROL       48
LOWYIELD    PARAM  DECLARED       14 ASSIGNED       33      REF       35
MEAN        PARAM  DECLARED       17  DEFINED       19      REF       33
                         47
PORTFOLIO   MODEL  DECLARED       50  DEFINED       50 IMPL-ASN       52
                        REF       52
TARGET      PARAM  DECLARED       13  DEFINED       13      REF       47
V           PARAM  DECLARED       24  DEFINED       24      REF       34
                         48
VARIANCE    VAR    DECLARED       38 IMPL-ASN       52      REF       48
                         52
X           VAR    DECLARED       37 IMPL-ASN       52      REF       40
                         46       47     2*48
```

For each symbol, the name and type of the symbol are first provided. For example, the last symbol listed is `X` which is defined to be of type `VAR`. The complete list of data types are given in table 10.1.

Entry in symbol reference table	*GAMS Data Type*
`EQU`	`equation`
`MODEL`	`model`
`PARAM`	`parameter`
`SET`	`set`
`VAR`	`variable`

Table 10.1: List of GAMS data types

Then comes a list of references to the symbol, grouped by reference type and identified by the line number in the output file. The actual reference can then be found by referring to the echo print of the program, which has line numbers on it. In the case of the symbol `X` in the example above, the list of references as shown in the symbol reference map are as follows,

```
DECLARED       37
IMPL-ASN       52
REF            40          46        47      2*48
```

This means that `X` is declared on line 37, implicitly assigned through a `solve` statement on line 52, and referenced on lines 40, 46, and 47. The entry 2*48 means that there are two references to `X` on line 48 of the input file .

The complete list of reference types is given below.

`DECLARED`	This is where the identifier is declared as to type. This must be the first appearance of the identifier.
`DEFINED`	This is the line number where an initialization (a table or a data list between slashes) or symbolic definition (equation) starts for the symbol.
`ASSIGNED`	This is when values are replaced because the identifier appears on the left of an assignment statement.
`IMPL-ASN`	This is an *implicit assignment*: an equation or variable will be updated as a result of being referred to implicitly in a solve statement.
`CONTROL`	This refers to the use of a set as the driving index in an assignment, equation, loop or other indexed operation (`sum`, `prod`, `smin` or `smax`).
`REF`	This is a reference: the symbol has been referenced on the right of an assignment, in a `display`, in an `equation`, or in a `model` or `solve` statement.

10.3.3 The Symbol Listing Map

The next map is called the *Symbol Listing.* All identifiers are grouped alphabetically by type and listed with their explanatory texts. This is another very useful aid to have handy when first looking into a large model prepared by someone else. The symbol listing map can be turned on by entering a line containing `$onsymlist` at the beginning of the program.

```
Symbol Listing

SETS

I           securities
J           Aliased with I

PARAMETERS

HIGHRISK    variance of highest security risk
LOWYIELD    yield of lowest yielding security
MEAN        mean annual returns on individual securities (%)
TARGET      target mean annual return on portfolio %
V           variance-covariance array (%-squared annual return)

VARIABLES

VARIANCE    variance of portfolio
X           fraction of portfolio invested in asset i

EQUATIONS

DMEAN       definition of mean return on portfolio
DVAR        definition of variance
FSUM        fractions must add to 1.0

MODELS

PORTFOLIO
```

10.3.4 The Unique Element Listing - Map

The following map is called the *Unique Element Listing.* All unique elements are first grouped in entry order and then in sorted order with their explanatory texts. The unique element listing map can be turned on by entering a line containing `$onuelxref` at the beginning of the program.

```
Unique Element Listing

Unique Elements in Entry Order

    1 hardware    software    show-biz    t-bills

Unique Elements in Sorted Order

    1 hardware    show-biz    software    t-bills

ELEMENT            REFERENCES

hardware     DECLARED       11       REF       19        26        28
show-biz     DECLARED       11       REF       21        26        30
software     DECLARED       11       REF       20        26        29
t-bills      DECLARED       11       REF       22        26        31
```

10.3.5 Useful Dollar Control Directives

This sub-section reviews the most useful of the *Dollar Control Directives.* These must not be confused with the dollar exception-handling operators that will be introduced later: the similarity of terminology is unfortunate.

The dollar control directives are compiler directives that can be put in the input file to control the appearance and amount of detail in the output produced by the GAMS compiler.

`$offlisting, $onlisting`
: This directive stops the echo print of the input file. `$onlisting` restores the default.

`$offsymxref, $offsymlist, $onsymxref, $onsymlist`
: These four directives are used to control the production of symbol maps. Maps are most often turned on or off at the beginning of the program and left as initially set, but it is possible to produce maps of part of the program by using a *on-map* directive followed later by an *off-map*. The `symlist` lists all the symbols in the model. The `symxref` shows a complete cross-reference list of symbols by number. Both these maps are suppressed by default.

`$offuelxref, $offuellist, $onuelxref, $onuellist`
: These four directives are used to control the production of Unique Element maps which show set membership labels. Maps are most often turned on or off at the beginning of the program and left as initially set, but it is possible to produce maps of part of the program by using a *on-map* directive followed later by an *off-map*. The `uellist` lists all labels in both GAMS entry and alphabetical order. The `uelxref` shows a complete cross-reference list by number. These label maps are suppressed by default.

`$offupper, $onupper`
: This directive causes the echo print of the portion of the GAMS program following the directive to appear on the output file in the case that it has been entered in. This is the default on newer GAMS systems. It is necessary if case conventions have been used in the program, for example to distinguish between variables and equations. `$onupper`, will cause all echo print to be in upper case.

`$ontext, $offtext`
: `$ontext-$offtext` pairs are used to create *block comments* that are ignored by GAMS. Every `$ontext` must have a matching `$offtext` in the same file. The `$offtext` must be on a line by itself.

`$title 'text'`
: The text can have up to 80 characters. This causes every page of the output to have the title specified.

☞ *In all dollar control directives, the $ symbol must be in the first character position on the line.*

☞ *Dollar control directives, are dynamic: they affect only what happens after they are encountered, and they can be set and reset wherever appropriate.*

They are remembered in *continued compilations* started from work files The directives that do not have following text can be entered many to a line, as shown below for the map controls.

10.4 Execution Output

The only output to the listing file while GAMS is executing (performing data manipulations) is from the `display` statement. All the user controls available to change the format will be discussed in detail later. The output from the display statement on line 41 of the example is shown below. Note the wrap of the explanatory text.

```
----     32 PARAMETER LOWYIELD             =        7.000 yield of lowest
                                                          yielding security
            PARAMETER HIGHRISK             =       10.000 variance of highest
                                                          security risk
```

If errors are detected because of illegal data operations, a brief message indicating the cause and the line number of the offending statement will appear.

10.5 Output Produced by a Solve Statement

In this section, the content of the output produced when a solve statement is executed will be explained. In Chapter 9 all the actions that are triggered by a solve were listed. All output produced as a result of a solve is labeled with a subtitle identifying the model, its type, and the line number of the solve statement.

10.5.1 The Equation Listing

The first output is the *Equation Listing*, which is marked with that subtitle on the output file. By default, the first three equations in every block are listed. If there are three or fewer single equations in any equation block, then all the single equations are listed. The equation listing section from the example is listed below. This model has three equation blocks, each producing one single equation.

```
A Quadratic Programming Model for Portfolio Analysis (ALAN,SEQ=124a)
Equation Listing    SOLVE PORTFOLIO USING NLP FROM LINE 48

---- FSUM        =E=  fractions must add to 1.0

FSUM..  X(hardware) + X(software) + X(show-biz) + X(t-bills) =E= 1 ;

      (LHS = 0, INFES = 1 ***)

---- DMEAN       =E=  definition of mean return on portfolio

DMEAN..  8*X(hardware) + 9*X(software) + 12*X(show-biz) + 7*X(t-bills) =E= 10

      ; (LHS = 0, INFES = 10 ***)

---- DVAR        =E=  definition of variance

DVAR..  (0)*X(hardware) + (0)*X(software) + (0)*X(show-biz) - VARIANCE =E= 0 ;

      (LHS = 0)
```

☞ *The equation listing is an extremely useful debugging aid. It shows the variables that appear in each constraint, and what the individual coefficients and right-hand-side value evaluate to after the data manipulations have been done.*

Most of the listing is self-explanatory. The name, text, and type of constraints are shown. The four dashes are useful for mechanical searching.

☞ *All the terms that depend on variables are collected on the left, and all the constant terms are combined into one number on the right, any necessary sign changes being made.*

Four places of decimals are shown if necessary, but trailing zeroes following the decimal point are suppressed. E-format is used to prevent small numbers being displayed as zero.

☞ *The nonlinear equations are treated differently. If the coefficient of a variable in the equation listing is enclosed in parentheses, then the corresponding constraint is nonlinear, and the value of the coefficient depends on the activity levels of one or more of the variables. The listing is not algebraic, but shows the partial derivative of each variable evaluated at their current level values.*

Note that, in the equation listing from our example, the equation `dvar` is nonlinear. A simpler example will help to clarify the point. Consider the following equation and associated level values.

```
eq1.. 2*sqr(x)*power(y,3) + 5*x - 1.5/y =e= 2; x.l = 2; y.l = 3 ;
```

then the equation listing will appear as

```
EQ1.. (221)*X + (216.1667)*Y  =E=  2 ; (LHS = 225.5 ***)
```

The coefficient of `x` is determined by first differentiating the equation above with respect to `x`. This results in `2*(2*x.l)*power(y.l,3)+ 5`, which evaluates to 221. Similarly the coefficient of `y` is obtained by differentiating the equation above with respect to `y` which results in `2*(sqr(x.l)*3*sqr(y.l) + 1.5/sqr(y.l)`, giving 216.1667. Notice that the coefficient of `y` could not have been determined if its level had been left at zero. The attempted division by zero would have produced an error and premature termination.

The result of evaluating the left-hand-side of the equation at the initial point is shown at the end of each individual equation listing. In the example above it is 225.5, and the three asterisks (`***`) are a warning that the constraint is infeasible at the starting point.

☞ *The order in which the equations are listed depends on how the model was defined. If it was defined with a list of equation names, then the listing will be in the order in that list. If it was defined as `/all/`, then the list will be in the order of declaration of the equations. The order of the entries for the individual constraints is determined by the label entry order.*

10.5.2 The Column Listing

The next section of the listing file is the *Column Listing*. This is a list of the individual coefficients sorted by column rather than by row. Once again the default is to show the first three entries for each variable, along with their bound and level values. The format for the coefficients is exactly as in the equation listing, with the nonlinear ones enclosed in parentheses and the trailing zeroes dropped. The column listing section from our example follows.

```
A Quadratic Programming Model for Portfolio Analysis (ALAN,SEQ=124a)
Column Listing      SOLVE PORTFOLIO USING NLP FROM LINE 48


---- X          fraction of portfolio invested in asset I

X(hardware)
                (.LO, .L, .UP = 0, 0, +INF)
        1       FSUM
        8       DMEAN
       (0)      DVAR

X(software)
                (.LO, .L, .UP = 0, 0, +INF)
        1       FSUM
        9       DMEAN
       (0)      DVAR

X(show-biz)
                (.LO, .L, .UP = 0, 0, +INF)
        1       FSUM
       12       DMEAN
       (0)      DVAR

REMAINING ENTRY SKIPPED
---- VARIANCE   variance of portfolio

VARIANCE
                (.LO, .L, .UP = -INF, 0, +INF)
       -1       DVAR
```

☞ *The order in which the variables appear is the order in which they were declared.*

10.5.3 The Model Statistics

The final information generated while a model is being prepared for solution is the statistics block, shown below. Its most obvious use is to provide details on the size and nonlinearity of the model.

```
Model Statistics    SOLVE PORTFOLIO USING NLP FROM LINE 48


MODEL STATISTICS

BLOCKS OF EQUATIONS       3     SINGLE EQUATIONS        3
BLOCKS OF VARIABLES       2     SINGLE VARIABLES        5
NON ZERO ELEMENTS        12     NON LINEAR N-Z          3
DERIVATIVE POOL          10     CONSTANT POOL          10
CODE LENGTH              87


GENERATION TIME      =        0.020 SECONDS    0.1 Mb      WAT-50-094
```

The BLOCK counts refer to GAMS `equations` and `variables`, the SINGLE counts to individual rows and columns in the problem generated. The NON ZERO ELEMENTS entry refers to the number of non-zero coefficients in the problem matrix.

There are four entries that provide additional information about nonlinear models. The NON LINEAR N-Z entry refers to the number of nonlinear matrix entries in the model.

All forms of nonlinearity do not have the same level of complexity. For example, `x*y` is a simpler form of nonlinearity than `exp(x*y)`. So, even though both these terms count as 1 nonlinear entry in the matrix, additional information is required to provide the user with a feel for the complexity of the nonlinearity. GAMS provides the CODE LENGTH entry as a good yardstick for this purpose. There are two other entries - DERIVATIVE POOL and CONSTANT POOL that provide some more information about the nonlinearity. In general, the more nonlinear a problem is, the more difficult it is to solve.

The times that follow statistics are also useful. The GENERATION TIME is the time used since the syntax check finished. This includes the time spent in generating the model. The measurement units are given, and represent ordinary clock time on personal computers, or central processor usage (CPU) time on other machines.

10.5.4 The Solve Summary

This is the point (chronologically speaking) where the model is solved, and the next piece of output contains details about the solution process. It is divided into two parts, the first being common to all solvers, and the second being specific to a particular one.

The section of the solve summary that is common for all solvers is first discussed. The corresponding section for the example model is shown below.

```
S O L V E     S U M M A R Y

     MODEL   PORTFOLIO           OBJECTIVE  VARIANCE
     TYPE    NLP                 DIRECTION  MINIMIZE
     SOLVER  MINOS5              FROM LINE  48

**** SOLVER STATUS     1 NORMAL COMPLETION
**** MODEL STATUS      2 LOCALLY OPTIMAL
**** OBJECTIVE VALUE               2.8990

 RESOURCE USAGE, LIMIT          0.020     1000.000
 ITERATION COUNT, LIMIT         5        10000
 EVALUATION ERRORS              0            0
```

The common part of the solve summary is shown above. It can be found mechanically by searching for four asterisks. The explanation for the information provided in this section follows.

```
MODEL   PORTFOLIO
```

This provides the name of the model being solved.

```
TYPE    NLP
```

This provides the model type of the model being solved.

```
SOLVER  MINOS5
```

This provides the name of the solver used to solve the model.

```
OBJECTIVE  VARIANCE
```

This provides the name of the objective variable being optimized

```
DIRECTION  MINIMIZE
```

This provides the direction of optimization being performed.

```
**** SOLVER STATUS     1 NORMAL COMPLETION
**** MODEL STATUS      2 LOCALLY OPTIMAL
```

These provide the solver status and model status for the problem, and are discussed in greater detail at the end of this subsection.

```
**** OBJECTIVE VALUE               2.8990
```

This provides the value of the objective function at the termination of the solve. If the Solver and Model have the right status, this value is the optimum value for the problem.

```
RESOURCE USAGE, LIMIT          0.109     1000.000
```

These two entries provide the amount of CPU time (in seconds) taken by the solver, as well as the upper limit allowed for the solver. The solver will stop as soon as the limit on time usage has been reached. The default limit on time usage is 1000 seconds. This limit can be changed by entering a line containing the statement option `reslim = xx ;` in the program before the `solve` statement, where `xx` is the required limit on CPU time in seconds.

```
ITERATION COUNT, LIMIT         5         1000
```

These two entries provide the number of iterations used by the solver, as well as the upper limit allowed for the solver. The solver will stop as soon as this limit is reached. The default limit on iterations used is 1000. This limit can be changed by entering a line containing the statement `option iterlim = nn ;` in the program before the `solve` statement, where `nn` is the required limit on the iterations used.

```
EVALUATION ERRORS              0           0
```

These two entries provide the number of numerical errors encountered by the solver, as well as the upper limit allowed for the solver. These errors result due to numerical problems like division by 0. This is suppressed for `LP`, `RMIP`, and `MIP` models since evaluation errors are not applicable for these model types. The default limit on evaluation errors used is 0. This limit can be changed by entering a line containing the statement option `domlim = nn ;` in the program before the `solve` statement, where `nn` is the required limit on the evaluation errors allowed.

The `SOLVER STATUS` and `MODEL STATUS` require special explanation. The status for the solver (the state of the program) and the model (what the solution looks like) are characterized, and a complete list of possible `MODEL STATUS` and `SOLVER STATUS` messages is given below.

Here is a list of possible `MODEL STATUS` messages:

`1 OPTIMAL`
: This means that the solution is optimal. It only applies to linear problems or relaxed mixed integer problems (`RMIP`).

`2 LOCALLY OPTIMAL`
: This message means that a local optimum has been found. This is the message to look for if the problem is nonlinear, since all we can guarantee for general nonlinear problems is a local optimum.

`3 UNBOUNDED`
: This means that the solution is unbounded. This message is reliable if the problem is linear, but occasionally it appears for difficult nonlinear problems that are not truly unbounded, but that lack some strategically placed bounds to limit the variables to sensible values.

`4 INFEASIBLE`
: This means that the linear problem is infeasible. Something is probably misspecified in the logic or the data.

`5 LOCALLY INFEASIBLE`
: This message means that no feasible point could be found for the nonlinear problem from the given starting point. It does not necessarily mean that no feasible point exists.

`6 INTERMEDIATE INFEASIBLE`
: This means that the current solution is not feasible, but that the solver program stopped, either because of a limit (iteration or resource), or because of some sort of difficulty. Check the solver status for more information.

`7 INTERMEDIATE NONOPTIMAL`
: This is again an incomplete solution, but it appears to be feasible.

`8 INTEGER SOLUTION`
: An integer solution has been found to a `MIP` (mixed integer problem). There is more detail following about whether this solution satisfies the termination criteria (set by options `optcr` or `optca`).

`9 INTERMEDIATE NON-INTEGER`
: This is an incomplete solution to a `MIP`. An integer solution has not yet been found.

`10 INTEGER INFEASIBLE`
: There is no integer solution to a MIP. This message should be reliable.

`11 LIC PROBLEM - NO SOLUTION`
: The solver cannot find the appropriate license key needed to use a specific subsolver.

`ERROR UNKNOWN`
: After a solver error, the model status is unknown.

`ERROR NO SOLUTION`
: An error occurred and no solution has been returned. No solution will be returned to GAMS because of errors in the solution process.

`14 NO SOLUTION RETURNED`
: A solution is not expected for this solve. For example, the convert solver only reformats the model but does not give a solution.

`15 SOLVED UNIQUE`
: This indicates a unique solution to a CNS model.

`16 SOLVED`
: A CNS model has been solved but multiple solutions may exist.

`17 SOLVED SINGULAR`
: A CNS model has been solved but the point is singular.

`18 UNBOUNDED - NO SOLUTION`
: The model is unbounded and no solution can be provided.

`19 INFEASIBLE - NO SOLUTION`
: The model is infeasible and no solution can be provided.

This is the list of possible `SOLVER STATUS` messages:

`1 NORMAL COMPLETION`
: This means that the solver terminated in a normal way: i.e., it was not interrupted by an iteration or resource limit or by internal difficulties. The model status describes the characteristics of the accompanying solution.

`2 ITERATION INTERRUPT`
: This means that the solver was interrupted because it used too many iterations. Use option `iterlim` to increase the iteration limit if everything seems normal.

`3 RESOURCE INTERRUPT`
: This means that the solver was interrupted because it used too much time. Use option `reslim` to increase the time limit if everything seems normal.

`4 TERMINATED BY SOLVER`
: This means that the solver encountered difficulty and was unable to continue. More detail will appear following the message.

`5 EVALUATION ERROR LIMIT`
: Too many evaluations of nonlinear terms at undefined values. You should use bounds to prevent forbidden operations, such as division by zero. The rows in which the errors occur are listed just before the solution.

`6 CAPABILITY PROBLEMS`
: The solver does not have the capability required by the model, for example, BARON has a more limited set of functions than other solvers.

`7 LICENSING PROBLEMS`
: The solver cannot find the appropriate license key needed to use a specific subsolver.

`8 USER INTERRUPT`
: The user has sent a message to interrupt the solver via the interrupt button in the IDE or sending a control C from a command line.

`9 ERROR SETUP FAILURE`
: The solver encountered a fatal failure during problem set-up time.

`ERROR SOLVER FAILURE`
: The solver encountered a fatal error.

`ERROR INTERNAL SOLVER FAILURE`
: The solver encountered an internal fatal error.

`12 SOLVE PROCESSING SKIPPED`
: The entire solve step has been skipped. This happens if execution errors were encountered and the GAMS parameter ExeErr has been set to a nonzero value, or the property MaxExecError has a nonzero value.

`ERROR SYSTEM FAILURE`
: This indicates a completely unknown or unexpected error condition.

10.5.5 Solver Report

The next section in the listing file is the part of the solve summary that is particular to the solver program that has been used. This section normally begins with a message identifying the solver and its authors: MINOS was used in the example here. There will also be diagnostic messages in plain language if anything unusual was detected, and specific performance details as well, some of them probably technical. The Solver Manual will help explain these. In case of serious trouble, the GAMS listing file will contain additional messages printed by the solver. This may help identify the cause of the difficulty. If the solver messages do not help, a perusal of the solver documentation or help from a more experienced user is recommended. The solver report from our example follows.

```
  GAMS/MINOS
       B. A. Murtagh, University of New South Wales
         and
       P. E. Gill,  W. Murray,  M. A. Saunders and M. H. Wright
       Systems Optimization Laboratory, Stanford University.

   Work space allocated           --    0.04 Mb


   EXIT -- OPTIMAL SOLUTION FOUND
   MAJOR ITNS, LIMIT           11     200
```

```
FUNOBJ, FUNCON CALLS         0      71
SUPERBASICS                  4
INTERPRETER USAGE         0.02
NORM RG / NORM PI    1.801E-09
```

The line 'work space allocated -- 0.04 MB' provides the amount of memory used by the solver for the problem. If the amount of memory the solver estimates that it needs is not available, GAMS will return a message saying that not enough memory was allocated. GAMS will also return the maximum amount of memory available on the machine. The user can direct the solver to use less memory by entering a line containing the statement `mymodel.workspace = xx`; were `mymodel` is the name of the model being solved as specified by the `model` statement, and `xx` is the amount of memory in Megabytes. Note that the solver will attempt to solve the problem with `xx` MB of memory, however it is not guaranteed to succeed since the problem may require more memory.

More information can be obtained for a successful run by entering a line containing the statement `option sysout = on ;` in the program above the `solve` statement.

10.5.6 The Solution Listing

The next section of the listing file is a row-by-row then column-by-column listing of the solutions returned to GAMS by the solver program. Each individual equation and variable is listed with four pieces of information.

This section of the listing file can be turned off by entering a line containing the statement `option solprint = off ;` in the program above the `solve` statement.

The solution listing section from our example is shown below.

```
                       LOWER     LEVEL     UPPER    MARGINAL

---- EQU FSUM           1.000     1.000     1.000   -13.529
---- EQU DMEAN         10.000    10.000    10.000     1.933
---- EQU DVAR             .         .         .      -1.000

  FSUM       fractions must add to 1.0
  DMEAN      definition of mean return on portfolio
  DVAR       definition of variance


---- VAR X           fraction of portfolio invested in asset i

            LOWER     LEVEL     UPPER    MARGINAL

hardware      .        0.303     +INF       .
software      .        0.087     +INF       EPS
show-biz      .        0.505     +INF       .
t-bills       .        0.106     +INF       EPS


                       LOWER     LEVEL     UPPER    MARGINAL

---- VAR VARIANCE       -INF      2.899     +INF       .

  VARIANCE   variance of portfolio
```

The order of the equations and variables are the same as in the symbol listing described before and will be described later

The four columns associated with each entry have the following meaning,

LOWER	lower bound (`.lo`)
LEVEL	level value (`.l`)
UPPER	upper bound (`.up`)
MARGINAL	marginal (`.m`)

For variables the values in the `LOWER` and `UPPER` columns refer to the lower and upper bounds. For equations they are obtained from the (constant) right-hand-side value and from the relational type of the equation. These relationships were described in Chapter 8.

☞ *The `LEVEL` and `MARGINAL` values have been determined by the solver, and the values shown are used to update the GAMS values. In the list they are shown with fixed precision, but the values are returned to GAMS with full machine accuracy. The single dots '`.`' on the list represent zero.*

`EPS` is the GAMS extended value that means very close to but different from zero. It is common to see a marginal value given as `EPS`, since GAMS uses the convention that marginal are zero for basic variables, and not zero for others.

☞ *EPS is used with non-basic variables whose marginal values are very close to, or actually, zero, or in nonlinear problems with superbasic variables whose marginals are zero or very close to it. A superbasic variable is one between its bounds at the final point but not in the basis.*

There are brief explanations of technical terms used in this section in the Glossary. For models that are not solved to optimality, some constraints may additionally be marked with certain flags. The list of these flags and their description is given below.

`INFES`	The row or column is infeasible. This mark is made for any entry whose level value is not between the upper and lower bounds.
`NOPT`	The row or column is non-optimal. This mark is made for any non-basic entries for which the marginal sign is incorrect, or superbasic ones for which the marginal value is too large.
`UNBND`	The row or column that appears to cause the problem to be unbounded.

10.5.7 Report Summary

The final section of the solution listing is the report summary, marked with four asterisks (as are all important components of the output). It shows the count of rows or columns that have been marked `INFES`, `NOPT`, or `UNBND` in the solution listing section. The sum of infeasibilities will be shown if it the reported solution is infeasible. The error count in is only shown if the problem is nonlinear.

```
**** REPORT SUMMARY :        0     NONOPT
                             0 INFEASIBLE
                             0  UNBOUNDED
                             0     ERRORS
```

If our example had display output for reporting, it would come here.

10.5.8 File Summary

The last piece of the output file is important: it gives the names of the input and output disk files. If work files (save or restart) have been used, they will be named here as well.

```
**** FILE SUMMARY

INPUT      C:\PROGRAM FILES\\gamsIDE\ALAN.GMS
OUTPUT     C:\PROGRAM FILES\\gamsIDE\ALAN.LST
```

10.6 Error Reporting

All the comments and description about errors have been collected into this section for easy reference when disaster strikes.

Effective error detection and recovery are important parts of any modeling system. GAMS is designed around the assumption that the *error State* is the normal state of modeling. Experience shows that most compilations during the early stages of development will produce errors. Not to Worry! The computer is much better at checking details that the human mind and should be able to provide positive feedback and suggestions about how to correct errors or avoid ambiguities. Developing a model is like writing a paper or an essay ; many drafts and rewrites are required until the arguments are presented in the most effective way for the reader and meet all the requirements of proper English. GAMS acts like a personal assistant with knowledge of mathematical modeling and of the syntactic and semantic details of the language.

Errors are detected at various stages in the modeling process. Most of them are caught at the compilation stage, which behaves like the proofreading stage of the modeling process. Once a problem has passed through the rigorous test of this stage, the error rate drops almost to zero. Most of the execution runs, which are much more expensive than compilation, proceed without difficulties because GAMS *knows* about modeling and has anticipated problems. Many of the typical errors made with conventional programming languages are associated with concepts that do not exist in GAMS. Those error sources – such as address calculations, storage assignment, subroutine linkages, input-output and flow control – create problems at execution time, are difficult to locate, often lead to long and frustrating searches, and leave the computer user intimidated. GAMS takes a radically different approach. Errors are spotted as early as possible, are reported in a way understandable to the user, including clear suggestions for how to correct the problem, and a presentation of the source of the error in terms of the user's problem.

☞ *All errors are marked with four asterisks '****' at the beginning of a line in the output listing.*

As soon as an error is detected, processing will be stopped at the next convenient opportunity. A model will never be solved after an error has been detected. The only remedy is to fix the error and repeat the run.

Errors are grouped into the three phases of GAMS modeling! compilation, execution and model generation (which includes the solution that follows). The following three sub-sections discuss these types of errors.

10.6.1 Compilation Errors

Compilation errors were discussed in some detail in Chapter 2. There is some overlap between the material in those sections and this one. Several hundred different types of errors can be detected during compilation and can often be traced back to just one specific symbol in the GAMS input. Most of the errors will be caused by simple mistakes: forgetting to declare an identifier, putting indices in the wrong order, leaving out a necessary semicolon, or misspelling a label. For errors that are not caused by mistakes, the explanatory error message text will help you diagnose the problem and correct it.

☞ *When a compilation error is discovered, a $-symbol and error number are printed below the offending symbol (usually to the right) on a separate line that begins with the four asterisks.*

If more than one error is encountered on a line (possibly because the first error caused a series of other spurious errors) the $-signs may be suppressed and error number squeezed. GAMS will not list more than 10 errors on any one line.

☞ *At the end of the echo print of the program, a list of all error numbers encountered, together with a description of the probable cause of each error, will be printed. The error messages are self-explanatory and will not be listed here.*

It is worth noting that it is easy to produce a model that does not do what you want it to do, but does not contain errors in the sense that the term is being used in this section. The best precaution is to check your work carefully and build in as many automatic consistency checks as possible.

One mistake that may cause confusion is if a GAMS reserved word is used for a label or an identifier. In this case, it is impossible to provide helpful messages for technical reasons.

☞ *In some cases, an error may not be detected until the statement following its occurrence, where it may produce a number of error conditions whose explanations seem quite silly. Always check carefully for the cause of the first error is such a group, and look at the previous statement (and especially for missing semicolons) if nothing seems obvious.*

The following example illustrates the general reporting format for compiler errors.

```
   1  set c crops / wheat, corn, wheat, longaname /
****                                $172
   2  parameter price(c) / wheat 200, cotton 700 /
****                                      $170
   3
Error Messages

170  Domain violation for element
172  Element is redefined

**** 2 ERROR(S)   0 WARNING(S)
..
**** USER ERROR(S) ENCOUNTERED
```

10.6.2 Compilation Time Errors

The reporting format for errors found while analyzing solve statements is more complicated than for normal compilation errors, mainly because many things must be checked. All identifiers referenced must be defined or assigned, the mathematics in the equations must match the model class, and so on. More elaborate reporting is required to accurately describe any problems found. The `solve` statement is only checked if the model has been found to be error free up to this point. This is not only because the check is comparatively expensive, but also because many erroneous and confusing messages can be produced while checking a `solve` in a program containing other errors.

☞ *Solve error messages are reported in two places and in two formats. First, they are shown immediately below the solve statement with a short text including the name of any offending identifier and the type of model involved. This will be sufficient in most cases. Second, a longer message with some hints appears with the rest of the error messages at the end of the compilation.*

The example below illustrates how the general reporting format for compiler errors associated with a solve statement.

```
   1  variables x,y, z ;
   2  equations eq1 , eq2;
   3
   4  eq1.. x**2 - y =e= z ;
   5  eq2.. min(x,y) =l= 20 ;
   6
   7  model silly / all / ;
   8  solve silly using lp maximizing z ;
****                                 $54,51,256
**** THE FOLLOWING LP ERRORS WERE DETECTED IN MODEL SILLY:
**** 54 IN EQUATION EQ1        .. ENDOG OPERANDS FOR **
**** 51 IN EQUATION EQ2        .. ENDOG ARGUMENT(S) IN FUNCTION
   9

Error Messages

 51  Endogenous function argument(s) not allowed in linear models
 54  Endogenous operands for ** not allowed in linear models
256  Error(s) in analyzing solve statement. More detail appears
     Below the solve statement above

**** 3 ERROR(S)   0 WARNING(S)
**** USER ERROR(S) ENCOUNTERED
```

10.6.3 Execution Errors

Execution time errors are usually caused by illegal arithmetic operations such as division by zero or taking the log of a negative number. GAMS prints a message on the output file with the line number of the offending statement and continues execution. A GAMS program should never abort with an unintelligible message from the computer's operating system if an invalid operation is attempted. GAMS has rigorously defined an extended algebra that contains all operations including illegal ones. The model library problem [CRAZY] contains all non-standard operations and should be executed to study its exceptions.

Recall that GAMS arithmetic is defined over the closed interval [`-INF`,`+INF`] and contains values `EPS` (small but not zero), `NA` (not available), and `UNDF` (the result of an illegal operation). The results of illegal operations are propagated through the entire system and can be displayed with standard display statements. However remember that one cannot solve a model or save a work file if errors have been detected previously.

10.6.4 Solve Errors

The execution of a `solve` statement can trigger additional errors called `MATRIX ERRORS`, which report on problems encountered during transformation of the model into a format required by the solver. Problems are most often caused by illegal or inconsistent bounds, or an extended range value being used as a matrix coefficient. The example below shows the general format of these errors:

```
   1  variable x;
   2  equation eq1;
   3
   4  eq1.. x =l= 10 ;
   5  x.lo = 10 ;
   6  x.up = 5 ;
   7  model wrong /eq1/;
   8  solve wrong using lp maximizing x ;
   9

**** MATRIX ERROR - LOWER BOUNDS > UPPER BOUND
X   (.LO, .L, .UP = 10, 0, 5)
...
**** SOLVE from line 8 ABORTED, EXECERROR = 1
**** USER ERROR(S) ENCOUNTERED
```

Some `solve` statement require the evaluation of nonlinear functions and the computation of derivatives. Since these calculations are not carried out by GAMS but by other subsystems not under its direct control, errors associated with these calculations are reported in the solution report. Unless reset with the `domlim` option the subsystems will interrupt the solution process if arithmetic exceptions are encountered. They are then reported on the listing as shown in the following example:

```
   1  variable x, y;
   2  equation one;
   3
   4  one.. y =e= sqrt(10/x);
   5  x.l = 10;
   6  x.lo = 0;
   7
   8  model divide /  all / ;
   9  solve divide maximizing y using nlp;

S O L V E      S U M M A R Y

     MODEL   DIVIDE              OBJECTIVE  Y
     TYPE    NLP                 DIRECTION  MAXIMIZE
     SOLVER  MINOS5              FROM LINE  9

**** SOLVER STATUS     5 EVALUATION ERROR LIMIT
**** MODEL STATUS      7 INTERMEDIATE NONOPTIMAL
**** OBJECTIVE VALUE               1.0000
```

```
    RESOURCE USAGE, LIMIT          0.141     1000.000
    ITERATION COUNT, LIMIT         0        10000
    EVALUATION ERRORS              2            0


    EXIT -- Termination requested by User in subroutine FUNOBJ after   7  calls

 **** ERRORS(S) IN EQUATION ONE
      2 INSTANCES OF - DIVISION BY ZERO (RESULT SET TO  0.1E+05)

 **** REPORT SUMMARY :        1     NONOPT ( NOPT)
                              0 INFEASIBLE
                              0  UNBOUNDED
                              2     ERRORS ( ****)
```

Note that the solver status returned with a value of 5, meaning that the solver has been interrupted because more than `domlim` evaluation errors have been encountered. The type of evaluation error and the equation causing the error are also reported.

If the solver returns an intermediate solution because of evaluation errors, the following solve will still be attempted. The only fatal GAMS error that can be caused by a solver program is the failure to return any solution at all. If this happens, as mentioned above, all possible information is listed on the GAMS output file and any solves following will not be attempted.

10.7 Summary

This is the end of the sequential discussion of the basic features of the GAMS language. All further chapters are geared towards more advanced use of GAMS.

11

Conditional Expressions, Assignments and Equations

11.1 Introduction

This chapter deals with the way in which conditional assignments, expressions and equations are made in GAMS. The index operations already described are very powerful, but it is necessary to allow for exceptions of one sort or another. For example, heavy trucks may not be able use a particular route because of a weak bridge, or some sectors in an economy may not produce exportable product. The use of a subset in an indexed expression has already been shown to provide some ability to handle exceptions.

11.2 Logical Conditions

Logical conditions are special expressions that evaluate to a value of True or False. Numerical Expressions can also serve as logical conditions. Additionally, GAMS provides for numerical relationship and logical operators that can be used to generate logical conditions. The next four sub-sections discuss these various building blocks that can be used to develop complex logical conditions.

11.2.1 Numerical Expressions as Logical Conditions

☞ *Numerical expressions can also serve as logical conditions - a result of zero is treated as a logical value of False, and a non-zero result is treated as a logical value of True.*

The following numerical expression can be used to illustrate this point.

```
    2*a - 4
```

This expression results in a logical value of False when `a` is 2 because the expression numerically evaluates to 0. For all other values of `a`, the expression results in a non-zero value, and therefore is equivalent to a logical value of True.

11.2.2 Numerical Relationship Operators

Numerical relationship operators compare two numerical expressions. For completeness all numerical relationship operators are listed below.

`lt`, `<`	strictly less than

`le`, `<=`	less than-or-equal to
`eq`, `=`	equal to
`ne`, `<>`	not equal to
`ge`, `>=`	greater than or equal to
`gt`, `>`	strictly greater than

The following example of a numerical relationship illustrates its use as a logical condition.

```
(sqr(a) > a)
```

This condition evaluates to False if $-1 \leq$ `a` ≤ 1. For all other values of `a`, this condition evaluates to True. Note that the same expression can also be written as `(sqr(a) gt a)`.

11.2.3 Logical Operators

The logical operators available in GAMS are listed below.

`not`	not
`and`	and
`or`	inclusive or
`xor`	exclusive or

The truth table generated by these logical operators is given in table 11.1.

Operands		*Results*			
a	*b*	*a and b*	*a or b*	*a xor b*	*not a*
0	0	0	0	0	1
0	non-zero	0	1	1	1
non-zero	0	0	1	1	0
non-zero	non-zero	1	1	0	0

Table 11.1: Truth table of logical operators

11.2.4 Set Membership

Set membership can also be used as a logical condition. The label results in a logical value of True if it is a member of the set in question, and False if it is not. This is used with subsets and dynamic sets.

Consider the following example for illustration.

```
set i          /1*10/
    subi(i)    /1*3/ ;
```

The set `subi(i)` results in a logical value of True for all elements that belong to `subi` and False for all elements of `i` that do not belong to `subi`.

The use of set membership as a logical condition is an extremely powerful feature of GAMS and while its use will be illustrated later on in this chapter, its full power becomes clear when considered with the description of dynamic sets later.

11.2.5 Logical Conditions Involving Acronyms

Acronyms, which are character string values, can be used in logical conditions only with the `=` or `<>` operators only.

Consider the following example of logical conditions involving the use of acronyms,

```
dayofweek = wednesday
dayofweek <> thursday
```

where `dayofweek` is a parameter, and `wednesday` and `thursday` are acronyms.

11.2.6 Numerical Values of Logical Conditions

The previous four sub-sections have described the various features in GAMS that can be used as logical conditions. However, GAMS does not have a Boolean data type.

☞ *GAMS follows the convention that the result of a relational operation is zero if the assertion is False, and one if True.*

Consider the following example for illustration,

```
x = (1 < 2) + (2 < 3)
```

The expression to the right of the assignment evaluates to 2 since both logical conditions within parenthesis are true and therefore assume a value of 1. Note that this is different from the assignment below,

```
x = (1 < 2) or (2 < 3)
```

which evaluates to 1 due to the or operator behaving as explained above.

11.2.7 Mixed Logical Conditions - Operator Precedence

The building blocks discussed in the first four subsections can be used to generate more complex logical conditions. The default precedence order in a logical condition used by GAMS in the absence of parenthesis is shown in table 11.2 in decreasing order.

Operation	*Operator*
Exponentiation	`**`
Numerical Operators	
- Multiplication, Division	`*, /`
- Unary operators - Plus, Minus	`+, -`
- Binary operators - addition, subtraction	`+, -`
Numerical Relationship operators	`<, <=, =, <>, >=, >`
Logical Operators	
- not	`not`
- and	`and`
- or, xor	`or, xor`

Table 11.2: Operator precedence

Note that in the case of operators with the same precedence, the order in which the operator appears in the expression is used as the precedence criterion, with the order reducing from left to right.

☞ *It is always advisable to use parentheses rather than relying on the precedence order of operators. It prevents errors and makes the intention clear.*

Consider the following example for illustration,

```
x - 5*y and z - 5
```

is treated equivalent to `(x - (5*y)) and (z-5)`. However, note that the use of parenthesis does make the expression clearer to understand.

11.2.8 Mixed Logical Conditions - Examples

Some simple examples of logical conditions, containing the building blocks described in the previous sub-sections, are shown in table 11.3 to illustrate the generation and use of more complex logical conditions.

Logical Condition	*Numerical Value*	*Logical Value*
`(1 < 2) + (3 < 4)`	2	True
`(2 < 1) and (3 < 4)`	0	False
`(4*5 - 3) + (10/8)`	17.125	True
`(4*5 - 3) or (10 - 8)`	1	True
`(4 and 5) + (2*3 <= 6)`	2	True
`(4 and 0) + (2*3 < 6)`	0	False

Table 11.3: Examples of logical conditions

11.3 The Dollar Condition

This section introduces the dollar operator, which is one of the most powerful features of GAMS. The dollar operator operates with a logical condition. The term `$`(condition) can be read as '*such that condition is valid*' where condition is a logical condition.

☞ *The dollar logical conditions cannot contain variables. Variable attributes (like `.l` and `.m`) are permitted however.*

The dollar operator is used to model conditional assignments, expressions, and equations. The following subsection provides an example that will clarify its use. The next section will deal individually with the topic of using dollar conditions to model conditional assignments, expressions, and equations respectively.

11.3.1 An Example

Consider the following simple condition,

```
if (b > 1.5), then a = 2
```

This can be modeled in GAMS using the dollar condition as follows,

```
a$(b > 1.5) = 2 ;
```

If the condition is not satisfied, no assignment is made. Note that one can *read* the `$` as '*such that*' to clarify the meaning: '`a`, *such that* `b` *is greater than 1.5*, *equals 2*'.

11.3.2 Nested Dollar Conditions

Dollar conditions can be also nested. The term `$(condition1$(condition2))` can be read as `$(condition1 and condition2)`.

☞ *For nested dollar conditions, all succeeding expressions after the dollar must be enclosed in parentheses.*

Consider the following example,

```
u(k)$(s(k)$t(k)) = a(k) ;
```

`K, s(k), t(k)`, and `i` are sets, while `u(k)` and `a(i)` are parameters. The assignment will be made only for those members of `k` that are also members of both `s` and `t`. Note the position of the parenthesis in the dollar condition. The statement above can be rewritten as

```
u(k)$(s(k) and t(k)) = a(k) ;
```

☞ *To assist with the readability of statements, it is strongly recommended to use the logical and operator instead of nesting dollar operators.*

11.4 Conditional Assignments

The statement comprising the example in the Section before was a conditional assignment. In this example, the dollar condition was on the left-hand-side of the assignment.

☞ *The effect of the dollar condition is significantly different depending on which side of the assignment it is in.*

☞ *In many cases, it may be possible to use either of the two forms of the dollar condition to describe an assignment. In such a case, clarity of logic should be used as the criterion for choice.*

The next two subsections describe the use of the dollar condition on each side of the assignment.

11.4.1 Dollar on the Left

The example illustrated in the section above uses the dollar condition on the left-hand side of the assignment statement.

☞ *For an assignment statement with a dollar condition on the left-hand side, no assignment is made unless the logical condition is satisfied. This means that the previous contents of the parameter on the left will remain unchanged for labels that do not satisfy the condition.*

☞ *If the parameter on the left-hand side of the assignment has not previously been initialized or assigned any values, zeroes will be used for any label for which the assignment was suppressed.*

Consider the following example adapted from [CHENERY],

```
rho(i)$(sig(i) ne 0) = (1./sig(i)) - 1. ;
```

The parameter `sig(i)` has been previously defined in the model and the statement above is used to calculate `rho(i)`. The dollar condition on the statement protects against dividing by zero. If any of the values associated with `sig(i)` turn out to be zero, no assignment is made and the previous values of `rho(i)` remain. As it happens, `rho(i)` was previously not initialized, and therefore all the labels for which `sig(i)` is 0 will result in a value of 0.

Now recall the convention, explained in Section 11.2.1 that non zero implies True and zero implies False. The assignment above could therefore be written as

```
rho(i)$sig(i)  =  (1./sig(i)) - 1. ;
```

11.4.2 Dollar on the Right

☞ *For an assignment statement with a dollar condition on the right hand side, an assignment is always made. If the logical condition is not satisfied, the corresponding term that the logical dollar condition is operating on evaluates to 0.*

Consider the following example, which is a slight modification to the one described in Section 11.3.1,

```
x = 2$(y > 1.5)  ;
```

Expressed in words, this is equivalent to,

```
if (y > 1.5)   then (x = 2),    else (x = 0)
```

Therefore an if-then-else type of construct is implied, but the else operation is predefined and never made explicit. Notice that the statement in the illustrative example above can be re-written with an explicit if-then-else and equivalent meaning as

```
x = 2$(y gt 1.5) + 0$(y le 1.5) ;
```

This use of this feature is more apparent for instances when an else condition needs to be made explicit. Consider the next example adapted from [FERTD]. The set `i` is the set of plants, and are calculating `mur(i)`, the cost of transporting imported raw materials. In some cases a barge trip must be followed by a road trip because the plant is not alongside the river and we must combine the separate costs. The assignment is:

```
mur(i) =(1.0 +. 0030*ied(i,'barge'))$ied(i,'barge')
       +(0.5  + .0144*ied(i,'road'))$ied(i,'road');
```

This means that if the entry in the distance table is not zero, then the cost of shipping using that link, which has a fixed and a variable components, is added to the total cost,. If there is no distance entry, there is no contribution to the cost, presumably because that mode is not used.

11.4.3 Filtering Controlling Indices in Indexed Operations

The controlling indices can, in certain cases, be filtered through the conditional set without the use of the dollar operator. Consider the example described in that section. The total cost of shipment is obtained through the following equation,

```
variable shipped(i,j), totcost ;
equation costequ ;

cost.. totcost =e= sum((i,j)$ij(i,j), shipcost(i,j)*shipped(i,j));
```

where `shipped` is the amount of material shipped from `i` to `j`, and `totcost` is the total cost of all shipment. The equation above can be written as,

```
cost.. totcost =e= sum(ij, shipcost(ij)*shipped(ij));
```

However, if the original equation is expressed as,

```
cost.. totcost =e= sum((i,j)$ij(i,j),
factor*congestfac(j)*distance(i,j) *shipped(i,j));
```

Index `j` appears separately from `i` in `congestfac(j)`. The equation then needs to be simplified as,

```
cost.. totcost =e= sum(ij(i,j),
factor*congestfac(j)*distance(ij) *shipped(ij));
```

Note that the presence of `j` separately in the indexed expression necessitated the use of `ij(i,j)` rather than `ij`.

11.4.4 Filtering Sets in Assignments

Consider the following statement,

```
u(k)$s(k) = a(k) ;
```

where `k` and `s(k)` are sets, while `u` and `a` are parameters. This can be rewritten as,

```
u(s) = a(s) ;
```

Note that the assignment has been filtered through the conditionality without the use of the dollar operator. This is a cleaner and more understable representation of the assignment. This feature gets more useful when dealing with tuples (sets with multiple indices).

Consider the following example for calculating the travel cost for a fictional parcel delivery service between collection sites (`i`) and regional transportation hubs (`j`),

```
set     i /miami,boston,chicago,houston,sandiego,phoenix,baltimore/
    j /newyork,detroit,losangeles,atlanta/ ;
set ij(i,j) /
    boston.newyork
    baltimore.newyork
    miami.atlanta
    houston.atlanta
    chicago.detroit
    sandiego.losangeles
    phoenix.losangeles  / ;

table distance(i,j) "distance in miles"
           newyork     detroit  losangeles     atlanta
miami         1327        1387        2737         665
boston         216         699        3052        1068
chicago        843         275        2095         695
houston       1636        1337        1553         814
sandiego       206
phoenix       2459        1977         398        1810;

parameter factor,shipcost(i,j) ; factor = 0.009 ;
```

The set `ij` denotes the regional transportation hub for each collection site. `Factor` is the cost estimate per unit mile. The cost of transporting parcels (`shipcost`) from a local collection site (`i`) to a regional hub(`j`) is then provided by the following assignment,

```
shipcost(i,j)$ij(i,j) = factor*distance(i,j) ;
```

Note that `i` and `j` do not appear separately in the assignment for shipcost. The assignment can then be simply written as,

```
shipcost(ij) = factor*distance(ij) ;
```

If `i` or `j` appear separately in any assignment, the above simplification cannot be made. For example, consider that travelcost depended not only on `factor` and the distance between collection sites and regional hubs but also the load on the regional hub.

```
Parameter congestfac(j) /
   newyork      1.5
   detroit      0.7
   losangeles   1.2
   atlanta      0.9/ ;
```

`Congestfac` is a parameter used to model the congestion at each regional hub. The unit cost of shipment is then computed as follows:

```
shipcost(i,j)$ij(i,j) = factor*congestfac(j)*distance(i,j) ;
```

This cannot be re-written as

```
shipcost(ij) = factor*congestfac(j)*distance(ij) ;
```

The above representation has the index `j` on the right hand side, but not on the left hand side. As explained before, GAMS will flag this assignment as an error. However, the following representation will work:

```
shipcost(ij(i,j)) = factor*congestfac(j)*distance(ij) ;
```

In the above assignment `ij` is specifically denoted as a tuple of `i` and `j` which then appear on the left hand side.

11.5 Conditional Indexed Operations

Another important use of the dollar condition is to control the domain of operation of indexed operations. This is conceptually similar to the '*dollar on the left*' described in Section 11.3.1.

Consider the following example adapted from [GTM].

```
tsubc  =  sum(i$(supc(i) ne inf), supc(i))  ;
```

This statement evaluates the sum of the finite values in `supc`.

☞ *A common use of dollar controlled index operations is where the control is itself a set. This importance of this concept will become apparent with the discussion of dynamic sets.*

A set has been used to define the mapping between mines and ports in Chapter 4. Another typical example is a set-to-set mapping defining the relationship between states and regions, used for aggregating data obtained by state to the models requirements (by region).

```
sets r / west,east /
     s / florida,texas,vermont,maine  /
     corr(r,s) / north.(vermont,maine)
                 south.(florida,texas) /

parameter y(r)
   income (s)  "income of each state"
         / florida   4.5, vermont   4.2
           texas     6.4, maine     4.1 / ;
```

The set `corr` provides a correspondence to show which states belong to which regions. The parameter `income` is the income of each state. `Y(r)` can be calculated with this assignment statement:

```
y(r) = sum(s$corr(r,s), income(s)) ;
```

For each region `r`, the summation over `s` is only over those pairs of `(r,s)` for which `corr(r,s)` exists. Conceptually, set existence is analogous to the Boolean value True or the arithmetic value '*not zero*'. The effect is that only the contributions for '`vermont`' and '`maine`' are included in the total for '`north`', and '`south`' includes only '`texas`' and '`florida`'.

Note that the summation above can also be written as `sum(s, income(s)$corr(r,s))` but this form is not as easy to read as controlling the index of summation.

11.5.1 Filtering Controlling Indices in Indexed Operations

The controlling indices can, in certain cases, be filtered through the conditional set without the use of the dollar operator. Consider the example described in that section. The total cost of shipment is obtained through the following equation,

```
variable shipped(i,j), totcost ;
equation costequ ;

cost.. totcost =e= sum((i,j)$ij(i,j), shipcost(i,j)*shipped(i,j));
```

where `shipped` is the amount of material shipped from `i` to `j`, and `totcost` is the total cost of all shipment. The equation above can be written as,

```
cost.. totcost =e= sum(ij, shipcost(ij)*shipped(ij));
```

However, if the original equation is expressed as,

```
cost.. totcost =e= sum((i,j)$ij(i,j),
factor*congestfac(j)*distance(i,j) *shipped(i,j));
```

Index `j` appears separately from `i` in `congestfac(j)`. The equation then needs to be simplified as,

```
cost.. totcost =e= sum(ij(i,j),
factor*congestfac(j)*distance(ij) *shipped(ij));
```

Note that the presence of `j` separately in the indexed expression necessitated the use of `ij(i,j)` rather than `ij`.

11.6 Conditional Equations

The dollar operator is also used for exception handling in equations. The next two subsections discuss the two main uses of dollar operators within equations - within the body of an equation, and over the domain of definition.

11.6.1 Dollar Operators within the Algebra

A dollar operator within an equation is analogous to the dollar control on the right of assignments as discussed in Section 11.4.2, and if one thinks of '*on the right*' as meaning on the right of the '`..`' then the analogy is even closer. An if-else operation is implied as it was with assignments. It is used to exclude parts of the definition from some of the generated constraints.

Consider the following example adapted from [CHENERY],

```
mb(i).. x(i) =g= y(i) + (e(i) - m(i))$t(i) ;
```

The term is added to the right hand side of the equation only for those elements of `i` that belong to `t(i)`.

Controlling indexing operations using the dollar condition can also be done as with any assignment. Consider the following supply balance (`sb`) equation from [GTM],

```
sb(i)..  sum(j$ij(i,j), x(i,j))  =l=  s(i)  ;
```

11.6.2 Dollar Control over the Domain of Definition

This is analogous to the dollar control on the left of assignments as discussed in Section 11.4.1, and if one thinks of '*on the left*' as meaning on the left of the '`..`' then the analogy is even closer.

☞ *The purpose of the dollar control over the domain of definition of equations is to restrict the number of constraints generated to less than that implied by the domain of the defining sets.*

Consider the following example adapted from [FERTS]:

```
cc(m,i)$mpos(m,i)..
sum(p$ppos(p,i), b(m,p)*z(p,i))  =l= util*k(m,i);
```

`Cc` is a capacity constraint defined for all units (`m`) and locations (`i`).

Not all types of units exist at all locations, however, and the mapping set `mpos(m,i)` is used to restrict the number of constraints actually generated. The control of the summation over `p` with `ppos(p,i)` is an additional one, and is required because not all processes (`p`) are possible at all locations (`i`).

11.6.3 Filtering the Domain of Definition

The same rules that apply to filtering assignments and controlling indices in indexed operations applies to equation domains as well. Consider the following equation using the same set definitions as described before,

```
parameter bigM(i,j) ;
variable shipped(i,j) ;
binary variable bin(i,j) ;

equation logical(i,j) ;
logical(i,j)$ij(i,j).. shipped(i,j) =l= bigM(i,j)*bin(i,j) ;
```

The equation `logical` relates the continuous variable `shipped(i,j)` to the binary variable `bin(i,j)`. This can be simplified as follows:

```
logical(ij).. shipped(ij) =l= bigM(ij)*bin(ij) ;
```

Note that if the right hand side of the equation contained any term that was indexed over `i` or `j` separately, then the equation `logical(i,j)$ij(i,j)` would have to be simplified as `logical(ij(i,j))`.

12

Dynamic Sets

12.1 Introduction

All the sets that have been discussed so far had their membership declared as the `set` itself was declared, and the membership was never changed. In this chapter we will discuss changing the membership of `sets`. A set whose membership can change is called a dynamic set to contrast it with a static set whose membership will never change. The distinction is important and will be discussed in detail in this chapter. This is a topic that has been avoided until now because of a potential confusion for new users. Advanced Users will, however, find it useful.

12.2 Assigning Membership to Dynamic Sets

Sets can be assigned in a similar way to other data types. One difference is that arithmetic operations cannot be performed on sets in the same way that they can on *value typed* identifiers (`parameters`, or `variables` and `equations` subtypes). A dynamic set is most often used as a *controlling index* in an assignment or an equation definition, or as the controlling entity in a dollar-controlled indexed operation.

12.2.1 The Syntax

In general, the syntax in GAMS for assigning membership to dynamic sets is:

```
set_name(domain_name | domain_label) = yes | no ;
```

`Set_name` is the internal name of the `set` (also called an identifier) in GAMS. `Yes` and `no` are keywords used in GAMS to denote membership or absence respectively from the assigned set.

☞ *The most important principle to follow is that a dynamic set should always be domain checked at declaration time to be a subset of a static set (or sets).*

☞ *It is of course possible to use dynamic sets that are not domain checked, and this provides additional power, flexibility, lack of intelligibility, and danger. Any label is legal as long as the dimensionally, once established, is preserved.*

12.2.2 Illustrative Example

The following example, adapted from [ZLOOF], is used to illustrate the assignment of membership to dynamic sets.

```
set item   all items   / dish,ink,lipstick,pen,pencil,perfume /
subitem1(item)   first subset of item   / pen,pencil /
subitem2(item)   second subset of item;

subitem1('ink')  =  yes ;  subitem1('lipstick')  =  yes ;
subitem2(item)  =  yes  ;  subitem2('perfume')   =  no ;
display subitem1, subitem2;
```

Note that the sets subitem1 and subitem2 are declared like any other set. The two sets become dynamic because of assignments. They are also domain checked: the only members they will ever be able to have must also be members of item. And item is a static set and henceforth its membership is frozen. The first two assignments each add one new element to subitem1. The third is an example of the familiar indexed assignment: subitem2 is assigned all the members of item. The output caused by the display statement, that will reveal the membership of the sets, is shown below for verification.

```
----      7 SET       SUBITEM1      first subset of item
INK     ,    LIPSTICK,    PEN     ,    PENCIL

----      7 SET       SUBITEM2      second subset of item
DISH    ,    INK     ,    LIPSTICK,    PEN     ,    PENCIL
```

☞ *The elements are displayed in the order specified in the declaration of item.*

12.2.3 Dynamic Sets with Multiple Indices

Dynamic sets, like static sets, can have up to 20 dimensions. The following example illustrates assignments for multi-dimensional sets.

```
Sets item items sold /pencil, pen/
     sup suppliers  /bic, parker, waterman /
     supply(item,sup) ;

supply('pencil','bic') = yes ;
supply('pen',sup) = yes ;
```

All the mechanisms using asterisks and parenthesized lists that we introduced in the discussion on static sets in chapter 4 are available for dynamic sets as well.

12.2.4 Assignments over the Domain of Dynamic Sets

One can make an assignment over the domain of a dynamic set because dynamic sets are known to be proper subsets of static sets. This is not the same as doing domain checking using a dynamic set.

The following example, adapted from the Section 12.2.2 illustrates the use of dynamic sets as domains:

```
subitem1(item)  =  no
subitem1(subitem2)  =  yes;
```

The first assignment ensures that subitem1 is empty. Note that this can also be done with parameters. For example,

```
parameter inventory(item) ;
inventory(subitem1) = 25 ;
```

12.2.5 Equations Defined over the Domain of Dynamic Sets

It is sometimes necessary to define an equation over a dynamic set.

☞ *The trick is to* declare *the equation over the entire domain but* define *it over the dynamic set.*

The following example illustrates its use,

```
set  allr   all  regions  /  n, s, w, e, n-e, s-w  /
     r(alr) region subset for particular solution ;

scalar price /10/ ;
equations   prodbal(allr)  production balance ;

variables   activity(allr)    first activity
            revenue(allr)      revenue          ;

prodbal(r).. activity(r)*price =e= revenue(r) ;
```

To repeat the important point: the equation is *declared* over `allr` but referenced over `r`. Then arbitrary assignments can be made to `r` within the membership of `allr`.

12.3 Using Dollar Controls with Dynamic Sets

The rest of this chapter requires an understanding of the dollar condition. All the dollar control machinery is available for use with dynamic sets. In fact, the full power of dynamic sets can be exploited using these dollar controls.

Note that the dynamic set has values of yes and no only, and can therefore be treated as a logical statement. The only operations that can be performed on dynamic sets inside the dollar operator are therefore not, and, or, or xor , as well as the set operations described in Section 12.4, page 116.

The main uses of dynamic sets inside dollar conditions are in assignments, indexed operations and in equations. Each of these will be discussed in detail in the following subsections. Examples will be used to illustrate its use in each of the three cases.

12.3.1 Assignments

Dynamic sets can be used inside dollar conditions within assignments defining other dynamic sets or parameters.

As an illustration of its use in defining other dynamic sets, the two statements in the example from Section 12.2.4 can be written with equivalent effect as

```
subitem1(item)  =  yes$subitem2(item)  ;
```

which is a terse form of the following statement

```
subitem1(item)  =  yes$subitem2(item) + no$(not subitem2(item))  ;
```

☞ *The value used in the implied "else" that goes with "dollar on the right" is no in a set assignment, rather than zero which is used with normal data.*

The second example from Section 12.2.4 can be rewritten as follows to illustrate the use of dynamic sets in defining parameters,

```
inventory(item)$subitem1(item) = 25 ;
```

12.3.2 Indexed Operations

Another important use of dollar controls with dynamic sets is to control the domain while performing indexed operations like `sum` and `prod`. Consider the following adaptation of the second example from Section 12.3.1.

```
parameter totinv  total inventory ;
totinv = sum(item$subitem1(item),inventory(item)) ;
```

This example has been shown only for illustration. Note that the second statement above can also be rewritten tersely as

```
totinv = sum(subitem1,inventory(subitem1)) ;
```

This is not always possible. Consider the following artificially created example,

```
sets item items sold /pencil, pen/
     sup suppliers   /bic, parker, waterman /
     dep department  /stationery, household/
     supply(item,sup) ;
supply('pencil', 'bic') = yes ; supply('pen',sup) = yes ;

parameter totsales(dep) ;
totsales(dep) = sum(item$supply(item,'bic'), sales(dep,item)) ;
```

The assignment above is used to find the total sales of all departments that sell items supplied by `bic`. Note that the dynamic set is used to limit the domain of summation to those for which `supply(item,'bic')` is true.

12.3.3 Equations

Dynamic sets can be used inside dollar conditions in equations both as part of the equation algebra, or while defining the domain of the equation. The first case is similar to the case of assignments discussed in Section 12.3.1. The latter case is used to restrict the equation over the domain of a dynamic set. The equation defined in the example from Section 12.2.5 can be rewritten with equivalent effect as follows,

```
prodbal(allr)$r(allr).. activity(allr)*price =e= revenue(allr) ;
```

The domain of definition of equation `prodbal` is restricted to those elements that belong to the dynamic set `r`.

12.3.4 Filtering through Dynamic Sets

The filtering process explained in previous sections is valid when the conditional set is a dynamic one. Consider the following two examples as described before,

```
inventory(item)$subitem1(item) = 25 ;
prodbal(allr)$r(allr).. activity(allr)*price =e= revenue(allr) ;
```

These statements can be rewritten as,

```
inventory(subitem1) = 25 ;
prodbal(r).. activity(r)*price =e= revenue(r) ;
```

12.4 Set Operations

This section describes how various symbolic set operations can be performed in GAMS using dynamic sets. The Union, Intersection, Complement, and Difference set operations are described individually in the following subsections. Once again the example from Section 12.2.2 is used to illustrate each operation.

12.4.1 Set Union

The symbol + performs the set union operation. Consider the following example,

```
subitem3(item)  =  subitem1(item) + subitem2(item)  ;
```

The membership of `subitem3` is set equal to all the elements of `subitem1` and all the elements of `subitem2`. The operation above is equivalent to the following longer way of representation,

```
subitem3(item)=no; subitem3(subitem2)=yes; subitem3(subitem1)=yes;
```

12.4.2 Set Intersection

The symbol * performs the set intersection operation. Consider the following example,

```
subitem3(item)  =  subitem1(item) * subitem2(item)  ;
```

The membership of `subitem3` is set equal to only those present in both `subitem1` and `subitem2`. The operation above is equivalent to the following longer way of representation,

```
subitem3(item)=yes$(subitem1(item) and subitem2(item)) ;
```

12.4.3 Set Complement

The operator `not` performs the set complement operation. Consider the following example,

```
subitem3(item)  =  not subitem1(item)  ;
```

The membership of `subitem3` is set equal to all those in `item` but not in `subitem1`. The operation above is equivalent to the following longer way of representation,

```
subitem3(item)=yes; subitem3(subitem1)=no;
```

12.4.4 Set Difference

The operator - performs the set difference operation. Consider the following example,

```
subitem3(item)  =  subitem1(item) - subitem2(item)  ;
```

The membership of `subitem3` is set equal to all elements that are members of `subitem1` but `subitem2`. The operation above is equivalent to the following longer way of representation,

```
subitem3(item)=yes$(subitem1(item)); subitem3(subitem2)=no;
```

12.5 Summary

The purpose of set assignments is to make calculations based on given data (the static sets) for use in exception handling. It is one more example of the principle of entering a small amount of data and building a model up from the most elemental information.

13

Sets as Sequences: Ordered Sets

13.1 Introduction

In our original discussion of sets in Chapter 4, we said that unless there is a special need to do things differently, a one-dimensional set should be regarded as an unordered collection of labels. In this chapter we will discuss special features that can be used when you need to be able to deal with a set as if it were a sequence.

For example, in economic models that explicitly represent conditions in different time periods, it is necessary to refer to the *next* or *previous* time period, because there must be links between the periods. As another example, stocks of capital are normally tracked through such models by equations of the form '*stocks at the end of period* n *are equal to stocks at the end of period* $n-1$ *plus net gains during period* n'. Location problems, where the formulation may require a representation of contiguous areas, as in a grid representation of a city, and scheduling problems are other classes of problems in which sets must also have the properties of sequences.

☞ *Models involving sequences of time periods are often called dynamic models, because they describe how conditions change over time. This use of the word* dynamic *unfortunately has a different meaning from that used in connection with sets, but this is unavoidable.*

13.2 Ordered and Unordered Sets

As with sets used in domain checking, restrictions are imposed when the set needs to be referred as if it were a sequence. The notion of static sets was introduced already: the set must be initialized with a list of labels enclosed in slashes at the time the set is declared, and never changed afterwards.

☞ *Ordered sets must be static sets. In other words, no order is possible for dynamic sets.*

☞ *GAMS maintains one list of* unique *elements - the labels that are used as elements in one or more sets. The order of the elements in any one set is the same as the order of those elements in that unique element list. This means that the order of a set may not be what it appears to be if some of the labels were used in an earlier definition.*

☞ *The map of your labels in the GAMS order can be seen by putting the compiler directive* `$onuellist` *somewhere before the first set declaration.*

☞ *A good rule of thumb is that if the labels in a set one wants to be ordered have not been used already, then they will be ordered.*

The map is shown with the other compiler maps after the listing of your program. In the example below we show ordered and unordered sets and the map showing the order. The input is:

```
$onuellist
set    t1  / 1987, 1988, 1989, 1990, 1991 /
       t2  / 1983, 1984, 1985, 1986, 1987 /
       t3  / 1987, 1989, 1991, 1983, 1985 / ;
```

The map below shows the entry order (the important one) and the sorted order, obtained by sorting the labels into dictionary order. The single digits on the left are the sequence numbers of the first label on that line.

```
G e n e r a l   A l g e b r a i c   M o d e l i n g   S y s t e m
Unique Element Listing

Unique Elements in Entry Order

    1   1987       1988       1989       1990       1991      1983
    7   1984       1985       1986
Unique Elements in Sorted Order
    1   1983       1984       1985       1986       1987      1988
    7   1989       1990       1991
```

A set can always be made ordered by moving its declaration closer to the beginning of the program. With these restrictions in mind, we move on the operations that are used in dealing with sets as sequences.

13.3 Ord and Card

In Chapter 4, it was explained that labels do not have a numerical value. The examples used were that the label '`1986`' does not have a numerical value of 1986 and the label '`01`' is different from the label '`1`'. This section introduces two operators - `ord` and `card` that return integer values when applied to sets. While the integer values returned do not represent the numerical value of the label, they can be used for the same purpose.

The next two subsections describe each of these two functions in turn.

13.3.1 The Ord Operator

`Ord` returns the relative position of a member in a set. ☞ *`Ord` can be used only with a one-dimensional, static, ordered set.*

Some examples show the usage.

```
set  t  time periods  / 1985*1995 /
parameter val(t) ;
val(t)  =  ord(t);
```

As a result of the statements above, the value of `val('1985')` will be 1, `val('1986')` will be 2 and so on.

A common use of `ord` is in setting up vectors that represent quantities growing in some analytically specified way. For example, suppose a country has 56 million people in the base period and population is growing at the rate of 1.5 percent per year. Then the population in succeeding years can be calculated by using:

```
population(t)  =  56*(1.015**(ord(t) - 1))  ;
```

It is often useful to simulate general matrix operations in GAMS. The first index on a two dimensional parameter can conveniently represent the rows, and the second the columns, and order is necessary. The example below shows how to set the upper triangle of a matrix equal to the row index plus the column index, and the diagonal and lower triangle to zero.

```
set  i   row and column labels  / x1*x10 /; alias (i,j);
parameter a(i,j)  a  general square matrix;
a(i,j)$(ord(i) lt ord(j))  =  ord(i) + ord(j) ;
```

13.3.2 The Card Operator

`Card` returns the number of elements in a set. `Card` can be used with any set, even dynamic or unordered ones. The following example illustrates its use:

```
set  t  time periods  / 1985*1995 /
parameter s  ;  s  =  card(t);
```

As a result of the statement above, `s` will be assigned the value 11.

A common use of card is to specify some condition only for the final period, for example to fix a variable. An artificial example is:

```
c.fx(t)$(ord(t) = card(t))  =  demand(t)  ;
```

which fixes the variable for the last member only: no assignment is made for other members of `t`. The advantage of this way of fixing `c` is that the membership of `t` can be changed safely and this statement will always fix `c` for the last one.

13.4 Lag and Lead Operators

The lag and lead operators are used to relate the *current* to the *next* or *previous* member of a set. In order to use these operators the set in question must, of course, be ordered. GAMS provides two forms of lag and lead operators

➢ Linear Lag and Lead Operators (`+`, `-`)

➢ Circular Lag and Lead Operators (`++`, `--`)

The difference between these two types of operators involves the handling of endpoints in the sequence. GAMS provides some built in facilities to deal with this issue, but in any work involving sequences the user must think carefully about the treatment of endpoints, and all models will need special exception handling logic to deal with them.

In the linear case, the members of the set that are endpoints are left hanging. In other words, there are no members preceding the first member or following the last one. This may cause the use of non-existent elements. The next section will describe how this is handled in GAMS. This form of the lag and lead operators is useful for modeling time periods that do not repeat. A set of years (say 1990 to 1997) is an example. The operators are `+` and `-`.

☞ *GAMS is able to distinguish linear lag and lead operators (`+,-`) from arithmetic operators by context.*

In the circular case, the first and last members of the set are assumed to be adjacent, so as to form a circular sequence of members. The notion is that '`first - 1`' is a reference to '`last`' and '`last + 2`' is the same as '`first + 1`' and so on. All references and assignments are defined. This is useful for modeling time periods that repeat, such as months of the year or hours in the day. It is quite natural to think of January as the month following December. Agricultural farm budget models and workforce scheduling models are examples of applications where circular leads occur naturally. The operators are `++` and `--`.

The next two sections will describe the use of these lag and lead operators in assignment statements and in equations respectively.

13.5 Lags and Leads in Assignments

One use of the lag and lead operator is in assignment statements. The use of a lag and lead operator on the right-hand-side of an assignment is called a reference, while its use in the left-hand-side is called an assignment and involves the definition of a domain of the assignment. The concepts behind reference and assignment are equally valid for the linear and circular forms of the lag and lead operator. However, the importance of the distinction between reference and assignment is not pronounced for circular lag and lead operators because non-existent elements are not used in this case.

☞ *A reference to a non-existent element causes the default value (zero in this case) to be used, whereas an attempt to assign to a non-existent element results in no assignment being made.*

The next two sub-sections provide examples illustrating the use of the linear form of the lag and lead operators for reference and assignment. Section 13.5.3 will illustrate the use of the circular form of the lag and lead operator.

13.5.1 Linear Lag and Lead Operators - Reference

Consider the following example, where two parameters a and b are used to illustrate the linear lag and lead operators for reference.

```
set  t  time sequence  / y-1987*y-1991 / ;
parameter a(t), b(t) ;
a(t)  =  1986 + ord(t) ;
b(t)  =  -1;  b(t)  =  a(t-1) ;
option decimals=0; display a, b ;
```

The `option` statement suppresses the decimal places from the `display.` The results are shown below.

```
----      6 PARAMETER A
Y-1987 1987, Y-1988 1988, Y-1989 1989, Y-1990 1990, Y-1991 1991

----      6 PARAMETER B
Y-1988 1987, Y-1989 1988, Y-1990 1989, Y-1991 1990
```

For a, as expected, the values 1987, 1988 up to 1991 are obtained corresponding to the labels `y-1987`, `y-1988` and so on. `b` is initialized to −1.

For `b`, the assignment is done over all members of `t`, and for each, the value of a from the previous period is assigned to the current member of `b`. If no previous period, as with `y-1987`, zero is used, and `b('y-1987')` becomes zero, replacing the previous value of −1.

13.5.2 Linear Lag and Lead Operators - Assignment

Consider the following example, where two parameters `a` and `c` are used to illustrate the assignment of linear lag and lead operators.

```
set   t  time sequence  / y-1987*y-1991 / ;
parameter a(t), c(t) ;
a(t)  =  1986 + ord(t) ;
c(t)  =  -1;  c(t+2)  =  a(t) ;0; display a, c;
```

The results are shown below,

```
----      6 PARAMETER A
Y-1987 1987, Y-1988 1988, Y-1989 1989, Y-1990 1990, Y-1991 1991

----      6 PARAMETER C
Y-1987  -1, Y-1988  -1,  Y-1989 1987, Y-1990 1988, Y-1991 1989
```

The assignment to `a` is explained in Section 13.5.1. The assignment to `c` is different. It is best to spell it out in words. For each member of `t` in sequence, find the member of `c` associated with `t+2`. If it exists, replace its value with that of `a(t)`. If not (as with `y-1990` and `y-1991`) make no assignment. The first member of `t` is `y+1987`, and therefore the first assignment is made to `c('y-1989')` which takes the value of `a('y-1987')`, viz., 1987. No assignments at all are made to `c('y-1987')` or `c('y-1988')`: these two retain their previous values of −1.

The lag (or lead) value does not have to be an explicit constant: it can be arbitrary expression, provided that it evaluates to an integer. If it does not, error messages will be produced. A negative result causes a switch in sense (from lag to lead, for example). The following is guaranteed to set `d(t)` to all zero:

```
d(t)  =  d(t - ord(t));
```

13.5.3 Circular Lag and Lead Operators

The following example illustrates the use of circular lag and lead operators.

```
set      seasons / spring, summer, autumn, winter /;
parameter    val(s) /spring 10, summer 15, autumn 12, winter  8 /
             lagval2(s)
             leadval(s);
lagval2(s) = -1 ; lagval2(s)  =  val(s--2) ;
leadval(s) = -1 ; leadval(s++1)  =  val(s) ;
option decimals=0; display val, lagval2, leadval;
```

The results are shown below,

```
----      7 PARAMETER VAL
SPRING 10,    SUMMER 15,    AUTUMN 12,    WINTER  8

----      7 PARAMETER LAGVAL2
SPRING 12,    SUMMER  8,    AUTUMN 10,    WINTER 15

----      7 PARAMETER LEADVAL
SPRING  8,    SUMMER 10,    AUTUMN 15,    WINTER 12
```

The parameter `lagval2` is used for reference while `lagval1` if used for assignment. Notice that the case of circular lag and lead operators does not lead to any non-existent elements. The difference between reference and assignment is therefore not important. Note that the following two statements from the example above,

```
lagval2(s)      =  val(s--2) ;
leadval(s++1)    =  val(s) ;
```

are equivalent to

```
lagval2(s++2)  =  val(s) ;
leadval(s)  =  val(s--1) ;
```

The use of reference and assignment have been reversed with no difference in effect.

13.6 Lags and Leads in Equations

The principles established in the previous section follow quite naturally into equation definitions. A lag or lead operation in the body of an equation (to the right of the '`..`' symbol) is a reference, and if the associated label is not defined, the term vanishes. A lag or lead to the left of the '`..`' is a modification to the domain of definition of the equation. The linear form may cause one or more individual equations to be suppressed.

☞ *All lag and lead operands must be exogenous.*

The next two sub-sections provide examples illustrating the use of the linear form of the lag and lead operators in equations for reference and to modify the domain of its definition. Section 13.5.3 will illustrate the use of the circular form of the lag and lead operator in equations.

13.6.1 Linear Lag and Lead Operators - Domain Control

Consider the following example adapted from [RAMSEY],

```
sets  t  time periods  /1990*2000/
      tfirst(t)  first period
      tlast(t)   last period;

tfirst(t)  =  yes$(ord(t) eq 1);
tlast(t)   =  yes$(ord(t) eq card(t) ) ;
display tfirst, tlast;

variables k(t)   capital stock (trillion rupees)
          i(t)   investment (trillion rupees per year)  ;

equations kk(t)   capital balance (trillion rupees)
          tc(t)   terminal condition(provides for post-term growth) ;

kk(t+1)..   k(t+1)      =e=  k(t)  +  i(t) ;
tc(tlast).. g*k(tlast)  =l=  i(tlast);
```

The declaration of `t` is included, as are a couple of dynamic sets that are used to handle the first and last periods (`terminal conditions`) in a clean way.

The interesting equation is `kk`, the capital balance. The set `t` contains members 1990 to 2000, and so there will be a capital stock constraint for 1991 to 2000. Spelling out the constraint for 1991,

```
k('1991')  =e=  k('1990') + i('1990')  ;
```

The lead operator on the domain of definition has restricted the number of constraints generated so that there are no references to non-existent variables: the generated problem will have 10 `kk` constraints defining the relationship between the 11 `k` capital values.

The other interesting point in the [RAMSEY] excerpt is that the constraint `tc` is explicitly defined only for the final period because of the assignment to the set `tlast`. Notice the use of dynamic sets to control the domain of the two equations. The set `tfirst` is also used in other parts of the model to set initial conditions, particularly the capital stock in the first period, `k('1990')`.

13.6.2 Linear Lag and Lead Operators - Reference

In the example discussed in Section 13.6.1, equation `kk` can be rewritten with equivalent effect as

```
kk(t)$(not tfirst(t))..  k(t+1)  =e=  k(t)  +  i(t) ;
```

The dollar condition will cause one of the individual equations to be suppressed.

However, note that using lags and leads in the equation domain will always cause one or more individual equations to be suppressed, and this may not be desirable in every case. Consider the following modified set of constraints to the one discussed in the previous example. It is expressed with the lag and lead operators being used to control the domain of the equation definition.

```
kk(t+1)..      k(t+1)  =e=  k(t) + i(t);
kfirst(tfirst)   k(tfirst) =e= k0 ;
```

Here, the important boundary is the one at the beginning of the set rather than at the end. This can be expressed more compactly as

```
kk(t)..  k(t)  =e=  k(t-1) + k0$tfirst(t) + i(t-1);
```

In general, the choice between using lag and lead operators as reference or in domain control is often a matter of taste.

13.6.3 Circular Lag and Lead Operators

In the case of circular lag and lead operators, the difference between its use in domain control and as reference is not important because it does not lead to any equations or terms being suppressed. Consider the following artificial example,

```
set      s  seasons / spring, summer, autumn, winter /;

variable prod(s) amount of goods produced in each season
         avail(s) amount of goods available in each season
         sold(s) amount of goods sold in each season ;

equation matbal(s) ;

matbal(s).. avail(s++1) =e= prod(s) + sold(s) ;
```

In this example, four individual examples are generated. They are listed below.

```
avail(summer)  =e=  prodn(spring) + sold(spring) ;
avail(autumn)  =e=  prodn(summer) + sold(summer) ;
avail(winter)  =e=  prodn(autumn) + sold(autumn) ;
avail(spring)  =e=  prodn(winter) + sold(winter) ;
```

Note that none of the equations are suppressed.

13.7 Summary

This chapter introduced the concept of ordering in sets. All the features in GAMS that dealt with this issue including the `ord` and `card` functions, as well as the linear and circular forms of the lag and lead operators were described in detail.

14

The Display Statement

14.1 Introduction

In this chapter we will provide more detail about `display` statements, including the controls that a user has over the layout and appearance of the output. These controls are a compromise to provide some flexibility. The `display` statement will not provide a publication quality reporting function, but is instead aimed for functionality that is easy to use, and provides graceful defaults. The execution of the `display` statement allows the data to be written into the listing file only.

14.2 The Syntax

In general, the syntax in GAMS for the `display` statement is:

```
display ident-ref | quoted text {, ident-ref | quoted text}
```

`Ident-ref` means the name without domain lists or driving indices of a `set` or `parameter`, or a sub-field of an `equation` or `variable`. The identifier references and the text can be mixed and matched in any order, and the whole statement can be continued over several lines.

The output produced by a display consists of labels and data. For sets, the character string `yes` (indicating existence) is used instead of values.

☞ *Only the non-default values are displayed for all data types.*

The default value is generally zero, except for the `.lo` and `.up` subtypes of `variables` and `equations`. The default values for these are shown in table 14.1.

14.3 An Example

An example of a display statement is given below.

```
set s /s1*s4/ , t /t5*t7/ ;
parameter p(s)  / s1  0.33, s3  0.67 / ;
parameter q(t)  / t5  0.33, t7  0.67 / ;
variable  v(s,t) ; v.l(s,t) = p(s)*q(t);
display 'first a set', s, 'then a parameter',p,
        'then the activity level of a variable',v.l;
```

The resulting listing file will contain the following section that corresponds to the display statement.

		.lo	*.up*
Variable			
	positive	0	+INF
	free	-INF	+INF
	negative	-INF	0
	integer	0	100
	binary	0	1
Equation			
	=g=	0	+INF
	=n=	-INF	+INF
	=c=	0	+INF
	=l=	-INF	0
	=e=	0	0

Table 14.1: Default values for `.lo` and `.up subtypes`

```
----      5 first a set
----      5 SET       S

S1,    S2,    S3,    S4

----      5 then a parameter
----      5 PARAMETER P

S1 0.330,    S3 0.670

----      5 then the activity level of a variable
----      5 VARIABLE  V.L

             T5          T7

S1       0.109       0.221
S3       0.221       0.449
```

Note that the only the non-zero values are displayed. In the case of multi-dimensional identifiers, the data is reported in a tabular form that is easy to read.

14.4 The Label Order in Displays

The default layout of a `display` for identifiers of different dimensionality is summarized in table 14.2. The figures in the table refer to the index position in the domain list of the identifier. As an example, if we display `c`, where `c` has been declared as `c(i,j,k,l)`, then the `i` labels (the first index) will be associated with the planes or individual sub-tables, the `j` and `k` with the row labels, and the `l` (the fourth and last index) with the column headings.

Numbers of Indices	*Plane*	*Index Position(s) on the Row*	*Column*
1		List Format	1
2	-	1	2
3	-	1,2	3
4	1	2,3	4
5	1,2	3,4	5
6	1,2,3	4,5	6

Table 14.2: Default layout of `display` output

For 7 to 10 indices, the natural progression is followed. The labels vary slowest for the first index position, and quickest for the highest. Within each index position the order is the GAMS entry order of the labels.

The order of the indices is always as in the declaration statement for the symbol. One can declare them in the order that is found appealing, or make an assignment to a new identifier with a different order.

☞ *The only way to change the order in which the labels for each index position appear on display output is to change the order of appearance of the labels in the GAMS program. This is most easily done by declaring a set whose only purpose is to list all the labels in the order that is needed. Make this set the very first declaration in the GAMS program.*

14.4.1 Example

Consider the following example. `X` has four dimensions or index positions. It is initialized using parameter format and then displayed as shown below:

```
set    i   first index      /first, second /
       j   second index     /one, two, three /
       k   third index      /a, b /
       l   fourth index     /i, ii /  ;

parameter x(i,j,k,l)  a four dimensional structure /
       second.one.a.i         +inf,   first .three.b.i    -6.3161
       first .one.b.i      5.63559,   second.two  .b.i    19.8350
       second.one.b.ii   -17.29948,   first .two  .b.ii   10.3457
       first .two.a.ii     0.02873,   second.one  .a.ii    1.0037
       second.two.a.ii        +inf,   first .two  .a.i    -2.9393
       first .one.a.ii     0.00000               / ;
display x;
```

This code fragment produces the following output:

```
----     12 PARAMETER X             a four dimensional structure

INDEX 1 = first

                  i          ii

one  .b       5.636
two  .a      -2.939       0.029
two  .b                  10.346
three.b      -6.316

INDEX 1 = second

                i          ii

one.a        +INF       1.004
one.b                 -17.299
two.a                    +INF
two.b      19.835
```

Notice that there are two sub-tables, one for each label in the first index position. Note that the zero in the list for `x('first','one','a','ii')` has vanished, since zero values are suppressed in each sub-table separately. The order of the labels is not the same as in the input data list.

14.5 Display Controls

GAMS allows the user to modify the number of row and column labels in the display listing, as well as the accuracy of the data being displayed. The global display controls allows the user to affect more than one display statement. If specific data need to be listed in a particular format, the local display controls can be used to over-ride the global controls. The next two sub-sections will deal with each of these display controls in turn.

14.5.1 Global Display Controls

The simplest of these options is the one controlling the number of digits shown after the decimal point. It affects numbers appearing in all display output following the option statement, unless changed for a specific identifier as shown below. The general form of the statement is: '`option decimals = value;`' where `value` is an integer between 0 and 8. If you use 0, the decimal point is suppressed as well. The width of the number field does not change, just the number of decimals, but this may cause numbers which would normally be displayed in fixed to appear in E-format, i.e., with the exponent represented explicitly.

Consider the following extension to the example discussed in the previous section.

```
option decimals = 1;  display x  ;
```

GAMS has rounded or converted numbers to E-format where necessary and the output is as follows:

```
----     12 PARAMETER X             a four dimensional structure

INDEX 1 = first

                  i          ii

one  .b         5.6
two  .a        -2.9 2.873000E-2
two  .b                    10.3
three.b        -6.3

INDEX 1 = second

                i          ii

one.a        +INF         1.0
one.b                   -17.3
two.a                    +INF
two.b        19.8
```

14.5.2 Local Display Control

It is often more useful to control the number of decimals for specific identifiers separately. Using a statement whose general form can do this:

```
option ident:d-value:
```

`Ident` represent the name of a `parameter`, `variable` or `equation`, and `d-value` must be (as before) in the range 0 and 8 . Exactly `d-value` places of decimals will be shown on all displays of `ident` that follow. This form can be extended to control layout of the data. The general form is:

```
option ident:d-value:r-value:c-value ;
```

Here `r-value` means the number of index positions that are combined to form the row label and `c-value` means the number on the column headers.

The example discussed in the previous section is further extended in order to illustrate the local display control.

```
option x :5:3:1;  display  x;
```

and the output:

```
----     12 PARAMETER X             a four dimensional structure

                          i          ii
```

```
first .one  .b     5.63559
first .two  .a    -2.93930     0.02873
first .two  .b                10.34570
first .three.b    -6.31610
second.one  .a        +INF     1.00370
second.one  .b               -17.29948
second.two  .a                    +INF
second.two  .b    19.83500
```

Five places of decimals are shown, and three labels are used to mark the rows and one on the column. Since this is a four-dimensional structure, there are no remaining indices to be used as sub-table labels (on the plane), and we now have the results in one piece. The option statement is checked for consistency against the dimensionality of the identifier, and error messages issued if necessary. Here is an example that puts two indices on each of the row and column labels, and retains five decimal places:

```
option x:5:2:2; display x ;
```

The output is :

```
----     12 PARAMETER X             a four dimensional structure

                   a.i        a.ii         b.i        b.ii

first .one                             5.63559
first .two      -2.93930     0.02873                10.34570
first .three                          -6.31610
second.one          +INF     1.00370               -17.29948
second.two                      +INF    19.83500
```

14.5.3 Display Statement to Generate Data in List Format

This is a special use of the local display controls to generate data in list format using the display statement. This is when all the labels are spelled out for each value as in the parameter style of data initialization. The format of the option is `option:ident:d-value:0:c-value;` and in this case the `c-value` specifies the maximum number of items displayed on a line. The actual number will depend on the page width and the number and length of your labels.

Using the same example as in the previous sections, the following extension:

```
option  x:5:0:1;  display x;
```

changes the output to look like below:

```
----     12 PARAMETER X             a four dimensional structure

first .one  .b.i    5.63559
first .two  .a.i   -2.93930
first .two  .a.ii   0.02873
first .two  .b.ii  10.34570
first .three.b.i   -6.31610
second.one  .a.i       +INF
second.one  .a.ii   1.00370
second.one  .b.ii -17.29948
second.two  .a.ii      +INF
second.two  .b.i   19.83500
```

This output nicely illustrates the label order used. The first index varies the slowest, the last the fastest, and each one runs from beginning to end before the next one to the left advances. This ordering scheme is also used on equation and column lists and on the solution report, all produced by the solve statement.

15

The Put Writing Facility

15.1 Introduction

In this chapter, the `put` writing facility of the GAMS language is introduced. The purpose of this writing facility is to output individual items under format control onto different files. Unlike the `display` statement, the entire set of values for indexed identifiers cannot be output using a single `put` statement (identifiers are the names given to data entities such as the names for `parameters`, `sets`, `variables`, `equations`, `models`, etc). While its structure is more complex and requires more programming than is required for the display statement, there is much greater flexibility and control over the output of individual items.

In this chapter, the working of the `put` writing facility is described as well as the syntax for accessing files and globally formatting documents using file suffixes for various attributes of a file. The `put` writing facility enables one to generate structured documents using information that is stored by the GAMS system. This information is available using numerous suffixes connected with identifiers, models, and the system. Formatting of the document can be facilitated by the use of file suffixes and control characters.

The `put` writing facility generates documents automatically when GAMS is executed. A document is written to an external file sequentially, a single page at a time. The current page is stored in a buffer, which is automatically written to an external file whenever the page length attribute is exceeded. Consequently, the `put` writing facility only has control of the current page and does not have the ability to go back into the file to alter former pages of the document. However, while a particular page is current, information placed on it can be overwritten or removed at will.

15.2 The Syntax

The basic structure of the `put` writing facility in its simplest form is:

```
file fname(s);
put fname;
put item(s);
```

where `fname` represents the name used inside the GAMS model to refer to an external file. Items are any type of output such as explanatory text, labels, parameters, variable or equation values. In the basic structure shown above, the first line defines the one or more files which you intend to write to. The second line assigns one of these defined files as the current file, that is the file to be written to. Lastly, the third line represents the actual writing of output items to the current file.

15.3 An Example

It is instructive to use a small example to introduce the basics of the put writing facility. The example will be based on the transportation model [TRNSPORT]. The following program segment could be placed at the end of the transportation model to create a report:

```
file factors /factors.dat/, results /results.dat/ ;
put factors ;
put 'Transportation Model Factors'///
    'Freight cost  ', f,
    @1#6, 'Plant capacity'/;
loop(i, put @3, i.tl, @15, a(i)/);
put /'Market demand'/;
loop(j, put @3, j.tl, @15, b(j)/);

put results;
put 'Transportation Model Results'// ;
loop((i,j), put i.tl, @12, j.tl, @24, x.l(i,j):8:4 /);
```

In the first line, the internal file names factors and results are defined and connected to the external file names `factors.dat` and `results.dat`. These internal file names are used inside the model to reference files, which are external to the model. The second line of this example assigns the file `factors.dat` as the current file, that is the file which is currently available to be written to.

In the third line of the example, writing to the document begins using a `put` statement with the textual item `'Transportation Model Factors'`. Notice that the text is quoted. The slashes following the quoted text represent carriage returns. The example continues with another textual item followed by the scalar `f`. Notice that these output items are separated with commas. Blanks, commas, and slashes serve as delimiters for separating different output items. As mentioned above, the slash is used as a carriage return. Commas and blank spaces serve as item delimiters. These delimiters leave the cursor at the next column position in the document following the last item written. In most cases, the blank and the comma can be used interchangeably; however, the comma is the stronger form and will eliminate any ambiguities.

In the fifth line of the program above, the cursor is repositioned to the first column of the sixth row of the output file where another textual item is written. The cursor control characters `#` and `@` serve to reposition the cursor to a specific row or column as designated by the row or column number following the cursor control character. Lastly, the put statement is terminated with a semicolon.

Next, the parameters `a` and `b` are written along with their corresponding set labels. Only one element of the index set can be written using a `put`. To write the entire contents of the parameters `a` and `b`, the `put` statement is embedded inside a loop which iterates over the index set. In the example above, the set element labels are identified using their set identifier and the suffix `.tl`. As can be seen, the set element labels are located starting in the third column and the parameter `a` at column 15. The example continues with the display of another quoted textual item followed by the parameter `b`. When executed, the `factors.dat` file will look like:

```
Transportation Model Factors

Freight cost         90.00

Plant capacity
  seattle           350.00
  san-diego         600.00

Market demand
  new-york          325.00
  chicago           300.00
  topeka            275.00
```

This output has been formatted using the default file format values. The methods to change these defaults will be described later in this chapter.

In the last two lines of the example, the file `results.dat` is made current and the values associated with the variable `x` along with their corresponding set element index labels are written line by line. The output results of the variable x are formatted by specifying a field width of eight spaces with four of these spaces reserved for the decimal. Notice that the local formatting options are delimited with colons. The `results.dat` file will look like:

```
Transportation Model Results

seattle    new-york      0.0000
seattle    chicago     300.0000
seattle    topeka        0.0000
san-diego  new-york    325.0000
san-diego  chicago       0.0000
san-diego  topeka      275.0000
```

With just this brief introduction to the `put` writing facility, it is easy to envision its many uses such as report writing, providing output to a file for use by another computer program, or simply the display of intermediate calculations. But, the surface of the `put` writing facility has just barely been scratched. In the sections that follow, the many features and structure of the put writing facility are described in more detail, along with examples.

15.4 Output Files

As noted earlier, the `put` statement allows the user to write to external files. This section describes the various features related to the use of external files.

15.4.1 Defining Files

The complete syntax for defining files is:

```
file  fname  text  / external file name /
```

where `file` is the keyword used to define files. `Fname` is the internal file name and is used inside the GAMS model to refer to an external file. External files are the actual files that output is written to. During file declaration, the external file name and explanatory text are optional. When the external file name is omitted, GAMS will provide a system specific default external file name, often `fname.put`. Note that multiple files can be defined using a single file statement. Consider the following example:

```
file  class1
      class2   this defines a specific external file  /report.txt/
      con      this defines access to the console (screen) for PC systems;
```

The first output file is recognized in the model by the name `class1` and corresponds to the default file `class1.put` for a PC system. The second output file is recognized in the model by the name `class2` and it corresponds to the defined external file `report.txt`. Lastly, the special internal file name `con` is defined to write output to the console (screen) for a PC systems. Writing to the screen can be useful to advise the user of various aspects of the model during the model's execution.

15.4.2 Assigning Files

The `put` statement is used both to assign the current file and to write output items to that file. The complete syntax for using the `put` statement is:

```
put  fname item(s)  fname item(s)  . . . ;
```

As indicated by this syntax, multiple files can be sequentially written using a single `put` statement. Note that only one file is current at a time. After the output items following an internal file name are written, the current file is reassigned based on the next internal file name in the statement. The last internal file name used in a `put` statement remains as the current file until a subsequent `put` statement uses an internal file name.

15.4.3 Closing a File

The keyword `putclose` is used to close a file during the execution of a GAMS program. The syntax is as follows:

```
putclose myfile item(s)
```

where `myfile` is the internal name of the file to be closed, and `item(s)` are the final entries into the file before it is closed. If the internal file name is omitted from the `putclose` statement, the current `put` file is closed. Note that after using the `putclose` command, the file does not have to be redefined in order to use it again. Simply make the file current and use `put` statements as would be done normally. Of course, the existing file will either be overwritten or appended to depending on the value of the append file suffix.

☞ *One application where this is useful is to write the solver option file from within the GAMS model. Option file statements can be written using put and the file closed with a* `putclose` *prior to the solve statement. This makes the option file available for use by the solver.*

The following example shows the creation and closing of an option file for the MINOS solver:

```
file opt Minos option file  / minos.opt /;
put opt;
put 'Iteration limit         500'/
    'Feasibility tolerance   1.0E-7'/ ;
putclose opt;
```

This program segment would be placed inside the GAMS model prior to the solve statement.

15.4.4 Appending to a File

The `put` writing facility has the ability to append to or overwrite an existing file. The file suffix `.ap` determines which operation occurs. The default suffix value 0 overwrites the existing file while the value 1 causes appending to the file. Let's consider our `report.txt` file to be an existing file.

Using the following statement appends output items to it:

```
class2.ap = 1;
```

Any items put into `report.txt` will from that point on be added to the end of the existing file contents. If the file had not existed, the file would be created.

15.5 Page Format

The pages within files can also be structured using file suffixes to specify many attributes such as the printing format, page size, page width, margins, and the case which text is displayed in. The following file suffixes can be used for formatting:

print control (`.pc`) Used to specify the format of the external file. The options 4,5,6, and 8 create delimited files, which are especially useful when preparing output for the direct importation into other computer programs such as spreadsheets.

0 Standard paging based on the current page size. Partial pages are padded with blank lines. Note that the `.bm` file suffix is only functional when used with this print control option.

1 FORTRAN page format. This option places the numeral one in the first column of the first row of each page in the standard FORTRAN convention.

2 Continuous page (default). This option is similar to `.pc` option zero, with the exception that partial pages in the file are not padded with blank lines to fill out the page.

3 ASCII page control characters inserted.

4 Formatted output; Non-numeric output is quoted, and each item is delimited with a blank space.

5 Formatted output; Non-numeric output is quoted, and each item is delimited with commas.

6 Formatted output; Non-numeric output is quoted, and each item is delimited with tabs.

7 Fixed width; Fills up line with trailing blanks.

8 Formatted output; Each item is delimited with a blank space.

page size (`.ps`) Used to specify the number of rows (lines) which can be placed on a page of the document. Can be reset by the user at any place in the program. However, an error will result if set to a value less than the number of rows which have already been written to the current page. Maximum value is 130. The default value is 60

page width (`.pw`) Used to specify the number of columns (characters) which can be placed on a single row of the page. Can be reset by the user at any place in the program. However, an error will result if set to a value less than the number of rows or columns which have already been written to the current page. The default value is 255.

top margin (`.tm`) Number of blank lines to be placed at the top margin of the page. These lines are in addition to the number of lines specified in the `.ps` file suffix. Default value is 0.

bottom margin (`.bm`) Number of blank lines to be placed in the bottom margin of the page. These lines are in addition to the number of lines specified in the `.ps` file suffix. This is functional with `.pc` option 0 only. Default value is 0.

alphabetic case (`.case`) Used to specify the case in which alphabetic characters are displayed in the output file.

0 (default) Causes mixed case to be displayed.

1 Causes the output to be displayed in upper case regardless of the case used for the input.

To illustrate the use of these file suffixes, the following example involves formatting `report.txt` so that the pages are 72 spaces wide with 58 lines of output, an additional top margin of 6 lines, using ASCII page control characters (inserted every 64 lines), and with the output displayed in upper case.

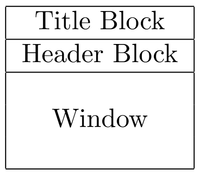
```
file class2 /report.txt/ ;
class2.pw = 72;  class2.ps = 58;   class2.tm = 6;
class2.pc = 3;   class2.case = 1;
```

☞ *Using a value of 4, 5, or 6 for the print control suffix (`.pc`) will cause data to be squeezed and therefore will ignore spacing information provided by the user through the `@` character. However, these values can be used to pass data on to be read by spreadsheets.*

15.6 Page Sections

There are three independent writing areas on each page of a document. These areas are the title block, the header block, and the window. This is quite useful when there are sections of a page which remain relatively constant throughout a document. Title and header blocks are often used to provide organizational information in a document with the window being used for specific reporting.

These writing areas are always sequentially located on the page in the order shown on the following diagram. It is important to note that the title and header blocks are essentially the same as the window and use exactly the same syntax rules. However, the window is required in each page of your document, while the title and headers are optional. Also note that once the window is written to, any further modifications of the title or header blocks will be shown on subsequent pages and not the current page. Writing to the window is what ultimately forces a page to be written



In the illustrative example described in Section 15.3, all the data was written to the window. A title block might have been included, if more elaboration were needed, to provide the model name along with the page number. In addition, a header block might have been used to display a disclaimer or an instruction, which we wanted consistently, repeated on every page. Once this information is placed in the title or header blocks, it is displayed on each page thereafter unless modified. This could be especially useful for a long document covering many pages.

15.6.1 Accessing Various Page Sections

Each of these areas of a page are accessed by using different variations of the keyword `put`. These variations are:

`puttl`	write to title block
`puthd`	write to header block
`put`	write to window

The size of any area within a given page is based entirely on the number of lines put into it. Note that the total number of lines for all areas must fit within the specified page size. If the total number of lines written to the title and header block equals or exceeds the page size, an overflow error will be displayed in the program listing. When this occurs, this means there is no room remaining on the page to write to the window.

As mentioned above, the syntax for writing an output item to any of the three possible writing areas of the page is basically the same, the only difference being the choice of put keyword. This is illustrated by writing to the title block of our `report.dat` file:

```
puttl class2 'GAMS Put Example' ;
```

In this case, the text `'GAMS Put Example'` has been placed in the first column of the first row of the title block. Any subsequent pages in the `report.dat` file will now start with this information.

☞ *If the title block was modified or the header block was started after the window of the current page has been written to, these modifications would appear in the next page and not the current page.*

15.6.2 Paging

Paging occurs automatically whenever a page is full. However, note that the window must be used in order for the page to be written to the output file. When a page has no output in its window, the page is not written to file regardless of whether there are output items in the title or header blocks. To force a page that has an empty window out to file, simply write something innocuous to the window such as:

```
put '';
```

Now the window of the page has been initiated and it will be written.

15.7 Positioning the Cursor on a Page

The cursor is positioned at the space immediately following the last character written unless the cursor is specifically moved using one of the following cursor control characters:

`#n`	Move cursor position to row `n` of current page

`@n`	Move cursor position to column `n` of current line
`/`	Move cursor to first column of next line. Also acts as a delimiter between output items

In addition to numerals, any expression or symbol with a numeric value can be used to follow the `#` and `@` characters. The following example illustrates the use of these position controls to write out the value of a parameter `a(i,j)` in a tabular form:

```
file out; put out;
scalar col column number /1/ ;
loop(i,
    loop (j, put @col a(i,j); col=col+10; ) ; put / ;
   ) ;
```

15.8 System Suffixes

The complete list of system suffixes that can be used to recover information about the GAMS run are:

`.date`	program execution date
`.ifile`	input file name
`.ofile`	output file name
`.page`	current file page
`.rdate`	restart file date
`.rfile`	restart file name
`.rtime`	restart file time
`.sfile`	save file name
`.time`	program execution time
`.title`	title of the model as specified by `$title`

As an illustration, consider the example discussed in the previous section. One can add page numbers to the title of the report file by modifying the `puttl` statement to read

```
puttl class2 'GAMS Put Example', @65,'page ',system.page ///;
```

This causes the word page followed by the page number to appear on the title of every page starting at column 65.

15.9 Output Items

Output items for the `put` statement are of the following forms:

text	Any quoted text, set element label or text, any identifier symbol text or contents of the system suffixes.
numeric	Values associated with parameters, variables, equations, or any of the model suffixes.
set values	Represent existence of set elements and carry the values yes or no only.

The methods for identifying and using each of these different types of output items are described in the following sub-sections.

15.9.1 Text Items

Output items, which are quoted text, are any combination of characters or numbers set apart by a pair of single or double quotes. However, the length of quoted text, as well as any output item, has a limit. No portion of the output item can be placed outside of the page margin. When the page width is exceeded, several asterisks are placed at the end of the line and a `put error` is recorded in the program listing.

In addition to quoted text, the output of other text items is possible through the use of system and identifier suffixes. The identifier suffixes are:

identifier symbol text (`.ts`) Displays the text associated with any identifier

set element labels (`.tl`) Displays the individual element labels of a set

set element text (`.te(index)`) Displays the text associated with an element of a `set`. Notice that the `.te` suffix requires a driving index. This driving index controls the `set`, which will be displayed and does not necessarily have to be the same as the controlled `set`. Often a subset of indices of the controlled `set` is used.

text fill (`.tf`) Used to control the display of missing text for set elements.

0 no fill

1 fill existing only

2 (default) fill always

The following example illustrates these ideas:

```
file out; put out;
set  i    master set of sites / i1  Seattle, i2  Portland
                                i3  San Francisco, i4  Los Angeles
                                i5   /
     j    subset of sites     / i3 * i5 / ;
put j.ts /;
loop(j, put j.tl, i.te(j) /);
```

The resulting file `out.put` will look like:

```
subset of sites
i3   San Francisco
i4   Los Angeles
i5   i5
```

In this example, the symbol text for the identifier of the subset `j` is written first. This is followed with the labels for the subset `j` and the associated element text found in its domain, that is, the set `i`. Notice the driving set `j` is used for the element text specification of the set `i`. Since there was no set element text associated with the `i5` element of set `i`, the set element label was displayed again. By placing the following before the last line:

```
out.tf = 0;
```

The missing element text is now no longer replaced with the label text. The resulting file `out.put` file would now look like:

```
subset of sites
i3   San Francisco
i4   Los Angeles
i5
```

15.9.2 Numeric Items

The syntax used for the display of numeric items is generally easier to work with. To output a parameter, only the identifier along with its index set (as appropriate) has to be used. To output a variable or equation value, the identifier is combined with one of the `variable` and `equation` suffixes. The `variable` and `equation` suffixes are:

`.l`	level or marginal value
`.lo`	lower bound
`.m`	marginal or dual value
`.prior`	priority
`.scale`	scaling
`.up`	upper bound

15.9.3 Set Value Items

Set value items are easy to work with. To output the set value, only the identifier along with its index set has to be used. In the example from Section 15.9.1, consider altering the loop statement to read:

```
loop(i, put i.tl, j(i), '  ',i.te(j) /);
```

The resulting output file looks like follows:

```
subset of sites
i1       NO  Seattle
i2       NO  Portland
i3      YES  San Francisco
i4      YES  Los Angeles
i5      YES
```

The second columns represents whether the element belongs to set `j` or not.

15.10 Global Item Formatting

It is often important to be able to control the display format of output items. In this section we describe how this is done. For formatting purposes, output items are classified into four categories. These are labels, numeric values, set values, and text. For each, global formatting of the field width and field justification is possible.

15.10.1 Field Justification

The possible global justifications are *right* (value 1), *left* (value 2), and *center* (value 3). The field justification is represented by the following file suffixes:

`.lj`	label justification (default 2)
`.nj`	numeric justification (default 1)
`.sj`	set value justification (default 1)
`.tj`	text justification (default 2)

15.10.2 Field Width

This is done using the following file suffixes:

`.lw`	label field width (default 12)
`.nw`	numeric field width (default 12)
`.sw`	set value field width (default 12), (maximum 20)
`.tw`	text field width (default 0)

The field width is specified with the number of spaces to be allocated to the field. Variable length field widths are possible by using a suffix value of 0. This forces the field width to match the exact size of the item being displayed. If a textual output item does not fit within the specified field, truncation occurs to the right. For numeric output items, the decimal portion of a number is rounded or scientific notation used to fit the number within the given field. If a number is still too large, asterisks replace the value in the output file.

As an example, to set the global numeric field width to four spaces from its default of 12 in the file `out.put`, we would use the following statement:

```
out.nw = 4;
```

15.11 Local Item Formatting

It is often useful to format only specific `put` items. For this, we use the local format feature, which overrides global format settings. The syntax of this feature is as follows:

```
item:{<>}width:decimals;
```

The `item` is followed by a justification symbol, the field `width`, and the number of `decimals` to be displayed. The specification of the number of `decimals` is only valid for numeric output. The following local justification symbols are applicable:

`>`	right justified
`<`	left justified
`<>`	center justified

Omitting any of the components causes their corresponding global format settings to be used. As with global formatting, when the field width is given a value of 0, the field width is variable in size. The `item`, `width`, and `decimals` are delimited with colons as shown above. The use of the local format feature as well as the inclusion any of the components for justification, field width, or the number of decimals is entirely optional.

The following example shows some examples of the local formatting feature:

```
* default justification and a field width of variable size
* with no decimals
loop(i, put dist(i):0:0 /);

put 'Right justified comment':>50,
    'Center justified truncated comment':<>20;

* left justified scalar with a six space field width and
* two decimals
put f:<6:2 ;
```

15.12 Additional Numeric Display Control

In addition to the numeric field width and the numeric justification as mentioned in the previous section, the following file suffixes can also be globally specified for numeric display:

number of decimals displayed (`.nd`) Sets the number of decimals displayed for numeric items. A value of 0 results in only the integer portion of a number being displayed. The maximum value is 10. The default value is 2.

numeric round format (`.nr`) Allows one to display a numeric value in scientific notation, which would otherwise be displayed as zero because of being smaller than the number of decimals allowed by the `.nd` suffix. This situation occurs when a number is smaller than the `.nd` specification, but is larger than the zero tolerance level set by `.nz`. In many situations, it is important to know that these small values exist. The default is 1.

0	displayed in F or E format
1	rounded to fit fields
2	displayed in scientific notation

numeric zero tolerance (`.nz`) Sets the tolerance level for which a number will be rounded to zero for display purposes. When it is set equal to zero, rounding is determined by the field width. Default value is `1.0e-5`.

The maximum size of a displayed number must fit within 20 spaces using at most 10 significant digits. The remaining 10 spaces are used for the sign, exponential notation, or padding with zeros.

15.12.1 Illustrative Example

The following illustrative example shows the results of different combinations of these numeric file suffixes. The example uses five combinations of the numeric file suffixes `.nd`, `.nz`, `.nr`, and `.nw`. Four number values, each of which is shifted by three decimal places from its predecessor, are used with these suffix combinations. The combinations are chosen to show various format results when these suffix values are used together in put statements:

```
set  c  suffix combinations  /  comb1 * comb4   /
     v  value indices        /  value1* value3  / ;

table   suffix(c,*)   numeric suffix combinations
            nd      nz      nr      nw
comb1        3       0       0      12
comb2        3    1e-5       0      12
comb3        3    1e-5       1      12
comb4        8       0       0      10
comb5        6    1e-5       2      12 ;

parameter  value(v)   test values
      / value1     123.4567
        value2       0.1234567
        value3       0.0001234567 / ;

file out; put out; out.nj=2; out.lw=10;
out.cc=11;
loop(v, put v.tl:21);
loop(c, out.nd=suffix(c,"nd");
     out.nz=suffix(c,"nz");
     out.nr=suffix(c,"nr");
     out.nw=suffix(c,"nw");
     put / c.tl;
loop(v, put @(ord(v)*21-10), value(v)));
```

For readability, the numeric values have purposely been made left justified using the `.nj` suffix since the numeric field width is changed as the model goes through the suffix combinations. The following is the resulting file `out.put`, which shows the value/suffix combinations:

```
          value1          value2          value3
 comb1    123.457         0.123           1.2345670E-4
 comb2    123.457         0.123           1.2345670E-4
 comb3    123.457         0.123           0.000
 comb4    1.23457E+2      0.12345670      0.00012346
 comb5    123.456700      0.123457        0.000123
```

Notice that in `comb1`, the display of values switch to exponential notation when a value becomes smaller than the number of decimal places allowed. This is triggered by the suffix `.nr` being set to zero. Of particular interest is `value3` for `comb2` and `comb3`. `Value3` is greater than the zero tolerance level in `.nz`, but smaller than the number of decimals allowed by `.nd`. In `comb2`, since `.nr` is set to zero, the value is displayed in exponential format. In `comb3`, `.nr` is set to 1, so this small value is rounded to 0. In `comb5`, `value1` is rounded to an integer because of `.nd` being set to 0.

15.13 Cursor Control

Having described the display of various output items using the `put` statement, this section describes features available to position these items in the output file. GAMS has several file suffixes which determine the location of the cursor and the last line of the file. These suffixes can also be used to reposition the cursor or reset the last line. As such, they are instrumental in formatting output items in documents. These suffixes are grouped by the title, header, or window writing area for which they are valid.

15.13.1 Current Cursor Column

These suffixes have numeric values corresponding to coordinates in the window of the page. Because of this, they can be used in conjunction with cursor control characters to manipulate the position of the cursor in the output file.

`.cc`	current cursor column in window
`.hdcc`	header current column
`.tlcc`	title current column

☞ *The convention for updating the values stored for the `.cc` suffix is that it are updated at the conclusion of a `put` statement. Consequently, the `.cc` value remains constant throughout the writing of items for the next put statement, even if multiple items are displayed.*

The following example illustrates the updating of the cursor control suffixes and the use of cursor control characters. The example is trivial but instructive:

```
scalar  lmarg  left margin   /6/;
file out; put out;
put @(lmarg+2) 'out.cc = ', out.cc:0:0 '  ';
put @out.cc 'x'/ @out.cc 'y'/ @out.cc 'z  ';
put 'out.cc = ' out.cc:0:0;
```

The following is the resulting file `out.put`:

```
out.cc = 1   x
             y
             z  out.cc = 23
```

Initially, the scalar `lmarg` is set to a specific value to use as an alignment tab. Symbols which hold common alignment values such as margins or tabs are often useful for large structured documents. The first `put` statement uses the current column cursor control character to relocate the cursor. In this example, the cursor is moved to column 8where `out.cc` and its value is displayed.

The second `put` statement illustrates the updating of the cursor control suffixes by writing the letters `x, y`, and `z` on three different lines. Each is preceded by the cursor being moved to the `out.cc` value. Initially, the value for the cursor control suffice is 20. Since a single `put` statement is used for these three items, the `out.cc` value remains constant and consequently the letters end up in the same column. Following this put statement, the `out.cc` value is updated to 23, which is the location of the cursor at the end of the second put statement (note the additional blank spaces displayed with the letter `z`).

15.13.2 Current Cursor Row

These suffixes have numeric values corresponding to coordinates in the window of the page. Because of this, they can be used in conjunction with cursor control characters to manipulate the position of the cursor in the output file.

`.cr`	current cursor row in window
`.hdcr`	header current row
`.tlcr`	title current row

The convention for updating the values stored for the `.cr` suffix is that it are updated at the conclusion of a `put` statement. Consequently, the `.cr` value remains constant throughout the writing of items for the next `put` statement, even if multiple items are displayed. It's behavior is similar to that of `.cl`.

15.13.3 Last Line Control

These suffixes control the last line used in a writing area.

`.ll`	last line used in window
`.hdll`	header last line
`.tlll`	title last line

Unlike the row and column control, the last line suffix is updated continuously. Last line suffixes are especially useful for modifying the various writing areas of a page.

☞ *The `.tlll` and `.hdll` suffixes may not hold values applicable to the current page because when the title or header blocks are modified, they correspond to the title or header blocks of the next page whenever the window has been written to on the current page.*

☞ *Not only can this suffix be used to determine the last line used in a writing area, but it can also be used to delete lines within this area.*

In the following example, the header section will be completely deleted by resetting the `.hdll` suffix to 0.

```
file out;
puthd out 'This header statement will be eliminated';
out.hdll = 0;
```

In this example, a header is initially written. By changing the `.hdll` suffix to 0, the cursor is reset to the top of the header block. Consequently the header will not be written unless something new is added to the header block.

15.14 Paging Control

In addition to the automatic paging, which occurs when the bottom of the page is reached, a page can also be written to file early. The keyword `putpage` is used to do this. `Putpage` forces the current page to immediately be written to file, making a new page available for `put` statements. In its simplest form, the keyword `putpage` is used by itself to eject the current page. Additionally, it can be used with output items. When it is used with output items, the page is written to file including the output items contained in the `putpage` statement. The `putpage` statement is in fact another variation of the `put` statement. In the following statement, the quoted text is placed in the current page, which is then written to the file `out.put`:

```
   putpage out 'This text is placed in window and the page ends';
```

Two additional file suffixes that can help the user in determining when to page a file are:

last page (`.lp`) Indicates the number of pages that are already in the document. Note that setting this to 0 does not erase the pages that have previously been written to the file.

window size (`.ws`) Shows the number of rows, which can be placed in the window, considering the number of lines that are in the title and header blocks of the current page and the existing page size. The `.ws` file suffix value is calculated by GAMS and is not changeable by the user. This suffix is useful for manual pagination when used in conjunction with the `.ll` file suffix.

15.15 Exception Handling

In this section, the topic of exception handling is dealt with. As with other GAMS statements, dollar control exception handling can be used with `put` statements to control whether particular output items are displayed. In the following example, the put statement is only displayed if the dollar condition is true. If it is not, the put statement is ignored:

```
   put$(flag gt 10) 'some output items';
```

15.16 Source of Errors Associated with the Put Statement

There are two types of errors that can occur when using the put writing facility: syntax errors and `put` errors. The following subsections discuss each of these types of errors.

15.16.1 Syntax Errors

Syntax errors are caused by the incorrect usage of the GAMS language. These errors are the same or are similar to what one finds elsewhere with GAMS such as unmatched parentheses, undefined identifiers, uncontrolled sets, or the incorrect use of a keyword or suffix. These errors are detected during program compilation and are always fatal to program execution. Errors of this kind are identified in the program listing at the location of the error with a `$` symbol and corresponding error numbers. The program listing includes a brief description of the probable cause of the error.

15.16.2 Put Errors

`Put` errors are unique to the `put` writing facility. This type of error occurs during program execution and is caused when one or more of the file or page attributes are violated. These errors are non-fatal and are listed at the end of the program listing. They typically occur when a `put` statement attempts to write outside of a page, such as moving the cursor with the `@` character to a location beyond the page width. Other typical errors are the inability to open a specified file, the overflow of a page, or an inappropriate value being assigned to a suffix. For many of these errors, an additional set of asterisks will be placed at the location of the error in the output file.

Since `put` errors are non-fatal and are not overemphasized in the output file, their presence is sometimes overlooked. Without reviewing the program listing, these `put` errors might go undetected, especially in large output files. Consequently, GAMS has included the following file suffix to help one detect errors:

`.errors`	Allows one to display the number of `put` errors occurring in a file.

To illustrate its use, the following statement could be inserted at any point of a program to detect the number of errors, which have occurred up to its location. The choice of output file could be the same file, a different file, or the console as appropriate:

```
putpage error ///'***  put errors: ', out.errors:0:0,'  ***'/;
```

In this example it is assumed that the files `out.put` and `error.put` have previously been defined with a file statement. With this statement, the number of `put` errors that occur in the file `out.put` are displayed in the file `error.put`. Using `putpage` would allow the immediate display to the screen of a PC system at the location of this statement if the console had been the output device.

15.17 Simple Spreadsheet/Database Application

This last section provides a simple example of the preparation of output for spreadsheets, databases, or other software packages, which allow importation of delimited files. As mentioned in Section 15.3, output items can be prepared with comma delimiters and text items in quotes. This is implemented by using `.pc` suffix value 5. Delimited files are different than normal `put` files. All output items are written with variable field widths and separated by delimiters. Consequently, all global and local format specifications for field widths and justification are ignored by GAMS. Note that the number of decimals for numeric items can still be specified with the `.nd` file suffix. Each item is written immediately following the previous delimiter on the same line unless the cursor is reset.

☞ *Avoid horizontal cursor relocations in a program, which creates a delimited file. Horizontally relocating the cursor in a delimited file is potentially damaging since a delimiter could be overwritten.*

While the comma is the most common delimiting character for spreadsheets, other delimiters like blank space and tab characters can also be used.

15.17.1 An Example

In the following example, the capacity sub-table of the [MEXSS] report program is prepared as a delimited file. The following program segment demonstrates `.pc` suffix value 5. The program segment could be placed at the end of the original [MEXSS] model:

```
file out; put out; out.pc=5;
put 'capacity (metric tons)';
loop(i, put i.tl);
loop(m,
     put / m.te(m);
     loop(i, put k(m,i));
);
```

The first line of this program segment creates the file `out.put` as the delimited file. Notice that in the remainder of this program, field widths, justifications, and horizontal cursor relocations are completely avoided. All text items are quoted. The following is the resulting output file:

```
"CAPACITY (tons)","AHMSA","FUNDIDORA","SICARTSA","HYLSA","HYLSAP"
"BLAST FURNACES",3.25,1.40,1.10,0.00,0.00
"oPEN HEARTH FURNACES",1.50,0.85,0.00,0.00,0.00
"BASIC OXYGEN CONVERTERS",2.07,1.50,1.30,0.00,0.00
"DIRECT REDUCTION UNITS",0.00,0.00,0.00,0.98,1.00
"ELECTRIC ARC FURNACES",0.00,0.00,0.00,1.13,0.56
```

Notice that each item is delimited with a comma and that textual output is quoted.

16

Programming Flow Control Features

16.1 Introduction

The previous chapters have focused on the ability of GAMS to describe models. This chapter will describe the various programming features available in GAMS to help the advanced user. The various programming flow control features discussed in this chapter are

`Loop` Statement	`If-Else` Statement
`For` Statement	`While` Statement

Each of these statements will be discussed in detail in the following sections.

16.2 The Loop Statement

The `loop` statement is provided for cases when parallel assignments are not sufficient. This happens most often when there is no analytic relationship between, for example, the values to be assigned to a parameter. It is, of course, also useful to have a looping statement for general programming - for example, the production of reports with the `put` statement.

16.2.1 The Syntax

The syntax of the `loop` statement is,

```
loop(controlling_domain[$(condition)],
     statement {; statement}
    ) ;
```

If the `controlling_domain` consists of more than one `set`, then parentheses are required around it.

The `loop` statement causes GAMS to execute the statements within the scope of the loop for each member of the driving set(s) in turn. The order of evaluation is the entry order of the labels. A loop is thus another, more general, type of indexed operation. The `loop set` may be dollar-controlled and does not need to be static or nested. Loops may be controlled by more than one set.

☞ *One cannot make declarations or define equations inside a `loop` statement.*

☞ *It is illegal to modify any controlling set inside the body of the loop.*

16.2.2 Examples

Consider a hypothetical case when a growth rate is empirical:

```
set   t   / 1985*1990 /
parameter  pop(t)        / 1985  3456 /
           growth(t)     / 1985  25.3,  1986  27.3,  1987  26.2
                           1988  27.1,  1989  26.6,  1990  26.6 /;
```

The `loop` statement is then used to calculate the cumulative sums

```
loop(t, pop(t+1)  = pop(t) + growth(t) ) ;
```

in an iterative rather than a parallel way. In this example there is one statement in the scope of the `loop`, and one driving, or controlling, `set`.

A `loop` is often used to perform iterative calculations. Consider the following example, which uses finds square roots by Newton's method. This example is purely for illustration - in practice, the function `sqrt` should be used. Newton's method is the assertion that if x is an approximation to the square root of v, then $(x + v/x)/2$ is a better one

```
set  i  "set to drive iterations"  /  i-1*i-100  /;
parameter  value(i)  "used to hold successive approximations" ;

scalars
        target   "number whose square root is needed"  /23.456  /
        sqrtval  "final approximation to sqrt(target)"
        curacc   "accuracy of current approximation"
        reltol   "required relative accuracy"  / 1.0e-06 / ;

abort$(target <= 0) "argument to newton must be positive", target;
value("i-1")  =  target/2  ; curacc  =  1  ;
loop(i$(curacc > reltol),
     value(i+1)  =  0.5*(value(i) + target/value(i));
     sqrtval  =  value(i+1);
     curacc  =  abs (value(i+1)-value(i))/(1+abs(value(i+1)))
) ;
abort$(curacc > reltol) "square root not found"
option decimals=8;
display  "square root found within tolerance",  sqrtval, value;
```

The output is:

```
----     18 square root found within tolerance

----     18 PARAMETER SQRTVAL             =   4.84313948 final approximation
                                                         to sqrt(target)

----     18 PARAMETER VALUE         used to hold successive approximations

i-1 11.72800000,    i-2  6.86400000,    i-3  5.14062471,    i-4  4.85174713
i-5  4.84314711,    i-6  4.84313948,    i-7  4.84313948
```

16.3 The If-Elseif-Else Statement

The `if-else` statement is useful to branch conditionally around a group of statements. In some cases this can also be written as a set of dollar conditions, but the `if` statement may be used to make the GAMS code more readable. An optional `else` part allows you to formulate traditional `if-then-else` constructs.

16.3.1 The Syntax

The syntax for an `if-elseif-else` statement is:

```
if (condition,
    statements;
{elseif condition, statements; }
[else statements;]
);
```

where condition is a logical condition.

☞ *One cannot make declarations or define equations inside an* `if` *statement.*

16.3.2 Examples

Consider the following set of statements

```
p(i)$(f <= 0) = -1 ;
p(i)$((f > 0) and (f < 1)) = p(i)**2 ;
p(i)$(f > 1) = p(i)**3 ;
q(j)$(f <= 0) = -1 ;
q(j)$((f > 0) and (f < 1)) = q(j)**2 ;
q(j)$(f > 1) = q(j)**3 ;
```

They can be expressed using the `if-elseif-else` statement as

```
if (f <= 0,
    p(i) = -1 ;
    q(j) = -1 ;
elseif ((f > 0) and (f < 1)),
    p(i) = p(i)**2 ;
    q(j) = q(j)**2 ;
else
    p(i) = p(i)**3 ;
    q(j) = q(j)**3 ;
   ) ;
```

The body of the `if` statement can contain `solve` statements. For instance, consider the following bit of GAMS code:

```
if ((ml.modelstat eq 4),
*            model ml was infeasible
*            relax bounds on x and solve again
     x.up(j) = 2*x.up(j) ;
     solve ml using lp minimizing lp ;
else
    if ((ml.modelstat ne 1),
        abort "error solving model ml ;
    );
);
```

The following GAMS code is illegal since one cannot define `equations` inside an `if` statement.

```
if (s gt 0,
    eq.. sum(i,x(i)) =g= 2 ;
);
```

The following GAMS code is illegal since one cannot make declarations inside an `if` statement.

```
if (s gt 0,
   scalar y ; y = 5 ;
);
```

16.4 The While Statement

The `while` statement is used in order to loop over a block of statements.

16.4.1 The Syntax

The syntax of the `while` statement is:

```
while(condition,
      statements;
     );
```

☞ *One cannot make declarations or define equations inside a `while` statement.*

16.4.2 Examples

One can use `while` statements to control the `solve` statement. For instance, consider the following bit of GAMS code that randomly searches for a global optimum of a non-convex model:

```
scalar count ; count = 1 ;
scalar globmin ; globmin = inf ;
option bratio = 1 ;
while((count le 1000),
       x.l(j) = uniform(0,1) ;
       solve ml using nlp minimizing obj ;
       if (obj.l le globmin,
           globmin = obj.l ;
           globinit(j) = x.l(j) ;
       ) ;
       count = count+1 ;
) ;
```

In this example, a non-convex model is solved from 1000 random starting points, and the global solution is tracked. The model [PRIME] from the model library illustrates the use of the `while` statement through an example where the set of prime numbers less than 200 are generated

The following GAMS code is illegal since one cannot define equations inside a `while` statement.

```
while (s gt 0,
       eq.. sum(i,x(i)) =g= 2 ;
);
```

The following GAMS code is illegal since one cannot make declarations inside a `while` statement.

```
while(s gt 0,
       scalar y ; y = 5 ;
);
```

16.5 The For Statement

The `for` statement is used in order to loop over a block of statements.

16.5.1 The Syntax

The syntax is:

```
for (i = start to|downto end [by incr],
      statements;
);
```

Note that `i` is not a `set` but a `parameter`. `Start` and `end` are the start and end, and `incr` is the increment by which `i` is changed after every pass of the loop.

☞ *One cannot make declarations or define equations inside a `for` statement.*

☞ *The values of `start`, `end` and `incr` need not be integer. The `start` and `end` values can be positive or negative real numbers. The value of `incr` has to be a positive real number.*

16.5.2 Examples

One can use `for` statements to control the `solve` statement. For instance, consider the following bit of GAMS code that randomly searches for a global optimum of a non-convex model:

```
scalar i ;
scalar globmin ; globmin = inf ;
option bratio = 1 ;
for (i = 1 to 1000,
     x.l(j) = uniform(0,1) ;
     solve m1 using nlp minimizing obj ;
     if (obj.l le globmin,
         globmin = obj.l ;
         globinit(j) = x.l(j) ;
     );) ;
```

In this example, a non-convex model is solved from 1000 random starting points, and the global solution is tracked.

The use of real numbers as `start`, `end` and `incr` can be understood from the following example,

```
for (s = -3.4 to 0.3 by 1.4,
     display s ;
);
```

The resulting listing file will contain the following lines,

```
----      2 PARAMETER S                    =      -3.400
----      2 PARAMETER S                    =      -2.000
----      2 PARAMETER S                    =      -0.600
```

Notice that the value of `s` was incremented by 1.4 with each pass of the loop as long as it did not exceed 0.3.

The following GAMS code is illegal since one cannot define equations inside a `for` statement.

```
for (s = 1 to 5 by 1,
     eq.. sum(i,x(i)) =g= 2 ;
);
```

The following GAMS code is illegal since one cannot make declarations inside a `for` statement.

```
for (s=1 to 5 by 1,
     scalar y ; y = 5 ;
);
```

17

Special Language Features

17.1 Introduction

This chapter introduces special features in GAMS that do not translate across solvers, or are specific to certain model types. These features can be extremely useful for relevant models, and are among the most widely used.

17.2 Special MIP Features

Some special features have been added to GAMS to help in simplifying the modeling of MIP problems. Two special types of discrete variables are defined and discussed. Finally, creating priorities for the discrete variables is discussed. The solvers use this information when solving the problem.

17.2.1 Types of Discrete Variables

The following types of discrete variables have been discussed so far in the book,

`binary variables` These can take on values of 0 or 1 only.

`integer variables` These can take on integer values between the defined bounds. The default lower and upper bounds are 0 and 100 respectively.

In addition to these two, two new types of discrete variables that are introduced in this section. Both these variables exploit special structures in MIP models during the solution phase. These are the following

Special Ordered Sets (SOS) The precise definition of special ordered sets differ from one solver to another and the development of these features has been driven more by internal algorithmic consideration than by broader modeling concepts. GAMS offers `sos1` and `sos2` variables as two types of compromise features that model special ordered sets. Sections 17.2.2 and 17.2.3 discuss these two types of variables in greater detail.

Semi-continuous variables GAMS offers `semicont` and `semiint` variables to model this class of variables. These are explained in Sections 17.2.3 and 17.2.4.

The presence of any of the above types of discrete variables requires a mixed integer model and all the discreteness is handled by the branch and bound algorithm in the same way as binary and general integer variables are handled.

17.2.2 Special Order Sets of Type 1 (SOS1)

At most one variable within a `SOS1` set can have a non-zero value. This variable can take any positive value. Special ordered sets of type 1 are defined as follows,

```
sos1 Variable s1(i), t1(k,j), w1(i,j,k) ;
```

The members of the innermost (the right-most) index belongs to the same set. For example, in the sets defined above, `s1` represents one special ordered set of type 1 with `i` elements, `t1` defines `k` sets of `j` elements each, and `w1` defines `(i,j)` sets with `k` elements each.

☞ *The default bounds for `SOS1` variables are 0 to $+\infty$. As with any other variable, the user may set these bounds to whatever is required.*

☞ *The user can, in addition, explicitly provide whatever convexity row that the problem may need through an equation that requires the members of the SOS set to be less than a certain value. Any such convexity row would implicitly define bounds on each of the variables.*

Consider the following example,

```
sos1 Variable s1(i) ;
Equation defsoss1 ;
defsoss1.. sum(i,s1(i)) =l= 3.5 ;
```

The equation `defsoss1` implicitly defines the non-zero value that one of the elements of the `SOS1` variable `s1` can take.

A special case of `SOS1` variables is when exactly one of the elements of the set have to be non-zero. In this case, the `defsoss1` equation will be

```
defsoss1.. sum(i,s1(i)) =e= 3.5 ;
```

A common use of the use of this set is for the case where the non-zero value is 1. In such cases, the `SOS1` variable behaves like a binary variable. It is only treated differently by the solver at the level of the branch and bound algorithm. For example, consider the following example to model the case where at most one out of n options can be selected. This is expressed as

```
sos1 variable x(i)
equation defx ;
defx.. sum(i,x(i)) =l= 1 ;
```

The variable `x` can be made binary without any change in meaning and the solution provided by the solver will be indistinguishable from the `SOS1` case.

The use of special ordered sets may not always improve the performance of the branch and bound algorithm. If there is no natural *order* the use of binary variables may be a better choice. A good example of this is the assignment problem.

☞ *Not all MIP solvers allow `SOS1` variables. Furthermore, among the solvers that allow their use, the precise definition can vary from solver to solver. Any model that contains these variables may not be transferable among solvers. Please verify how the solver you are interested in handles `SOS1` variables by checking the relevant section of the Solver Manual.*

17.2.3 Special Order Sets of Type 2 (SOS2)

At most two variables within a `SOS2` set can have non-zero values. The two non-zero values have to be adjacent. The most common use of `SOS2` sets is to model piece-wise linear approximations to nonlinear functions.

☞ *The default bounds for `SOS2` variables are 0 to $+\infty$. As with any other variable, the user may set these bounds to whatever is required.*

Special ordered sets of type 2 are defined as follows,

```
sos2 Variable s2(i), t2(k,j), w2(i,j,k) ;
```

The members of the innermost (the right-most) index belongs to the same set. For example, in the sets defined above, `s2` represents one special ordered set of type 2 with `i` elements, `t2` defines `k` sets of `j` elements each, and `w2` defines `(i,j)` sets with `k` elements each.

[PRODSCHX] shows SOS type formulations with binary, `SOS1` and `SOS2` sets. The default bounds for SOS variables are 0 to $+\infty$. As with any other variable, the user may set these bounds to whatever is required.

☞ *Not all MIP solvers allow `SOS2` variables. Furthermore, among the solvers that allow their use, the precise definition can vary from solver to solver. Any model that contains these variables may not be transferable among solvers. Please verify how the solver you are interested in handles `SOS2` variables by checking the relevant section of the Solver Manual.*

17.2.4 Semi-Continuous Variables

Semi-continuous variables are those whose values, if non-zero, must be above a given minimum level. This can be expressed algebraically as: Either $x = 0$ or $L \leq x \leq U$.

By default, this lower bound (L) is 1 and the upper bound (U) is $+\infty$. The lower and upper bounds are set through `.lo` and `.up`. In GAMS, a semi-continuous variable is declared using the reserved phrase `semicont variable`. The following example illustrates its use.

```
semicont variable x ;
x.lo = 1.5 ; x.up = 23.1 ;
```

The above slice of code declares the variable `x` to be semi-continuous variable that can either be 0, or can behave as a continuous variable between 1.5 and 23.1.

☞ *Not all MIP solvers allow semi-continuous variables. Please verify that the solver you are interested in can handle semi-continuous variables by checking the relevant section of the Solver Manual.*

☞ *The lower bound has to be less than the upper bound, and both bounds have to be greater than 0. GAMS will flag an error if it finds that this is not the case.*

17.2.5 Semi-Integer Variables

Semi-integer variables are those whose values, if non-zero, must be integral above a given minimum value. This can be expressed algebraically as: Either $x = 0$ or $x \in \{L, \ldots, U\}$

By default, this lower bound (L) is 1 and the upper bound (U) is 100. The lower and upper bounds are set through `.lo` and `.up`. In GAMS, a semi-integer variable is declared using the reserved phrase `semiint` variable. The following example illustrates its use.

```
semiint variable x ;
x.lo = 2 ; x.up = 25 ;
```

The above slice of code declares the variable `x` to be semi-continuous variable that can either be 0, or can take any integer value between 2 and 25.

☞ *Not all MIP solvers allow semi-integer variables. Please verify that the solver you are interested in can handle semi-integer variables by checking the relevant section of the Solver Manual.*

☞ *The lower bound (L) has to be less than the upper bound (U), and both bounds have to be greater than 0. GAMS will flag an error during model generation if it finds that this is not the case.*

☞ *The bounds for `semiint` variables have to take integer values. GAMS will flag an error during model generation if it finds that this is not the case.*

17.2.6 Setting Priorities for Branching

The user can specify an order for picking variables to branch on during a branch and bound search for MIP models through the use of priorities. Without priorities, the MIP algorithm will determine which variable is the most suitable to branch on. The GAMS statement to use priorities for branching during the branch and bound search is:

```
mymodel.prioropt = 1 ;
```

where `mymodel` is the name of the model specified in the `model` statement. The default value is 0 in which case priorities will not be used.

Using the `.prior` suffix sets the priorities of the individual variables. Note that there is one `prior` value for each individual component of a multidimensional variable. Priorities can be set to any real value. The default value is 1. As a general rule of thumb, the most important variables should be given the highest priority.

The following example illustrates its use,

```
z.prior(i,'small')   = 3 ;
z.prior(i,'medium')  = 2 ;
z.prior(i,'large')   = 1 ;
```

In the above example, `z(i,'large')` variables are branched on before `z(i, 'small')` variables.

☞ *The lower the value given to the `.prior` suffix, the higher the priority for branching.*

☞ *All members of any `SOS1` or `SOS2` set should be given the same priority value since it is the set itself which is branched upon rather than the individual members of the set.*

17.3 Model Scaling - The Scale Option

The rules for good scaling are exclusively based on algorithmic needs. GAMS has been developed to increase the efficiency of modelers, and one of the best ways seems to be to encourage modelers to write their models using a notation that is as *natural* as possible. The units of measurement are one part of this natural notation, and there is unfortunately a potential conflict between what the modeler thinks is a good unit and what constitutes a well-scaled model.

17.3.1 The Scale Option

To facilitate the translation between a natural model and a well scaled model, GAMS has introduced the concept of a scale factor, both for variables and equations. The notations and definitions are quite simple. Scaling is turned off by default. Setting the model suffix `.scaleopt` to 1 turns on the scaling feature. For example,

```
model mymodel /all/ ;
mymodel.scaleopt = 1 ;
solve mymodel using nlp maximizing dollars ;
```

The statement should be inserted somewhere after the `model` statement and before the `solve` statement. In order to turn scaling off again, set the `model.scaleopt` parameter to 0 before the next solve.

The scale factor of a variable or an equation is referenced with the suffix `.scale`, i.e. the scale factor of variable `x(i)` is referenced as `x.scale(i)`. Note that there is one scale value for each individual component of a multi-dimensional variable or equation. Scale factors can be defined using assignment statements. The default scale factor is always 1.

GAMS scaling is in most respects hidden from the user. The solution values reported back from a solution algorithm are always reported in the user's notation. The algorithm's versions of the equations and variables are only reflected in the derivatives in the equation and column listings in the GAMS output if the options `limrow` and `limcol` are positive, and the debugging output from the solution algorithm generated with `sysout` option set to on.

17.3.2 Variable Scaling

The scale factor on a variable, V_s, is used to relate the variable as seen by the user, V_u, to the variable as seen by the algorithm, V_a, as follows: $V_a = V_u/V_s$

For example, consider the following equation,

```
positive variables x1,x2 ;
equation eq ;
eq.. 200*x1 + 0.5*x2 =l= 5 ;
x1.up = 0.01; x2.up = 10 ;
x1.scale = 0.01; x2.scale = 10 ;
```

By setting `x1.scale` to 0.01 and `x2.scale` to 10, the model seen by the solver is,

```
positive variables xprime1,xprime2 ;
equation eq ;
eq.. 2*xprime1 + 5*xprime2 =l= 5 ;
xprime1.up = 1; xprime2.up = 1 ;
```

Note that the solver does not see the variables `x1` or `x2`, but rather the scaled (and better-behaved) variables `xprime1` and `xprime2`.

☞ *Upper and lower bounds on variables are automatically scaled in the same way as the variable itself.*

☞ *Integer and binary variables cannot be scaled.*

17.3.3 Equation Scaling

Similarly, the scale factor on an equation, G_s, is used to relate the equation as seen by the user, G_u, to the equation as seen by the algorithm, G_a, as follows: $Ga = G_u/G_s$

For example, consider the following equations,

```
positive variables y1,y2 ;
equation eq1, eq2 ;
eq1.. 200*y1 + 100*y2 =l= 500 ;
eq2.. 3*y1 - 4*y2 =g= 6 ;
```

By setting `eq1.scale` to 100, the model seen by the solver is,

```
positive variables y1,y2 ;
equation eqprime1, eq2 ;
eqprime1.. 2*y1 + 1*y2 =l= 5 ;
eq2.. 3*y1 - 4*y2 =g= 6 ;
```

☞ *The user may have to perform a combination of equation and variable scaling until a well-scaled model is obtained.*

Consider the following example,

```
positive variables x1,x2 ;
equation eq1, eq2 ;
eq1.. 100*x1 + 5*x2 =g= 20 ;
eq2.. 50*x1 - 10*x2 =l= 5 ;
x1.up = 0.2 ; x2.up = 1.5 ;
```

Setting the following scale values:

```
x1.scale = 0.1 ;
eq1.scale = 5 ;
eq2.scale = 5 ;
```

will result in the solver seeing the following well scaled model,

```
positive variables xprime1,x2 ;
equation eqprime1, eqprime2 ;
eqprime1.. 2*xprime1 + x2 =g= 4 ;
eqprime2.. xprime1 - 2*xprime2 =l= 1 ;
xprime1.up = 2 ; x2.up = 1.5 ;
```

17.3.4 Scaling of Derivatives

For nonlinear models, the derivatives also need to be well scaled. The derivatives in the scaled model seen by the algorithm, i.e. $d(G_a)/d(V_a)$ are related to the derivatives in the user's model, $d(G_u)/d(V_u)$ through the formula: $d(G_a)/d(V_a) = d(G_u)/d(V_u) \cdot V_s/G_s$.

The user can affect the scaling of derivatives by scaling both the equation and variable involved.

Appendix

A

Glossary

acronym A GAMS data type used to give logical classifications to data points.

alias An alternative name for a set.

algorithm This term may be used in two ways. It is either a prescription for how to solve a problem, or a particular solver system.

assignment The statement used to change values associated with an identifier.

basic A classification of a row or column that is in the basis maintained by solution methods that use linear programming iterations.

binding An inequality constraint is binding when the value of the associated slack is zero.

bounds Upper and lower limits on the possible values that a column may assume in a feasible solution. May be *infinite*, meaning that no limit is imposed.

column An individual decision variable in the model seen by a solver program. Many may be associated with one GAMS variable

compilation The initial phase of GAMS processing, when the program is being checked for syntax and consistency.

constant set A set is constant if it remains unchanged. It has to be initialized with a set definition statement and cannot be changed using assignment statement. Sets used in domain definitions must be constant. Sets used in lag operations must be ordered as well. Sometimes the word static is used instead of constant.

constraint A relationship between columns that must hold in a feasible solution. There may be many constraints associated with one GAMS equation.

continuous There are two contexts. First a classification of a function. A plot of the function values will be a line without breaks in it. Second, a classification of variables. A continuous variable may assume any value within its bounds.

controlling sets See **driving sets**.

data types Each symbol or identifier has to be declared to be one of the seven data types, which are `set`, `parameter`, `variable`, `equation`, `model`, `file` and `acronym`. The keywords `scalar` and `table` do not introduce separate data types but rather comprise a shorthand way to declare a symbol to be a `parameter` that will use a particular format for specifying initial values.

declaration The entry of a symbol and the specification of its data type. A declaration may include the specification of initial values, and then it is more properly called a definition.

default The value used, or the action taken, if the user provides no information.

definition The definitions of the algebraic relationships in an equation are the assignment of initial values to parameters or of elements to sets as part of the initial declaration of the identifier.

definition statements Units that describe symbols, assign initial values to them, and describe symbolic relationships. Some examples of the `set`, `parameter`, `table`, and `model` statements, and the `equation` definition statement.

direction Either maximization or minimization, depending on whether the user is interested in the largest or the smallest possible value for the objective function.

discontinuous A classification of a function. A plot of the function values will be a line with breaks in it.

discrete A discrete variable (type `binary` or `integer`) may not assume any value between the bounds, but must assume integer values.

dollar control option Directives or options used to control input or output detail associated with the GAMS compiler.

dollar operator An operator used for exceptions handling in assignment statements and in equation definitions.

domain checking The check that ensures that only legal label combination are used on every assignment to, or reference of, an identifier.

domain definition The label combinations whose data will be updated in an assignment statement, or that will generate an individual constraint in an `equation` definition.

domain restriction condition The alteration to the domain of definition caused when a dollar operator is used on the left (of the '`=` in an assignment or of the '`..`' in an equation definition).

driving set The set that determine the domain of definition, or that control and index operation such as sum.

dynamic set A set is dynamic if it has been changed with an assignment statement. Dynamic sets cannot be used with lag operations or in domain definitions.

endogenous Data values that change when a `solve` statement is processed. In GAMS most often associated with variables.

equation The GAMS data type used to specify required relationships between activity levels of variables.

execution The second phase of GAMS processing, when GAMS is actually carrying out data transformations or generating a model.

execution statements Instructions to carry out actions such as data transformations, model solutions, and report generation. Some examples are the assignment and the `option`, `display`, `loop` and `solve` statements.

exogenous Data values known before a `solve` statement is processed, and not changed by the solve. In GAMS most often parameters.

explanatory text See **text**.

exponent A scale factor used to conveniently represent very large or small numbers.

extended arithmetic The usual computer arithmetic is extended to include plus and minus infinity (`+inf` and `-inf`) and a special value for an arbitrarily a small number (i.e. one which is close to zero) known as epsilon (`eps`). Also, not available (`na`) can be used to indicate missing data, and undefined (`undf`) is the result of illegal operation. GAMS allows extended arithmetic for all operations and functions. The library problem [CRAZY] demonstrates extended arithmetic by showing the results for all operations and functions.

e-format The representation of numbers when an exponent is used explicitly. For example, 1.1E+07.

feasible Often used to describe a model that has at least one feasible solution (see below).

feasible solution A solution to a model in which all column activity levels are within the bounds and all the constraints are satisfied.

GAMS coordinator The person who looks after the administration of a GAMS system, and who will know what solvers are available and can tell you who to approach for help with GAMS problems. Unlikely to apply to personal computer versions.

identifiers Names given to data entities. Also called **symbols**.

index position(s) Another way of describing the set(s) that must be used when referencing a symbol of dimensionality one or more (i.e., a vector or a matrix).

inequality constraint A constraint in which the imposed relationship between the columns is not fixed, but must be either greater than or equal to, or less than or equal to, a constant. The GAMS symbols `=g=` and `=l=` are used in equation definitions to specify these relationships.

infeasible Used to describe either a model that has no feasible solution, or an intermediate solution that is not feasible (although feasible solutions may exist). See **feasible**, above.

initialization Associating initial values with sets or parameters using lists as part of the declaration or definition, or (for parameters only) using `table` statements.

list One of the ways of specifying initial values. Used with sets or parameters, most often for one-dimensional but also for two and higher dimensional data structures.

list format One of the ways in which sets and parameters, can be initialized and all symbol classes having data can be displayed. Each unique label combination is specified in full, with the associated non-default value alongside.

marginal Often called reduced costs or dual values. The values, which are meaningful only for non-basic rows or columns in optimal solutions, contain information about the rate at which the objective value will change of if the associated bound or right hand side is changed.

matrix element See **nonzero element**

model generation The initial phase of processing a solve statement: preparing a problem description for the solver.

model list A list of equations used in a model, as specified in a `model` statement.

nonbasic A column that is not basic and (in nonlinear problems) not superbasic. Its value will be the same as the one of the finite bounds (or zero if there are no finite bounds) if the solution is feasible.

nonlinear nonzero In a linear programming problem, the nonzero elements are constant. In a nonlinear problem, one or more of them vary because their values depend on that of one or more columns. The ratio of nonlinear (varying) to linear (constant) non linear zero elements is a good indicator of the pervasiveness of non-linearities in the problem.

nonoptimal There are two contexts. First, describing a *variable*: a non-basic variable that would improve the objective value if made basic. The sign of the marginal value is normally used to test for non-optimality. Second, for a solution: other *solutions* exists with better objective values.

nonsmooth A classification of function that does not have continuous first derivatives, but has continuous function values. A plot of the function values will be a line with *kinks* in it.

nonzero element The coefficient of a particular column in a particular row if it is not zero. Most mathematical programming problems are sparse meaning that only a small proportion of the entries in the full tableau of dimensions *number of rows* by *number of columns* is different from zero.

objective row (or function) Solver system require the specification of a row on (for nonlinear systems) a function whose value will be maximized or minimized. GAMS users, in contrast, must specify a scalar variable.

objective value The current value of the objective row or of the objective variable.

objective variable The variable specified in the `solve` statement.

optimal A feasible solution in which the objective value is the best possible.

option The statement that allows users to change the default actions or values in many different parts of the system.

ordered set A set is ordered if its content has been initialized with a `set` definition statement and the entry order of the individual elements of the set has the same partial order as the chronological order of the labels. A set name alone on the left-hand side of an assignment statement destroys the ordered property. `Lag` and `Ord` operations rely on the relative position of the individual elements and therefore require ordered sets. Ordered sets are by definition constant.

output A general name for the information produced by a computer program.

output file A disk file containing output. A GAMS task produces one such file that can be inspected.

parameter A constant or group of constants that may be a scalar, a vector, or a matrix of two or more dimensions. Of the six data types in GAMS.

problem type A model class that is dependent on functional form and specification. Examples are linear, nonlinear, and mixed integer programs.

program A GAMS input file that provides a representation of the model or models.

relational operator This term may be used in two ways. First, in an equation definition it describes the type of relationships the equation specifies, for example equality, as specified with the =e= symbol. Second, in a logical expression, the symbols `eq`, `ne`, `lt` and so on are also called relational operators, and are used to specify a required relationship between two values.

right hand side The value of constant term in a constraint.

scalar One of the forms of `parameter` inputs. Used for single elements.

set A collection of elements (labels). The `set` statement is used to declare and define a set.

simplex method The standard algorithm used to solve linear programming problems.

slack The amount by which an inequality constraint is not binding.

slack variable An artificial column introduced by a solver into a linear programming problem. Makes the implementation of simplex method much easier.

smooth A classification of a function that has continuous first derivatives.

solver A computer code used to solve a given problem type. An example is GAMS/MINOS, which is used to solve either linear or nonlinear programming problems.

statements Sometimes called units. The fundamental building block of GAMS programs. Statements or sentences that define data structures, initial values, data modifications, and symbolic relationships. Examples are `table`, `parameter`, `variable`, `model`, assignment and `display` statements.

static set See **constant set**

superbasic In nonlinear programming, a variable that it is not in the basis but whose value is between the bounds. Nonlinear algorithms often search in the space defined by the superbasic variables.

symbol An identifier.

table One of the ways of initializing parameters. Used for two and higher dimensional data structures.

text A description associated with an identifier or label.

type See **data type**, **problem type** or **variable type**.

unique element A label used to define set membership.

variable type The classification of variables. The default bounds are implicit in the type, and also whether continuous or discrete. The types are `free`, `positive`, `binary`, `integer`, `semicont`, `semiint` and `negative`.

vector A one-dimensional array, corresponding to a symbol having one index position.

zero default Parameter values are initially set to zero. Other values can be initialized using `parameter` or `table` statements. Assignment statements have to be used thereafter to change parameter values.

B

The GAMS Model Library

Professor Paul Samuelson is fond of saying that he hopes each generation economists will be able to "*stand on the shoulders*" of the previous generation. The library of models included with the GAMS system is a reflection of this desire. We believe that the quality of modeling will be greatly improved and the productivity of modelers enhanced if each generation can stand on the shoulders of the previous generation by beginning with the previous models and enhancing and improving them. Thus the GAMS systems includes a large library, collectively called GAMSLIB .

The models included have been selected not only because they collectively provide strong shoulders for new users to stand on, but also because they represent interesting and sometimes classic problems. For example the trade-off between consumption and investment is richly illustrated in the Ramsey problem, which can be solved using nonlinear programming methods. Examples of other problems included in the library are production and shipment by firms, investment planning in time and space, cropping patterns in agriculture, operation of oil refineries and petrochemical plants, macroeconomics stabilization, applied general equilibrium, international trade in aluminum and in copper, water distribution networks, and relational databases.

Another criterion for including models in the library is that they illustrate the modeling capabilities GAMS offers. For example, the mathematical specification of cropping patterns can be represented handily in GAMS. Another example of the system's capability is the style for specifying initial solutions as staring points in the search for the optimal solution of dynamic nonlinear optimization problems.

Finally, some models have been selected for inclusion because they have been used in other modeling systems. Examples are network problems and production planning models. These models permit the user to compare how problems are set up and solved in different modeling systems.

Most of the models have been contributed by GAMS users. The submission of new models is encouraged. If you would like to see your model in a future release of the library, please send the model and associated documents and reports to GAMS Development Corporation.

The most convenient way (Windows only) to access the model library is from within the GAMS IDE by going through: File → Model Library → Open GAMS Model Library. A window will pop up and give you access to all models.

Another way to access the library is through the `gamslib` command. This command copies a model from the library directory into the current directory. If you enter `gamslib` without any parameters, the command syntax will be displayed as shown below:

```
   >gamslib modelname [target]
```

or

```
   >gamslib modelnum [target]
```

where `modelname` is the modelname, `modelnum` is the model sequence number, and `target` is the target file name. If the target file name is not provided, the default is `modelname.gms`. For example, the [TRNSPORT] model could be copied in any of the following ways

```
>gamslib trnsport         target file: trnsport.gms
>gamslib 1                             trnsport.gms
>gamslib trnsport myname               myname
>gamslib 1 myname                      myname
```

The full and annotated list of the models of the GAMS Model Library is available at: http://www.gams.com/modlib/modlib.htm

C

The GAMS Call

The entire GAMS system appears to the user as a single call that reads the input file and produces an output file. Several options are available at this level to define the overall layout of the output page, and when to save and restore the entire environment. Although details will vary with the type of computer and operating system used, the general operating principles are the same on all machines.

C.1 The Generic "no frills" GAMS Call

The simplest way to start GAMS is to enter the command

```
>gams myfile
```

from the system prompt and GAMS will compile and execute the GAMS statements in the file `myfile`. If a file with this name cannot be found, GAMS will look for a file with the extended name `myfile.gms`. The output will be written by default on the file `myfile.lst` on PC and Unix systems, and `myfile.lis` on OpenVMS systems. For example, the following statement compiles and executes the example problem [TRNSPORT] from the GAMS model library,

```
>gams trnsport
```

The output goes by default to the file `trnsport.lst`.

C.1.1 Specifying Options through the Command Line

GAMS allows for certain options to be passed through the command line. The syntax of the simple GAMS call described in Section C.2 is extended to look as follows,

```
>gams myfile key1=value1, key2=value2, ...
```

where `key1` is the name of the option that is being set on the command line, and `value1` is the value to which the option is set. Depending on the option, `value1` could be a character string, or an integer number. For example, consider the following commands to run [TRNSPORT] from the GAMS model library,

```
gams trnsport  o myrun.lst lo 2
gams trnsport -o myrun.lst -lo 2
gams trnsport  o=myrun.lst lo=2
gams trnsport -o=myrun.lst -lo=2
```

All the four commands above are equivalent, and each directs the output listing to the file `myrun.lst`. `o` is the name of the option, and it is set to `myfile.lst`. In addition, in each case, the log of the run is redirected to the file `myrun.log`.

C.2 List of Command Line Parameters

The options available through the command line are grouped into the following functional categories affecting

the specific GAMS run	input file processing	other files
system settings	output in listing file	

Table C.1 briefly describes the various options in each of the categories. Section C.3 contains a reference list of all options available through the command line with detailed description for each.

C.3 Detailed Description of Command Line Parameters

This section describes each of the command line parameters in detail. These parameters are in alphabetical order for easy reference. In each of the following options, an abbreviation and the default value, if available, are bracketed.

action (a=ce) Processing option

GAMS currently processes the input file in multiple passes. The three passes in order are:

Compilation During this pass, the file is compiled, and syntax errors are checked for. Data initialization statements like scalar, parameter, and table statements are also processed during this stage.

Execution During this stage, all assignment statements are executed.

Model Generation During this stage, the variables and equations involved in the model being solved are generated.

Values:	`c`	compile only
	`e`	execute only
	`ce`	compile and execute
	`r`	restart

The `a=e` setting can only be used during restart on files that have previously been compiled, since models first need to be compiled before they can be executed.

appendlog (al=0) log file append option

This option is used in conjunction with the `lo=2` setting where the log from the GAMS run is redirected to a file. Setting this option to 1 will ensure that the log file is appended to and not rewritten.

Values:	`0`	reset log file
	`1`	append to log file

appendout (ao=0) output listing file append option

Setting this option to 1 will ensure that the listing file is appended to and not rewritten.

Values:	`0`	reset listing file
	`1`	append to listing file

botmargin (bm=0) bottom margin

This option controls the width of the bottom margin of the text in the listing file. If `bm` is greater than 0, blank lines added at the end of a page. This option is used only with `pagecontr=0` padding.

case (case=0) output case option

Values:		
	`0`	write listing file in mixed case
	`1`	write listing file in upper case only

cerr (cerr=0) compile time error limit

The compilation will be aborted after n errors have occurred. By default, there is no error limit and GAMS compiles the entire input file and collects all the compilation errors that occur. If the file is too long and the compilation process is time consuming, `cerr` could be used to set to a low value while debugging the input file.

Values:		
	`0`	no error limit
	n	stop after n errors

charset (charset=0) extended character set

Values:		
	`0`	use limited GAMS characters set
	`1`	accept any charcater in comments and text items (foreign langage characters)

cns (cns=*text*) default CNS solver

codex (cx=0) overrides default size of execution code length (codex)

Values:		
	`0`	use system defaults
	`1`	use size 1
	`2`	use size 2
	`3`	use size 3
	`4`	use largest size possible

ctrlm (ctrlm=0) control-M indicator

The Control-M character appears as the end-of-line character when files have been incorrectly transferred from PC to Unix platforms. This option allows for recognizing these Control-M characters, and interpreting them as blanks.

Values:		
	`0`	Ctrl-M is not a valid input
	`1`	Ctrl-M will be interpreted as blank

ctrlz (ctrlz=0) control-Z indicator

The Control-Z character appears as the end-of-file character when files have been incorrectly transferred from PC to Unix platforms. This option allows for recognizing these Control-Z characters, and interpreting them as blanks.

Values:		
	`0`	Ctrl-Z is not a valid input
	`1`	Ctrl-Z will be interpreted as blank

curdir (curdir=*text*) set current directory

This option sets the current directory. This option is useful when GAMS is called from an external system like Visual Basic. If not specified, it will be set to the directory the GAMS module is called from.

dformat (df=0) date format

This option controls the date format in the listing file. The three date formats correspond to the various conventions used around the world. For example, the date December 2, 1996 will be written as `12/02/96` with the default `df` value of 0, as `02.12.96` with `df=1`, and as `96-12-02` with `df=2`.

Values:		
	0	mm/dd/yy
	1	dd.mm.yy
	2	yy-mm-dd

dnlp (dnlp=*text*) default DNLP solver

dumpopt (dumpopt=0) workfile dump option

Extracts selected portions of the workfile and writes it in GAMS source format to another file that has the extension `dmp`.

Values:		
	0	no dumpfile
	1	use original element names
	2	use new element names and change text
	3	use new element names and drop text

To illustrate the use of the `dumpopt` option, [TRNSPORT] has been split into two files. The first file (say `trans1.gms`) contains most of the original file except for the solve statement, and looks as follows,

```
sets
       i   canning plants   / seattle, san-diego /
       j   markets          / new-york, chicago, topeka / ;

parameters
       a(i)  capacity of plant i in cases
         /    seattle     350
              san-diego   600  /

       b(j)  demand at market j in cases
         /    new-york    325
              chicago     300
              topeka      275  / ;

table d(i,j)  distance in thousands of miles
                    new-york       chicago      topeka
      seattle          2.5           1.7          1.8
      san-diego        2.5           1.8          1.4  ;

scalar f  freight in dollars per case per thousand miles  /90/ ;

parameter c(i,j) transport cost in thousands of dollars per case ;

  c(i,j) = f * d(i,j) / 1000 ;

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/ ;
```

All comments have been removed from [TRNSPORT] for brevity. Running this model and saving the work files through the save parameter leads to the generation of eight work files. The second file (say `trans2.gms`) generated from [TRNSPORT] looks as follows,

```
solve transport using lp minimizing z ;
display x.l, x.m ;
```

One can then run `trans2.gms` restarting from the saved work files generated from running `trans1.gms`. The result obtained is equivalent to running [TRNSPORT].

☞ *In order to use the* `dumpopt` *parameter effectively, it is required that the first line in the restart file be the solve statement.*

To illustrate the use of the `dumpopt` option, run the second model using the following command

```
gams trans2 s=trans dumpopt=1
```

where `trans` is the name of the saved files generated through the `save` parameter from `trans1.gms`. A new file `trans2.dmp` is created as a result of this call, and looks as follows,

```
* This file was written with DUMPOPT=1 at 01/06/97  08:42:39
*   INPUT = C:\GAMS\TEST\TRANS2.GMS
*    DUMP = C:\GAMS\TEST\TRANS2.DMP
* RESTART = C:\GAMS\TEST\TRANS.G0?
*           with time stamp of 01/06/97  08:42:19
*
* You may have to edit this file and the input file.

set labelorder dummy set to establish the proper order /
   "seattle","san-diego","new-york","chicago","topeka" /;

model transport;

variable z "total transportation costs in thousands of dollars";

set i(*) "canning plants" /
   "seattle","san-diego" /;

set j(*) "markets" /
   "new-york","chicago","topeka" /;

parameter c(i,j) "transport cost in thousands of dollars per case"
/  "seattle"."new-york" 2.250000000000000e-001,
   "seattle"."chicago" 1.530000000000000e-001,
   "seattle"."topeka" 1.620000000000000e-001,
   "san-diego"."new-york" 2.250000000000000e-001,
   "san-diego"."chicago" 1.620000000000000e-001,
   "san-diego"."topeka" 1.260000000000000e-001 /;

positive variable x(i,j) "shipment quantities in cases";

parameter a(i) "capacity of plant i in cases" /
   "seattle" 3.500000000000000e+002,
   "san-diego" 6.000000000000000e+002 /;

parameter b(j) "demand at market j in cases" /
   "new-york" 3.250000000000000e+002,
   "chicago" 3.000000000000000e+002,
   "topeka" 2.750000000000000e+002 /;

equation demand(j) "satisfy demand at market j";
equation supply(i) "observe supply limit at plant i";

equation cost "define objective function";

*      *** EDITS FOR INPUT FILE ***

*      *** END OF DUMP ***
```

Note that all the data entering the model in the solve statement has been regenerated. The parameter `d` has not been regenerated since it does not appear in the model, but the parameter `c` is. Changing the value of the parameter `dumpopt` will result in alternate names being used for the identifiers in the regenerated file.

dumpparms (dp=0) GAMS parameter logging

The `dumpparms` parameter provides more detailed information about the parameters used during the current run.

Values:		
	0	no logging
	1	lists accepted parameters
	2	log of file operations plus parameters

Note that with `dp=2`, all the file operations are listed including the full path of each file on which any operation is performed.

eolonly (ey=0) single key-value pair option

By default, any number of keyword-value pairs can be present on the same line. This parameter is an immediate switch that forces only one keyword-value pair to be read on a line. If there are more than one such pairs on a line, then this option will force only the first pair to be read while all the other pairs are ignored.

Values:		
	0	any number of keys or values
	1	only one key-value pair on a line

error (error=*text*) Force a parameter error with message *text*

Forces a parameter error with given message string. This option is useful if one needs to incorporate GAMS within another batch file and need to have control over the conditions when GAMS is called. To illustrate the use of the `error` option, the default GAMS log file from running a model with the option `error=hullo`.

```
*** ERROR = hullo
*** Status: Terminated due to parameter errors
--- Erasing scratch files
Exit code = 6
```

errmsg (errmsg=0) error message option

This option controls the location in the listing file of the messages explaining the compilation errors.

Values:		
	0	error messages at the end of compiler listing
	1	error messages immediately following error line
	2	no error messages

To illustrate the option, consider the following slice of GAMS code:

```
set i /1*10/ ;  set j(i) /10*11/;
parameter a(jj) /  12   25.0    / ;
```

The listing file that results from running this model contains the following section,

```
    1  set i /1*10/ ;  set j(i) /10*11/;
****                                $170
    2  parameter a(jj) /  12   25.0    / ;
****               $120
    3

120  Unknown identifier entered as set
170  Domain violation for element

**** 2 ERROR(S)   0 WARNING(S)
```

Note that numbers (`$170` and `$120`) flags the two errors as they occur, but the errors are explained only at the end of the source listing. However, if the code is run using the option `errmsg=1`, the resulting listing file contains the following,

```
    1  set i /1*10/ ;  set j(i) /10*11/;
****                                 $170
**** 170  Domain violation for element
    2  parameter a(jj) /  12   25.0    / ;
****                $120
**** 120  Unknown identifier entered as set
    3

**** 2 ERROR(S)   0 WARNING(S)
```

Note that the explanation for each error is provided immediately following the error marker.

errnam (errnam=*text*) error message file name

Used to change the name `GAMSERRS.TXT`. The name *text* will be used as is.

errorlog (er=0) error messages are written to log file

Values:	0	no error messages to log file
	n	number of lines for each error written to log file

execerr (execerr=0) execution time error limit

Entering or processing a solve statement with more than `execerr` will abort.

Values:	0	no errors allowed limit
	n	don't execute solve if more errors

expand (ef=*text*) expand file name

The expand parameter generates a file that contains information about all the input files processed during a particular compilation. The names of the input files are composed by completing the name with the current directory. The following example illustrates the use of the expand parameter. Consider the following slice of code,

```
parameter a ; a = 0 ;
$include file2.inc
$include file2.inc
```

The content of the include file `file2.inc` is shown below,

```
a = a+1 ;
display a ;
```

Running the model with the command line flag `expand myfile.fil` results in the creation of the file `myfile.fil`. The content of this file is provided below,

```
     1 INPUT       0     0        0        1        7  E:\TEMP\FILE1.GMS
     2 INCLUDE     1     1        2        2        4  E:\TEMP\FILE2.INC
     3 INCLUDE     1     1        3        5        7  E:\TEMP\FILE2.INC
```

The first column gives the sequence number of the input files encountered. The first row always refers the parent file called by the GAMS call. The second column refers to the type of file being referenced. The various types of files are

0	INPUT	1	INCLUDE
2	BATINCLUDE	3	LIBINCLUDE
4	SYSINCLUDE		

The third column provides the sequence number of the parent file for the file being referenced. The fifth column gives the local line number in the parent file where the `$include` appeared. The sixth column gives the global (expanded) line number which contained the `$include` statement. The seventh column provides the total number of lines in the file after it is processed. The eighth and last column provides the name of the file In the example listed above, the include files `file1.inc` and `file2.inc` were included on lines 1 and 4 of the parent file `test1.gms`.

ferr (ferr=*text*) compilation error message file

Instructs GAMS to write error messages into a file. Completing the name with the scratch directory and the scratch extension composes the file name. The default is no compilation error messages. This option can be used when GAMS is being integrated into other environments like Visual Basic. The error messages that are reported in the listing file can be extracted through this option and their display can be controlled from the environment that is calling GAMS.

To illustrate the option, consider the following slice of GAMS code used to explain the `errmsg` option. Calling GAMS on this code with `ferr=myfile.err`, will result in a file called `myfile.err` being created in the scratch directory. This file contains the following lines:

```
0     0      0      0 D:\GAMS\NEW.LST
1     1    170     31 D:\GAMS\NEW.GMS
2     2    120     14 D:\GAMS\NEW.GMS
```

The first column refers to the global row number of the error in the listing file. The second column refers to the row number of the error in the individual file where the problem occurs. This will be different from the first column only if the error occurs in an include file. In this case, the second column will contain the line number in the include file where the error occurs, while the first number will contain the global line number (as reported in the listing file) where the error occurs. The number in the third column refers to the error number of the error. The fourth number refers to the column number of the error in the source file. The fifth column contains the individual file in which the error occurred.

forcework (fw=0) force workfile translation

Most of the work files generated by GAMS using the save option are in binary format. The information inside these files will change from version to version. Every attempt is made to be backward compatible and ensure that all new GAMS systems are able to read save files generated by older GAMS systems. However, at certain versions, we are forced to concede default incompatibility (regarding save files, not source files) in order to protect efficiency. The `forcework` option is used to force newer GAMS systems into translating and reading save files generated by older systems.

Values:	0	no translation
	1	try translation

fsave (fsave=0) force workfile to be written

Values:	0	workfile only written if `save`
	1	workfile written if no `save`

The option value 1 is mainly used by solvers that can be interrupted from the terminal.

g205 (g205=0) GAMS version 2.05 backward compatability

This option sets the level of the GAMS syntax. This is mainly used for backward compatibility. New key words have been introduced in the GAMS language since Release 2.05. Models developed earlier that use identifiers that have since become keywords will cause errors when run with the latest version of GAMS. This option will allow one to run such models.

Values:		
	0	latest syntax
	1	syntax from Release 2.05 only
	2	syntax from the first version of Release 2.25 only

For example, the word `if` is a key word in GAMS introduced with the first version of Release 2.25. Setting the `g205=1` option allows if to be used as an identifier since it was not a keyword in Release 2.05. As another example, the word `for` is a key word in GAMS introduced with the later versions of Release 2.25. Setting the `g205=2` option allows `for` to be used as an identifier since it was not a keyword in the first version of Release 2.25.

☞ *Using values of 1 or 2 for `g205` will not permit the use of enhancements to the language introduced in the later versions.*

ide (ide=0) Integrated Development Environment flag

Values:		
	n	tells GAMS about the environment
	1	runs under GAMS IDE

input (i) input file name

Completing the input file name with the current directory composes the final name. If such a file does not exist and the extension was not specified, the standard input extension is attached and a second attempt is made to open an input file.

inputdir (idir) input search path

In general, GAMS searches for input and include files in the current working directory only. This option allows the user to specify additional directories for GAMS to search for the input files. A maximum of 18 separate directories can be included with the directories separated by Operating System specific symbols. On a PC the separator is a semicolon (`;`) character, and under Unix it is the colon (`:`) character. Note that `libinclude` and `sysinclude` files are handled differently, and their paths are specified by `libincdir` and `sysincdir` respectively.

Consider the following illustration,

```
gams myfile idir \mydir;\mydir2
```

The search order for the file `myfile` (or `myfile.gms`) and all included files in PC systems is as follows: current directory directories specified by `inputdir` (`\mydir` and `\mydir2` directories) in order under Unix, the corresponding command is

```
gams myfile idir \mydir:\mydir2
```

inputdir1 to inputdir18 (idir1=*text*,...,idir18=*text*) Input search path

The same information as in `inputdir` can be transferred to GAMS by entering the individual directories separately. A maximum of 18 directories can be passed on in this manner. The number appended to `inputdir` is important because the earlier `inputdir` directories are searched first.

The example used to illustrate the inputdir option can also be equivalently called as

```
gams myfile idir1 mydir1 idir2 mydir2
```

Note that the search order in this case is as follows:

1. current directory

2. `mydir1`

3. `mydir2`

However, if the command was altered to be

```
gams myfile idir3 \mydir1 idir2 \mydir2
```

then the search order is altered to be as follows:

1. current directory

2. `mydir2`

3. `mydir1`

Note that it is not the order in which they are specified that matters but the number of the inputdir that they have been assigned to.

keep (keep=0) keep flag (internal use only)

Values:		
	`0`	delete all files
	`1`	keep intermediate files

leftmargin (lm=0) left margin for listing file

This option controls the width of the left margin of the text in the listing file. If `lm` is greater than 0, the output is shifted `lm` positions to the right.

libincdir (ldir=*text*) library include directory

Used to complete a file name for `$libinclude`. If the `ldir` option is not set, the sub-directory `inclib` in the GAMS system directory is searched.

☞ *Unlike `idir`, additional directories cannot be set with `ldir`. The string passed will be treated as one directory. Passing additional directories will cause errors.*

☞ *Note that if the `ldir` parameter is set, the default library include directory is not searched.*

Consider the following illustration,

```
gams myfile ldir mydir
```

GAMS searches for any referenced `$libinclude` file in the directory `mydir`.

license (license=*text*) license file name

This option is only to be used by advanced users attempting to override internal license information. The file name is used as given. The default license file is `gamslice.txt` in the GAMS system directory.

limcol (limcol=3) default column listing

Values:		
	n	first n columns listed

limrow (limrow=3) default row listing

Values:	*n*	first *n* rows listed

logfile (lf=*text*) log file name

This option is used in conjunction with the `lo` option. If `lo` is set to 2, then this option will specify the name of the log file name. The name provided by the option is completed using the current directory. If no logfile is given but the value of `lo` is 2, then the file name will be input file name with the extension `.log`

To illustrate the use of the `logfile` option, run [TRNSPORT] with the options `lo=2` and `lf=myfile.log`. The resulting log file is redirected to `myfile.log`, and looks as follows:

```
--- Starting compilation
--- TRNSPORT.GMS(0)
--- TRNSPORT.GMS(33)
--- TRNSPORT.GMS(66)
--- TRNSPORT.GMS(66)

--- Starting execution
--- TRNSPORT.GMS(43)
--- Generating model TRANSPORT
--- TRNSPORT.GMS(56)
--- TRNSPORT.GMS(58)
--- TRNSPORT.GMS(60)
--- TRNSPORT.GMS(64)   ---    6 rows, 7 columns, and 19 non-zroes.
--- Executing BDMLP
 GAMS/BDMLP 1.1   Aug  1, 1994  001.049.030-033.030  386/486 DOS-W
 READING DATA...
 Work space allocated           --    0.03 Mb
    Iter    Sinf/Objective  Status    Num  Freq
       1    2.25000000E+02  infeas      1     1
       4    1.53675000E+02  nopt        0
 SOLVER STATUS: 1 NORMAL COMPLETION
 MODEL STATUS : 1 OPTIMAL
 OBJECTIVE VALUE     153.67500

--- Restarting execution
--- TRNSPORT.GMS(64)
--- Reading solution for model TRANSPORT
--- TRNSPORT.GMS(66)
--- All done
```

logline (ll=2) amount of line tracing to log file

This option is used to limit the number of line tracing sent out to the log file during the compilation phase of a GAMS run. Values of 0 and 1 are special. Setting `ll=0` will cause the line tracing to be suppressed for all phases of the GAMS processing.

Values:	0	all line tracing suppressed
	1	limited line tracing
	n	full line tracing with increments of *n*

The log file that results from running [TRNSPORT] with the option `ll=0` is shown below,

```
--- Starting compilation
--- Starting execution
--- Generating model TRANSPORT
---    6 rows, 7 columns, and 19 non-zeroes.
--- Executing BDMLP
 GAMS/BDMLP 1.1   Aug  1, 1994  001.049.030-033.030  386/486 DOS-W
 READING DATA...
 Work space allocated           --    0.03 Mb
    Iter    Sinf/Objective  Status    Num  Freq
       1    2.25000000E+02  infeas      1     1
       4    1.53675000E+02  nopt        0
    SOLVER STATUS: 1 NORMAL COMPLETION
    MODEL STATUS : 1 OPTIMAL
    OBJECTIVE VALUE     153.67500

   --- Restarting execution
   --- Reading solution for model TRANSPORT
   --- All done
```

Comparing this output to the one shown in the example of option `logfile`, one can see that the line numbers are absent from the log file.

logoption (lo=1) log file option

This option controls the location of the output log of a GAMS run. By default, GAMS directs the log of the run to the screen/console. If `lo=2`, the log is redirected to a file. With `lo=3` all the output goes to the standard output. If no file name is provided for the log through the `lf` option, the file name will be the input file name with the extension `.log`.

Values:		
	0	no log output
	1	log output to screen/console
	2	log output to file
	3	log output to stdout

To illustrate the use of the `lo` option, run [TRNSPORT] with the options `lo=2`. The resulting log file, `trnsport.log`, looks exactly as shown in the example of option `logfile`.

lp (lp=*text*) default LP solver

mcp (mcp=*text*) default MCP solver

minlp (minlp=*text*) default MINLP solver

miqcp (miqcp=*text*) default MIQCP solver

mpec (mpec=*text*) default MPEC solver

multipass (mp=0) Multipass facility

This option allows slices of GAMS code to be independently checked for syntax errors. This option is useful when a large model is being put together from smaller pieces.

Values:		
	0	standard compilation
	1	check out compilation

As an example, consider the following example,

```
a(i) = b(i)*5 ;
b(i) = c(j) ;
```

By default, running a file containing just the two statements shown above results in the following listing file,

```
   1  a(i) = b(i)*5 ;
****  $140$120$140
   2  b(i) = c(j) ;
****         $140$120$149

120  Unknown identifier entered as set
140  Unknown symbol
149  Uncontrolled set entered as constant
**** 6 ERROR(S)   0 WARNING(S)
```

None of the sets `i`, or `j` have been defined or initialized, and the identifiers `a`,`b` and `c` have not been defined. Further, an assignment cannot be made without the right hand side of the assignment being known. In both the assignments in the example above, there is no data available for the right hand side. Running the model with the setting `mp=1` results in the following listing file,

```
   1  a(i) = b(i)*5 ;
   2  b(i) = c(j) ;
****            $149

Error Messages
149  Uncontrolled set entered as constant
**** 1 ERROR(S)   0 WARNING(S)
```

Note that the statements in the example have now been processed independently of its context. They are now checked only for consistency. GAMS now assumes that sets `i` and `j`, as well as the identifiers `a`, `b`, and `c` are defined and, if necessary, initialized elsewhere. The only error that is reported is the inconsistency of indices in the second statement.

nlcon (nlcon=0) nonlinear instructions search length

Values:		
	`0`	use system default
	n	max number of unique constants

A pool of n unique nonlinear constants is kept. Lookup for first n constants only.

nocheck (nocheck=0) ignore parameter errors

This options controls the report of parameter errors. The effect of this option is immediate and affects all options that follow it on the command line.

Values:		
	`0`	report parameter errors
	`1`	ignore parameter errors

Consider the following call,

```
gams myfile a=q
```

Since there is no `action` called `q`, GAMS will complain and provide the following message:

```
*** Incorrect action q
*** Status: Terminated due to parameter errors
--- Erasing scratch files
```

nocr (nocr=0) ignore copyright messages everywhere

Values:		
	`0`	report copyright
	`1`	suppress copyright

opt (opt=0) optimization level for GAMS execution

Values:		
	`0`	standard optimization
	`1`	First Level

optdir (optdir=*text*) option file directory

Solver option files are assumed to be located in `optdir`. Path name completed with `workdir`.

optfile (optfile=0) option file indicator

This option initializes the `modelname.optfile` parameter to the value set. This parameter has to be set to a value between 1 and 999 in order for GAMS to inform the solver to read the solver option file. `Modelname` is the name of the model specified in the model statement. For example, the file `myfile` contains the slice of GAMS code

```
model m /all/ ;
solve m using nlp maximizing dollars ;
```

Consider the following call,

```
gams myfile optfile=1
```

The option file that is being used after this assignment is `solvername.opt`, where `solvername` is the name of the solver that is specified. For CONOPT, the option file is called `conopt.opt`; for MINOS, it is `minos.opt`. The names that you can use are listed in the Solver Manual.

☞ *Setting `modelname.optfile` in the GAMS input file overrides the value of the `optfile` parameter passed through the command line.*

To allow different option file names for the same solver, the `optfile` parameter can take other values as well. Formally, the rule is `optfile=`n will use `solvename.opt` if $n = 1$, and `solvername.opX`, `solvername.oXX` or `solvername.XXX`, where `X`'s are the characters representing the value of n, for $n > 1$ and will use no option file at all for $n = 0$. This scheme implies an upper bound on n of 999. For example, the following `optfile` values profile the option file names for the CONOPT solver

0	no option file used	1	`conopt.opt`
2	`conopt.op2`	26	`conopt.o26`
345	`conopt.345`		

output (o=*text*) output file name

If no name is given, the input file name is combined with the current directory and the standard output file extension is applied. If the output parameter is given as a file name without an absolute path, using the current directory composes the final name. If the absolute path is included in the file name, then the name is used as given.

Consider the following examples,

```
gams trnsport
gams trnsport o=trnsport.out
gams trnsport o=c:\test\trnsport.out
```

The first call will create an output file called `trnsport.lst` (for PC and Unix platforms) in the current directory. The second call will create a file called `trnsport.out` in the current directory. The last call will create the file as listed. If the directory `c:\test` does not exist, GAMS will exit with a parameter error.

pagecontr (pc=3) page control

This option affects the page control in the listing file.

Values:	0	no page control with padding
	1	Fortran style line printer format
	2	no page control, no padding
	3	Form feed character for new page

pagesize (ps=58) page size

This is the number of lines that are used on a page for printing the listing file. If value of the option is set to less than 30 it will be reset to the default of 58. Note that the total number of lines on a page are `ps+2*bm`. The `botmargin` lines are only added if padding is requested (`pc=0`).

pagewidth (pw=255) print width

This option sets the print width on a page in the listing file. If the value is outside the range, the default value of 255 will be used.

parmfile (pf=*text*) secondary parameter file

profile (profile=0) global execution profiling option

This option initializes the profile option (see Appendix E) to the value set, and allows the profile of a GAMS run to be printed in the listing file. The profile contains the individual and cumulative time required for the various sections of the GAMS model.

☞ *Setting the `profile` option through the option statement in the GAMS input file overrides the value of the profile parameter passed through the command line.*

Values:	0	no profiling
	1	minimum profiling
	2	detailed profiling

A value of 0 does not cause an execution profile to be generated. A value of 1 reports execution times for each statement and the number of set elements over which the particular statement is executed. A value of 2 reports specific times for statements inside control structures like loops. Running [TRNSPORT] with `profile=1` provides the following additional information in the listing file,

```
----      1 EXEC-INIT                0.010     0.010 SECONDS
----     43 ASSIGNMENT C             0.000     0.010 SECONDS    6
----     63 ASSIGNMENT TRANSPORT     0.000     0.010 SECONDS
----     65 SOLVE INIT TRANSPORT     0.000     0.020 SECONDS
----     56 EQUATION   COST          0.000     0.020 SECONDS    1
----     58 EQUATION   SUPPLY        0.030     0.050 SECONDS    2
----     60 EQUATION   DEMAND        0.000     0.050 SECONDS    3
----     65 SOLVE FINI TRANSPORT     0.040     0.090 SECONDS
----     65 GAMS FINI                0.030     0.120 SECONDS
----      1 EXEC-INIT                0.000     0.000 SECONDS
----     65 SOLVE READ TRANSPORT     0.020     0.020 SECONDS
----     67 DISPLAY                  0.010     0.030 SECONDS
----     67 GAMS FINI                0.000     0.030 SECONDS
```

The first column provides the line number in the input file of the statement being executed. The second column provides the type of statement being executed.

`EXEC-INIT`	denotes the beginning of the execution phase of the GAMS input file.
`GAMS-FINI`	denotes the end of this phase.

Note that GAMS finishes processing of an input file as soon as a solve statement is processed, and passes control to the solver being called. After the solver is done, GAMS restarts. This causes two `EXEC-INIT GAMS-FINI` pairs to be generated for [TRNSPORT].

`ASSIGNMENT C` denotes an assignment statement involving the identifier `c`.

`SOLVE INIT`, `SOLVE FINI` are book ends enclosing the generation of the model [TRNSPORT].

Note that only equations are listed, and not variables. This happens because GAMS uses an equation based scheme to generate a model. The third and fourth columns provide the individual time needed to execute the statement, and the cumulative time taken by the GAMS system so far. The last column gives the number of assignments generated in the specified line.

putdir (pdir=*text*) put directory

This option specifies the directory where the `put` files are generated and saved. If not specified, it will be set to the working directory. This option does not work if an absolute file name is provided through the file statement.

qcp (qcp=*text*) default QCP solver

reference (rf=*text*) symbol reference file

If specified, all symbol references will be written to this file. If not specified, symbol references are written to the listing file.

To illustrate the use of the `rf` option, a part of the `trnsport.ref` file generated by running [TRNSPORT] using the option `rf=trnsport.ref` is shown below,

```
1  47 I       SETS    DECLARED    26    26   9  0     1
   E:\WORK\TRNSPORT.GMS
2  47 I       SETS    DEFINED     26    26  29  0     1
   E:\WORK\TRNSPORT.GMS
3  48 J       SETS    DECLARED    27    27   9  0     1
   E:\WORK\TRNSPORT.GMS
4  48 J       SETS    DEFINED     27    27  29  0     1
   E:\WORK\TRNSPORT.GMS
```

relpath (relpath=0) relative or absolute path names

By default, the maximum length of a file name under Windows is 255, and the maximum length of a command line is 255 characters. The internal call to GAMS requires five file names to be passed as arguments. If these files are nested deep in the directory structure, the 255 character limit may be crossed, and system errors may result. This option allows for relative paths to be used instead of absolute paths (as is the default) in the file names. Note that this may not always reduce the length of the file name.

Values:	`0`	pathnames are completed to be absolute
	`1`	pathnames beginning with a '`.`' will be used as is

restart (r=*text*) restart file name

This option provides the name of the save files to restart from. The final name is composed by completing the file name with the current directory and the standard workfile extension. The name provided for the restart file follows the same convention as that of the save file (see command line parameter `save`).

rminlp (rminlp=*text*) default RMINLP solver

rmip (rmip=*text*) default RMIP solver

save (s=*text*) save file name

The final name is composed by completing the save file name with the current directory and the standard workfile extension. Eight save files are generated, so the name provided by the user for the save file should be such that GAMS can generate eight names from it. GAMS distinguishes file names from their extensions. If no extension is provided by the user, GAMS adds the extensions `g01` through `g08` to name the eight saved work files. The presence of a `?` character in the save file name is used by GAMS to substitute the numbers 1 through 8 in its place.

The following table illustrates through examples, the generation of names for the save files by GAMS from the name provided through the `save` parameter.

```
myfile:       myfile.g01,   myfile.g02,   ...,  myfile.g08
myfile?:      myfile1.g01,  myfile2.g02,  ...,  myfile8.g08
myfile.00?:   myfile.001,   myfile.002,   ...,  myfile.008
myfile?.wrk:  myfile1.wrk,  myfile2.wrk,  ...,  myfile8.wrk
myfile?.???:  myfile1.111,  myfile2.222,  ...,  myfile8.888
```

☞ *On Unix platforms the* `?` *character is a special character and may require a backslash character (\) in front of it in order to be interpreted correctly. The name* `myfile?` *should be written on this platform as* `myfile\?`.

scrdir (sd=*text*) scratch directory

This option sets the scratch directory where the intermediate files generated by GAMS and the various solvers. The files in the scratch directory are used by GAMS and the various solvers to communicate with each other. The scratch directory and all its contents are usually deleted at the end of a GAMS run. If not specified, the scratch directory will be set to the default one generated by GAMS.

scriptexit (sl=gamsexit) program or script executed at the end of a GAMS run

scriptfrst (sf=*text*) first line to be written to gamsnext file

The default is an empty string and the *first* line is not written.

scriptnext (script=gamsnext) script mailbox file name

scrnam (sn=*text*) scratch name

Name stem used to complete the names of intermediate work files. This name stem has to have at least one '?'. Name will be completed with the scratch directory and the standard scratch name extension.

solvercntr (scntr=*text*) solver control file name default name override

Name completed with scratch directory and scratch extension.

solverdict (sdict=*text*) solver dictionary file name default name override

Name completed with scratch directory and scratch extension.

solverdopt (sdopt=0) solver dictionary file name override

Values:	`0`	no override
	`1`	use this option for all solvers

solverinst (sinst=*text*) solver instruction file name default name override

Name completed with scratch directory and scratch extension.

solvermatr (smatr=*text*) solver matrix file name default name override

Name completed with scratch directory and scratch extension.

solversolu (ssolu=*text*) solver solution file name default name override

Name completed with scratch directory and scratch extension.

solverstat (sstat=*text*) solver status file name default name override

Name completed with scratch directory and scratch extension.

stepsum (stepsum=0) step summary option

This option controls the generation of a step summary of the processing times taken by GAMS during a given run.

Values:	`0`	no step summary
	`1`	step summary printed

To illustrate the use of the `stepsum` option, the default GAMS log file from running [TRNSPORT] with the option `stepsum=1` contains the following step summaries.

```
   STEP SUMMARY:     0.090       0.090 STARTUP
                     0.070       0.070 COMPILATION
                     0.090       0.090 EXECUTION
                     0.060       0.030 CLOSEDOWN
                     0.310       0.280 TOTAL SECONDS
                                 0.000 ELAPSED SECONDS
   STEP SUMMARY:     0.070       0.160 STARTUP
                     0.000       0.070 COMPILATION
                     0.030       0.120 EXECUTION
                     0.000       0.030 CLOSEDOWN
                     0.100       0.380 TOTAL SECONDS
                                 1.000 ELAPSED SECONDS
```

The first step summary occurs before the model is sent to the solver, and the second occurs after the solver completes its task and returns control back to GAMS. The first column reports time for the individual section of the run, while the second column reports accumulated times including previous sections.

stringchk (stringchk=0) string substitution check for %xxx% symbols

This option affects the result of the check for `%xxx%` symbols.

Values:	`0`	no substitution if symbol undefined
	`1`	error if symbol undefined
	`2`	remove %xxx% if symbol undefined

subsys (subsys=*text*) configuration file name

This option is only to be used by advanced users attempting to override internal sub-system information. The file name is used as given. The default sub-systems file is `gamscomp.txt` in the GAMS system directory.

suppress (suppress=0) compiler listing option

This option suppresses the echoing of the contents of the input file(s) to the listing file. This parameter is similar in functionality to the `$offlisting` dollar control option.

Values:	`0`	standard compiler listing
	`1`	suppress compiler listing

☞ *The `$offlisting` and `$onlisting` dollar control options effect the listing file only if `suppress` is set to 0. If `suppress` is set to 1, the input file(s) is not echoed to the listing file, and these dollar control options have no effect on the listing file.*

symbol (symbol=*text*) symbol file name

Writes a partial symbol table to be used in conjunction with reference files.

sysdir sysdir=*text* system directory

This option sets the GAMS system directory. This option is useful if there are multiple systems installed on the machine, or when GAMS is called from an external system like Visual Basic.

sysincdir (sdir=*text*) system library search directory

Used to complete a file name for `$sysinclude`. If the `sdir` option is not set, the GAMS system directory is searched.

☞ *Unlike `idir`, additional directories cannot be set with `sdir`. The string passed will be treated as one directory. Passing additional directories will cause errors.*

☞ *Note that if the `sdir` parameter is set, the default system include directory is not searched.*

Consider the following illustration,

```
gams myfile sdir mydir
```

GAMS searches for any referenced `$sysinclude` file in the directory `mydir`.

tabin (tabin=8) tab spacing

This option sets the tab spacing. By default, tabs are not allowed in GAMS. However, the most common setting is 8 which results in the positions of the tabs corresponding to columns $1, 9, 17, \ldots$ and the intermediate columns being replaced by blanks.

Values:	`0`	tabs are not allowed
	`1`	tabs are replaced by blanks
	n	tabs are 1, $n+1$, $2n+1$

tformat (tf=0) time format

This option controls the time format in the listing file. The three date formats correspond to the various conventions used around the world. For example, the time 7:45 PM will be written as 19:45:00 with the default `tf` value of 0, and as 19.45.00 with `tf=1`.

Values:	`0`	hh:mm:ss
	`1`	hh.mm.ss

topmargin (tm=0) top margin

This option controls the width of the top margin of the text in the listing file. If `tm` is greater than 0, blank lines added at the top of a page.

trace (trace=*text*) trace file name

The trace file name is completed using the current directory.

unittype (ut=*text*) unit/insert file operations override

All units from previous runs and current inserts are set to the codes below.

Values:	`X`	simulate without writing files
	`U`	unix type pipe style 1
	`C`	spawn process with coded files
	`B`	spawn process with binary files

user1 to user5 (u1=*text*,...,u5=*text*) strings passed on to the subsystems

workdir (wdir=curdir)

This option sets the working directory. This option is useful when GAMS is called from an external system like Visual Basic. If not specified, it will be set to the `curdir` directory.

xsave (xs=*text*) extended save file name

Uses and ASCII formated workfile, otherwise like **save**.

Parameters controlling the specific GAMS run:			
`action`	processing options	`cerr`	sets compile time error limit
`dumpopt`	workfile dump option	`eolonly`	singe keyword-value pair option
`error`	parameter error message	`errmsg`	error message option
`expand`	expands file name	`forcework`	force workfile translation
`fsave`	force workfile to be written	`keep`	keep flag
`nocheck`	ignores parameter errors		
Parameters controlling system settings:			
`charset`	extended character set	`cns`	default CNS solver
`codex`	size of execution code length	`curdir`	sets current directory
`dnlp`	default DNLP solver	`errnam`	error message file name
`errorlog`	error messages to log file	`execerr`	execution time error limit
`ide`	Integrated Development Environment	`inputdir`	sets input search path
`inputdir1`	sets individual input search path	`libincdir`	sets library include directory
`license`	sets license file name	`lp`	default LP solver
`mcp`	default MCP solver	`minlp`	default MINLP solver
`mpec`	default MPEC solver	`nlcon`	nonlinear instructions search length
`nocr`	copyright messages	`parmfile`	secondary parameter file
`putdir`	sets put directory	`reference`	symbol reference file
`relpath`	relative or absolute path	`rminlp`	default RMINLP solver
`rmip`	default RMIP solver	`scrdir`	sets scratch directory
`scriptexit`	script executed at the end of a GAMS run	`scriptfrst`	first line written to gamsnext
`scriptnext`	script mailbox file name	`scrnam`	scratch name
`solvercntr`	solver control file name	`solverdict`	solver dictionary file name
`solverdopt`	solver dictionary file name	`solverinst`	solver instruction file name
`solvermatr`	solver matrix file name	`solversolu`	solver solution file name
`solverstat`	solver status file name	`subsys`	sets configuration file name
`symbol`	symbol file name	`sysdir`	sets system directory
`sysincdir`	sets system library directory	`trace`	trace file name
`unittype`	unit/insert file operations	`user1`	strings passed to subsystems
`workdir`	sets working directory		
Parameters affecting input file processing:			
`ctrlm`	control-M indicator	`ctrlz`	control-Z indicator
`g205`	sets version compatibility	`input`	sets input file name
`multipass`	controls multiple pass facility	`opt`	optimization level for GAMS execution
`optdir`	option file directory	`optfile`	option file indicator
`stringchk`	controls string substitution check	`tabin`	sets tab spacing
Parameters affecting output in listing file:			
`appendout`	output listing file append option	`botmargin`	sets bottom margin in listing file
`case`	sets output case	`dformat`	sets date format
`leftmargin`	sets left margin in listing file	`limcol`	default column listing
`limrow`	default row listing	`output`	sets output file name
`pagecontr`	page control	`pagesize`	sets page size
`pagewidth`	sets page width	`profile`	global execution profiling option
`stepsum`	controls step summary in listing file	`suppress`	compilation listing option
`tformat`	sets time format	`topmargin`	sets top margin in listing file
Parameters affecting other files			
`appendlog`	log file append option	`dumpparms`	controls parameter logging
`ferr`	sets compilation error message file name	`logfile`	sets log file name
`logline`	controls amount of line tracing to log file	`logoption`	log file option
`restart`	sets restart file name	`save`	sets save file name
`xsave`	extended save file name		

Table C.1: GAMS command line parameters

D

Dollar Control Options

D.1 Introduction

The *Dollar Control Options* are used to indicated compiler directives and options. Dollar control options are not part of the GAMS language and must be entered on separate lines recognized by a `$` symbol in the first column. A dollar control option line may be placed anywhere within a GAMS program and it is processed during the compilation of the program. The `$` symbol is followed by one or more options identified by spaced. Since the dollar control options are not part of the GAMS language, they do not appear on the compiler listing unless an error had been detected. Dollar control option lines are not case sensitive and a continued compilation uses the previous settings.

D.1.1 Syntax

In general, the syntax in GAMS for dollar control options is as follows,

```
$option_name argument_list {option_name argument_list}
```

where `option_name` is the name of the dollar control option, while `argument_list` is the list of arguments for the option. Depending on the particular option, the number of arguments required can vary from 0 to many.

☞ *No blank space is permitted between the $ character and the first option that follows.*

☞ *In most cases, multiple dollar control options can be processed on a line. However, some dollar control options require that they be the first option on a line.*

☞ *The effect of the dollar control option is felt immediately after the option is processed.*

An example of a list of dollar control options is shown below,

```
$title Example to illustrate dollar control options
$onsymxref onsymlist
```

Note that there is no blank space between the `$` character and the option that follows. The first dollar control option `$title` sets the title of the pages in the listing file to the text that follows the option name. In the second line of the example above, two options are set - `$onsymxref` and `$onsymlist`. Both these options turn of the echoing of the symbol reference table and listings to the listing file.

D.2 List of Dollar Control Options

The Dollar Control Options are grouped into five major functional categories affecting

input comment format	input data format	output format
reference maps	program control	

Table D.1 briefly describes the various options in each of the categories. Section D.3 contains a reference list of all dollar control options in alphabetical order with detailed description for each.

Non-default settings are reported before the file summary at the end of a GAMS listing as a reminder for future continued compilations. This is only relevant if a restart file has been requested with the GAMS call.

Options affecting input comment format:			
`comment`	sets the comment character	`offnestcom`	turn off nested comments
`eolcom`	sets end of line comment character	`offtext`	off text mode
`inlinecom`	sets in line comment character	`oneolcom`	turn on end-of-line comments
`maxcol`	sets right hand margin of input file	`oninline`	turn on in-line comments
`mincol`	sets left hand margin of input file	`onmargin`	on margin marking
`offeolcom`	turn off end-of-line comments	`onnestcom`	turn on nested comments
`offinline`	turn off in-line comments	`ontext`	on text – following lines are comments
`offmargin`	turn off margin marking		
Options affecting input data format:			
`dollar`	sets the dollar character	`onempty`	allow empty data initialization statements
`offdigit`	off number precision check	`onend`	allow alternate program control syntax
`offempty`	disallow empty data initialization statements	`oneps`	interpret `eps` as 0
`offend`	disallow alternate program control syntax	`onglobal`	force inheritance of parent file settings
`offeps`	disallow interpretation of `EPS` as 0	`onwarning`	relax domain checking for data
`offglobal`	disallow inheritance of parent file settings	`use205`	Release 2.05 language syntax
`offwarning`	enforce domain checking for data	`use225`	Release 2.25 Version 1 language syntax
`ondigit`	on number precision check	`use999`	latest language syntax
Options affecting output format:			
`double`	double-spaced listing follows	`ondollar`	turns the listing of DCO lines on
`eject`	advance to next page	`oninclude`	include file name echoed to listing file
`hidden`	ignore text and do not list	`onlisting`	input file(s) echoed to listing file
`lines`	next number of lines have to fit on page	`onupper`	following lines will be printed in uppercase
`offdollar`	turns the listing of DCO lines off	`single`	single-spaced listing follows
`offinclude`	turn off listing of include file names	`stars`	sets `****` characters in listing file
`offlisting`	turns off echoing input file(s) to listing file	`stitle`	set subtitle and reset page
`offupper`	following lines will be printed in case as entered	`title`	set title, reset subtitle and page
Options affecting listing of reference maps:			
`offsymlist`	off symbol list	`onsymlist`	on symbol list
`offsymxref`	off symbol cross reference listing	`onsymxref`	on symbol cross reference listing
`offuellist`	off unique element listing	`onuellist`	on unique element listing
`offuelxref`	off unique element cross reference	`onuelxref`	on unique element cross listing
Options affecting program control:			
`abort`	abort compilation	`kill`	kill data connected with identifier
`batinclude`	batch include file	`label`	label name as entry point from `$goto`
`call`	executes program during compilation	`libinclude`	library include file
`clear`	clear data connected with identifier	`onglobal`	turns on global options
`echo`	echo text	`onmulti`	turns on redefinition of data
`error`	generate compilation error	`offglobal`	turns off global options
`exit`	exit from compilation	`offmulti`	turns off redefinition of data
`goto`	go to line with given label name	`phantom`	defines a special set element
`if`	conditional processing	`shift`	DOS shift operation
`include`	include file	`sysinclude`	system include file

DCO $\hat{=}$ Dollar Control Option

Table D.1: Dollar control options

D.3 Detailed Description of Dollar Control Options

This section describes each of the dollar control options in detail. The dollar control options are listed in alphabetical order for easy reference. In each of the following dollar control options, the default value, if available, is bracketed.

abort

This option will issue a compilation error and abort the compilation.

Consider the following example,

```
$if not %system.filesys% == UNIX
$abort We only do UNIX
```

This attempts to stop compilation if the operating system is not Unix. Running the above example on a non-Unix platform results in the compilation being aborted, and the following listing file,

```
   2  $abort We only do UNIX
****       $343

Error Messages
343  Abort triggered by above statement
```

batinclude

The `$batinclude` facility performs the same task as the `$include` facility in that it inserts the contents of the specified text file at the location of the call. In addition, however, it also passes on arguments which can be used inside the include file:

```
$batinclude file arg1 arg2 ...
```

The `$batinclude` option can appear in any place the `$include` option can appear. The name of the batch include file may be quoted or unquoted, while `arg1, arg2,..` are arguments that are passed on to the batch include file. These arguments are treated as character strings that are substituted by number inside the included file. These arguments can be single unbroken strings (quoted or unquoted) or quoted multi-part strings.

The syntax has been modeled after the DOS batch facility. Inside the batch file, a parameter substitution is indicated by using the character `%` followed immediately by an integer value corresponding to the order of parameters on the list where `%1` refers to the first argument, `%2` to the second argument, and so on. If the integer value is specified that does not correspond to a passed parameter, then the parameter flag is substituted with a null string. The parameter flag `%0` is a special case that will substitute a fully expanded file name specification of the current batch included file. The flag `%$` is the current `$` symbol (see `$dollar`). Parameters are substituted independent of context, and the entire line is processed before it is passed to the compiler. The exception to this is that parameter flags appearing in comments are not substituted.

☞ *GAMS requires that processing the substitutions must result in a line of less than or equal to the maximum input line length (currently 255 characters).*

☞ *The case of the passed parameters is preserved for use in string comparisons.*

Consider the following slice of code,

```
$batinclude "file1.inc" abcd "bbbb" "cccc dddd"
```

In this case, `file1.inc` is included with `abcd` as the first parameter, `bbbb` as the second parameter, and `cccc dddd` as the third parameter.

Consider the following slice of code,

```
parameter a,b,c ;
a = 1 ; b = 0 ; c = 2 ;
$batinclude inc2.inc b a
display b ;
$batinclude inc2.inc b c
display b ;
$batinclude inc2.inc b "a+5"
display b ;
```

where `inc2.inc` contains the following line,

```
%1 = sqr(%2) - %2 ;
```

the listing file that results is as follows,

```
 1  parameter a,b,c ;
 2  a = 1 ; b = 0 ; c = 2 ;
BATINCLUDE D:\GAMS\INC2.INC
 4  b = sqr(a) - a ;
 5  display b ;
BATINCLUDE D:\GAMS\INC2.INC
 7  b = sqr(c) - c ;
 8  display b ;
BATINCLUDE D:\GAMS\INC2.INC
 10  b = sqr(a+5) - a+5 ;
 11  display b ;
```

Note that the three calls to `$batinclude` with the various arguments lead to GAMS interpreting the contents of batch include file in turn as

```
b = sqr(a) - a ;
b = sqr(c) - c ;
b = sqr(a+5) - a+5 ;
```

Note that third call is not interpreted as `sqr(a+5)-(a+5)`, but instead as `sqr(a+5)-a+5`. The results of the display statement are shown at the end of the listing file,

```
----      5 PARAMETER B                    =        0.000
----      8 PARAMETER B                    =        2.000
----     11 PARAMETER B                    =       40.000
```

The third call leads to `b = sqr(6)-1+5` which results in `b` taking a value of 40. If the statement in the batch include file was modified to read as follows,

```
%1 = sqr(%2) - (%2) ;
```

the results of the display statement in the listing file would read,

```
----      5 PARAMETER B                    =        0.000
----      8 PARAMETER B                    =        2.000
----     11 PARAMETER B                    =       30.000
```

The third call leads to `b = sqr(6)-6` which results in `b` taking a value of 30.

☞ *A `$batinclude` call without any arguments is equivalent to a `$include` call.*

call

Passes a followed string command to the current operating system command processor and interrupts compilation until the command has been completed. If the command string is empty or omitted, a new interactive command processor will be loaded.

Consider the following slice of code,

```
$call 'dir'
```

This command makes a directory listing on a PC.

The command string can be passed to the system and executed directly without using a command processor by prefixing the command with an '=' sign. Compilation errors are issued if the command or the command processor cannot be loaded and executed properly.

```
$call 'gams trnsport'
$call '=gams trnsport'
```

The first call runs [TRNSPORT] in a new command shell. The DOS command shell does not send any return codes from the run back to GAMS. Therefore any errors in the run are not reported back. The second call, however, sends the command directly to the system. The return codes from the system are intercepted correctly and available to the GAMS system through the errorlevel DOS batch function.

☞ *Some commands (like `copy` on a PC and `cd` in Unix) are shell commands and cannot be spawned off to the system. Using these in a system call will create a compilation error.*

Consider the following slice of code,

```
$call 'copy myfile.txt mycopy.txt'
$call '=copy myfile.txt mycopy.txt'
```

The first call will work on a PC, but the second will not. The copy command can only be used from a command line shell. The system is not aware of this command (Try this command after clicking Run under the Start menu in Windows. You will find that it does not work).

clear

This option resets all data for an identifier to its default values:

```
$clear id1 id2 ...
```

`id1`, `id2`, `...` are the identifiers whose data is being reset. Note that this is carried out during compile time, and not when the GAMS program executes. Not all data types can be cleared - only `set`, `parameter`, `equation` and `variable` types can be reset.

Consider the following example,

```
set i /1*20/ ; scalar a /2/ ;
$clear i a
display i, a ;
```

The `$clear` option resets `i` and `a` to their default values. The result of the display statement in the listing file shows that `i` is now an empty set, and `a` takes a value of 0.

```
----      3 SET       I
                      (EMPTY)
----      3 PARAMETER A                    =        0.000
```

☞ *The two-pass processing of a GAMS file can lead to seemingly unexpected results. Both the dollar control options and the data initialization is done in the first pass, and assignments in the second, irrespective of their relative locations. This is an issue particularly with `$clear` since data can be both initialized and assigned.*

Consider the following example,

```
scalar a /12/ ;
a=5;
$clear a
display a ;
```

The scalar data initialization statement is processed during compilation and the assignment statement `a=5` during execution. In the order that it is processed, the example above is read by GAMS as,

```
* compilation step
scalar a /12/ ;
$clear a
* execution step
a=5;
display a ;
```

The example results in a taking a value of 5. The display statement in the resulting listing file is as follows,

```
----      4 PARAMETER A                    =        5.000
```

comment `(*)`

This option changes the start-of-line comment to a single character which follows immediately th `command` keyword. This should be used with great care, and one should reset it quickly to the default symbol `*`.

☞ *The case of the start-of-line comment character does not matter when being used.*

Consider the following example,

```
$comment c
c now we use a FORTRAN style comment symbol
C case doesn't matter
$comment *
* now we are back how it should be
```

dollar `($)`

This option changes the current `$` symbol to a single character which follows immediately the `$dollar` keyword. When the include file is inserted, all dollar control options are inherited, and the current `$` symbol may not be known. The special `%$` substitution symbol can be used to get the correct symbol (see `$batinclude`).

Consider the following example,

```
$dollar #
#hidden now we can use # as the '$' symbol
```

double

The lines following the `$double` statement will be echoed double spaced to the listing file.

Consider the following example,

```
set i /1*2/ ;
scalar a /1/ ;
$double
set j /10*15/ ;
scalar b /2/ ;
```

The resulting listing file looks as follows,

```
   1  set i /1*2/ ;
   2  scalar a /1/ ;

   4  set j /10*15/ ;

   5  scalar b /2/ ;
```

Note that lines before the `$double` option are listed singly spaced, while the lines after the option are listed with double space.

echo

The `echo` option allows to write text to a file:

```
$echo  'text' > file
$echo  'text' >> file
```

These options send the message '`text`' to the file `file`. Both the text and the file name can be quoted or unquoted. The file name is expanded using the working directory. The `$echo` statement tries to minimize file operations by keeping the file open in anticipation of another `$echo` to be appended to the same file. The file will be closed at the end of the compilation or when a `$call` or any kind of `$include` statement is encountered. The redirection symbols `>` and `>>` have the usual meaning of starting at the beginning or appending to an existing file.

Consider the following example,

```
$echo                                                 > echo
$echo  The message written goes from the first non blank  >> echo
$echo 'to the first > or >> symbol unless the text is'    >> echo
$echo "is quoted. The Listing File is %gams.input%. The"  >> echo
$echo 'file name "echo" will be completed with'           >> echo
$echo  %gams.workdir%.                                    >> echo
$echo                                                     >> echo
```

The contents of the resulting file echo are as follows,

```
The message written goes from the first non blank
to the first > or >> symbol unless the text is
is quoted. The Listing File is C:\PROGRAM FILES\GAMSIDE\CC.GMS. The
file name "echo" will be completed with
C:\PROGRAM FILES\GAMSIDE\.
```

eject

Advances the output to the next page.

Consider the following example,

```
$eject
Set i,j ;
Parameter data(i,j) ;
$eject
```

This will force the statements between the two `$eject` calls to be reported on a separated page in the listing file.

eolcom `(!!)`

This option redefines the end-of-line comment symbol, which can be a one or two character sequence. By default the system is initialized to '`!!`' but not active. The `$oneolcom` option is used to activate the end-of-line comment. The `$eolcom` option sets `$oneolcom` automatically.

Consider the following example,

```
$eolcom ->
set i /1*2/ ;     -> set declaration
parameter a(i) ;  -> parameter declaration
```

The character set `->` serves as the end-of-line-comment indicator.

☞ *GAMS requires that one not reset the `$eolcom` option to the existing symbol.*

The following code is illegal since `$eolcom` is being reset to the same symbol as it is currently,

```
$eolcom ->
$eolcom ->
```

error

This option will issue a compilation error and will continue with the next line.

Consider the following example,

```
$if not exist myfile
$error File myfile not found - will continue anyway
```

This checks if the file `myfile` exists, and if not, it will generate an error with the comment '`File not found - will continue anyway`', and then compilation continues with the following line.

exit

This option will cause the compiler to exit (stop reading) from the current file. This is equivalent to having reached the end of file.

Consider the following example,

```
scalar a ; a = 5 ;
display a ;
$exit end
a = a+5 ; display a ;
```

The lines following the `$exit` will not be compiled.

goto `id`

This option will cause GAMS to search for a line starting with '`$label id`' and then continue reading from there. This option can be used to skip over or repeat sections of the input files. In batch include files, the target labels or label arguments can be passed as parameters because of the manner in which parameter substitution occurs in such files. In order to avoid infinite loops, one can only jump a maximum of 100 times to the same label.

Consider the following example,

```
scalar a ; a = 5;
display a ;
$goto next
a = a+5 ; display a ;
$label next
a = a+10 ; display a ;
```

On reaching the `$goto next` option, GAMS continues from `$label next`. All lines in between are ignored. On running the example, `a` finally takes a value of 15.

☞ *The `$goto` and `$label` have to be in the same file. If the target label is not found in the current file, and error is issued.*

hidden

This line will be ignored and will not be echoed to the listing file. This option is used to enter information only relevant to the person manipulating the file.

Consider the following example,

```
$hidden You need to edit the following lines if you want to:
$hidden
$hidden     1. Change form a to b
$hidden     2. Expand the set
```

The lines above serve as comments to the person who wrote the file. However, these comments will not be visible in the listing file, and is therefore hidden from view.

if

The `$if` dollar control option provides the greatest amount of control over conditional processing of the input file(s). The syntax is similar to the `IF` statement of the DOS Batch language:

```
$if [not] {exist filename | string1 == string2} new_input_line
```

The syntax allows for negating the conditional with a `not` operator followed either of two types of conditional expressions: a file operation or a string comparison. The result of the conditional test is used to determine whether to read the remainder of the line, which can be any valid GAMS, input line.

The `exist` file operator can be used to check for the existence of the given file name specification. The string compare consists of two strings (quoted or unquoted) for which the comparison result is true only if the strings match exactly. Null (empty) strings can be indicated by an empty quote: `""`

☞ *The case of the strings provided either explicitly or, more likely, through a parameter substitution, is preserved and therefore will effect the string comparison.*

☞ *Quoted strings with leading and trailing blanks are not* trimmed *and the blanks are considered part of the string.*

☞ *If the string to be compared is a possibly empty parameter, the parameter operator must be quoted.*

`New_input_line` is the remainder of the line containing the `$if` option, and could be any valid GAMS input line.

☞ *The first non-blank character on the line following the conditional expression is considered to be the first column position of the GAMS input line. Therefore, if the first character encountered is a comment character the rest of the line is treated as a comment line. Likewise if the first character encountered is the dollar control character, the line is treated as a dollar control line.*

An alternative to placing `new_input_line` on the same line as the conditional is to leave the remainder of the line blank and place `new_input_line` on the line immediately following the `if` line. If the conditional is found to be false, either the remainder of the line (if any) is skipped or the next line is not read.

Consider the following example,

```
$if exist myfile.dat $include myfile.dat
```

The statement above includes the file `myfile.dat` if the file exists. Note that the `$` character at the beginning of the `$include` option is the first non-blank character after the conditional expression, `if exist myfile.dat` and is therefore treated as the first column position. The above statement can also be written as

```
$if exist myfile.dat
$include myfile.dat
```

Consider the following additional examples,

```
$if not "%1a" == a $goto labelname
$if not exist "%1" display "file %1 not found" ;
```

The first statement illustrates the use of the `$if` option inside a batch include file where parameters are passed through the `$batinclude` call from the parent file. The `$if` condition checks if the parameter is empty, and if not processes the `$goto` option. Note that the string comparison attempted, `"%1a" == a`, can also be done using `%1 == ""`.

The second statement illustrates using standard GAMS statements if the conditional is valid. If the file name passed as a parameter through the `$batinclude` call does not exist, the GAMS display statement is processed.

☞ *In line and end of line comments are stripped out of the input file before processing for `new_input_line`. If either of these forms of comments appears, it will be treated as blanks.*

Consider the following example,

```
parameter a ; a=10 ;
$eolcom ! inlinecom /*  */
$if exist myfile.dat
/* in line comments */   ! end of line comments
a = 4 ;
display a;
```

The fourth line is ignored, and the fifth line involving an assignment setting `a` to 4 will be treated as the result of the conditional. So the result of the display statement would be the listing of a with a value of 4 if the file `myfile.dat` exists, and a value of 10 if the file does not exist.

☞ *It is suggested that a `$label` not appear as part of the conditional input line. The result is that if the `$label` appears on the `$if` line, a `$goto` to this label will re-scan the entire line thus causing a reevaluation of the conditional expression. On the other hand, if the `$label` appears on the next line, the condition will not be reevaluated on subsequent gotos to the label.*

The following example illustrates how an unknown number of file specifications can be passed on to a batch include file that will include each of them if they exist. The batch include file could look as follows,

```
/* Batch Include File - inclproc.bch */
/* Process and INCLUDE an unknown number of input files */
$label nextfile
$if "%1a" == a  $goto end
$if exist "%1"  $include "%1"    /* name might have blanks */
$shift  goto nextfile
$label end
```

The call to this file in the parent file could look like:

```
$batinclude inclproc.bch  fil1.inc  fil2.inc  fil3.inc fil4.inc
```

include

The `$include` option inserts the contents of a specified text file at the location of the call. The name of the file to be included which follows immediately the keyword `include` may be quoted or unquoted. Include files can be nested.

The include file names are processed in the same way as the input file is handled. The names are expanded using the working directory. If the file cannot be found and no extension is given, the standard GAMS input extension is tried. However, if an incomplete path is given, the file name is completed using the include directory. By default, the library include directory is set to the working directory. The default directory can be reset with the `idir` command line parameter.

The start of the include file is marked in the compiler listing. This reference to the include file can be omitted by using the `$offinclude` option.

The following example illustrates the use of an include statement,

```
$include myfile
$include "myfile"
```

Both statements above are equivalent, and the search order for the include file is as follows:

1. `myfile` in current working directory
2. `myfile.gms` in current working directory
3. `myfile` and `myfile.gms` (in that order) in directories specified by `idir` parameter.

☞ *The current settings of the dollar control options are passed on to the lower level include files. However, the dollar control options set in the lower level include file are passed on to the parent file only if the `$onglobal` option is set.*

Compiler errors in include files have additional information about the name of the include file and the local line number.

At the end of the compiler listing, an include file summary shows the context and type of include files. The line number where an include file has been called is given. For example, in the *Include File Summary* below we see that:

```
SEQ   GLOBAL TYPE      PARENT   LOCAL   FILENAME

1          1 INPUT          0       0   C:\TEST\TEST1.GMS
2          1 INCLUDE        1       1  .C:\TEST\FILE1.INC
3          6 INCLUDE        1       4  .C:\TEST\FILE2.INC
```

The first column named `SEQ` gives the sequence number of the input files encountered. The first row always refers the parent file called by the GAMS call. The second column named `GLOBAL` gives the global (expanded) line number which contained the `$include` statement. The third column named `TYPE` refers to the type of file being referenced. The various types of files are `INPUT`, `INCLUDE`, `BATINCLUDE`, `LIBINCLUDE`, and `SYSINCLUDE`. The fourth column named `PARENT` provides the sequence number of the parent file for the file being referenced. The fifth column named `LOCAL` gives the local line number in the parent file where the `$include` appeared. In the example listed above, the include files `file1.inc` and `file2.inc` were included on lines 1 and 4 of the parent file `test1.gms`.

inlinecom `(/* */)`

This option redefines the in-line comment symbols, which are a pair of one or two character sequence. By default, the system is initialized to `/*` and `*/`, but is not active. The `$oninline` option is used to activate the in-line comments. The `$inlinecom` option sets the `$oninline` automatically.

Consider the following example,

```
$inlinecom {{ }}
set {{ this is an inline comment }} i /1*2/ ;
```

The character pair {{ }} serves as the indicator for in-line comments.

☞ *GAMS requires that one not reset the `$inlinecom` option to an existing symbol.*

The following code is illegal since `$inlinecom` is being reset to the same symbol as it is currently,

```
$inlinecom {{  }}
$inlinecom {{  }}
```

☞ *The `$onnestcom` enables the use of nested comments.*

kill

Removes all data for an identifier and resets the identifier, only the type and dimension are retained. Note that this is carried out during *compile time*, and not when the GAMS program executes. Not all data types can be killed - only `set`, `parameter`, `equation` and `variable` types can be reset.

Consider the following example,

```
set i / 1*20 /; scalar a /2/
$kill i a
```

Note that this is different from `$clear` in that after setting `$kill`, `i` and `a` are treated as though they have been only defined and have not been initialized or assigned. The result of the `$kill` statement above is equivalent to `i` and `a` being defined as follows,

```
set i ; scalar a ;
```

Unlike the `$clear`, a `display` statement for `i` and `a` after they are killed will trigger an error.

label `id`

This option marks a line to be jumped to by a `$goto` statement. Any number of labels can be used in files and not all of them need to be referenced. Re-declaration of a label identifier will not generate an error, and only the first occurrence encountered by the GAMS compiler will be used for future `$goto` references.

Consider the following example,

```
scalar a ; a = 5 ;
display a ;
$goto next
a = a+5 ; display a ;
$label next
a = a+10 ; display a ;
```

On reaching the `$goto next` option, GAMS continues from `$label next`. All lines in between are ignored. On running the example, a finally takes a value of 15.

☞ *The `$label` statement has to be the first dollar control option of multiple dollar control options that appear on the same line.*

libinclude

Equivalent to `$batinclude`:

```
$libinclude file arg1 arg2 ...
```

However, if an incomplete path is given, the file name is completed using the library include directory. By default, the library include directory is set to the `inclib` directory in the GAMS system directory. The default directory can be reset with the `ldir` command line parameter.

Consider the following example,

```
$libinclude abc x y
```

This call first looks for the include file `[GAMS System Directory]/inclib/abc`, and if this file does not exist, GAMS looks for the file `[GAMS System Directory]/inclib/abc.gms`. The arguments `x` and `y` are passed on to the include file to interpret as explained for the `$batinclude` option.

Consider the following example,

```
$libinclude c:\abc\myinc.inc x y
```

This call first looks specifically for the include file `c:\abc\myfile.inc`. The arguments `x` and `y` are passed on to the include file to interpret as explained for the `$batinclude` option.

lines n

This option starts a new page in the listing file if less than `n` lines are available on the current page.

Consider the following example,

```
$hidden Never split the first few lines of the following table
$lines 5
table io(i,j) Transaction matrix
```

This will ensure that the if there are less than five lines available on the current page in the listing file before the next statement (in this case, the table statement) is echoed to it, the contents of this statement are echoed to a new page.

log

This option will send a message to the log file. By default, the log file is the console. The default log file can be reset with the `lo` and `lf` command line parameters.

☞ *Leading blanks are ignored when the text is written out to the log file using the `$log` option.*

☞ *All special % symbols will be substituted out before the text passed through the `$log` option is sent to the log file.*

Consider the following example,

```
$log
$log       The following message will be written to the log file
$log  with leading blanks ignored. All special % symbols will
$log  be substituted out before this text is sent to the log file.
$log  This was line %system.incline% of file %system.incname%
$log
```

The log file that results by running the lines above looks as follows,

```
--- Starting compilation
--- CC.GMS(0) 138 Kb

The following message will be written to the log file
with leading blanks ignored. All special % symbols will
be substituted out before this text is sent to the log file.
This was line 5 of file C:\PROGRAM FILES\GAMSIDE\CC.GMS

--- CC.GMS(7) 138 Kb
--- Starting execution - empty program
*** Status: Normal completion
```

Note that `%system.incline%` has been replaced by 5 which is the line number where the string replacement was requested. Also note that `%system.incname%` has been substituted by the name of the file completed with the absolute path. Also note that the leading blanks on the second line of the example are ignored.

maxcol n (255)

Sets the right margin for the input file. All valid data is before and including column `n` in the input file. All text after column `n` is treated as comment and ignored.

Consider the following example,

```
$maxcol 30
set i /vienna, rome/          set definition
scalar a /2.3/ ;              scalar definition
```

The text strings '`set definition`' and '`scalar definition`' are treated as comments and ignored since they begin on or after column 31.

Any changes in the margins via `maxcol` or `mincol` will be reported in the listing file with the message that gives the valid range of input columns. For example, the dollar control option `$mincol 20 maxcol 110` will trigger the message:

```
NEW MARGIN = 20-110
```

☞ *GAMS requires that the right margin set by `$maxcol` is greater than 15.*

☞ *GAMS requires that the right margin set by `$maxcol` is greater than the left margin set by `$mincol`.*

mincol `n (1)`

Sets the left margin for the input file. All valid data is after and including column `n` in the input file. All text before column `n` is treated as comment and ignored.

Consider the following example,

```
$mincol 30
set definition              set i /vienna, rome/
scalar definition           scalar a /2.3/ ;
```

The text strings '`set definition`' and '`scalar definition`' are treated as comments and ignored since they begin before column 30.

Any changes in the margins via `maxcol` or `mincol` will be reported in the listing file with the message that gives the valid range of input columns. For example, the dollar control option `$mincol 20 maxcol 110` will trigger the message:

```
NEW MARGIN = 20-110
```

☞ *GAMS requires that the left margin set by `$mincol` is smaller than the right margin set by `$maxcol`.*

[on|off]digit `($ondigit)`

Controls the precision check on numbers. Computers work with different internal precision. Sometimes a GAMS problem has to be moved from a machine with higher precision to one with lower precision. Instead of changing numbers with too much precision the `$offdigit` tells GAMS to use as much precision as possible and ignore the rest of the number. If the stated precision of a number exceeds the machine precision an error will be reported. For most machines, the precision is 16 digits.

Consider running the following slice of code,

```
parameter y(*)   / toolarge 12345678901234.5678
$offdigit
                   ignored  12345678901234.5678  /
```

The resulting listing file contains,

```
    1  parameter y(*)   / toolarge 12345678901234.5678
****                                             $103
    3                     ignored  12345678901234.5678  /
Error Messages
103  Too many digits in number
     ($offdigit can be used to ignore trailing digits)
```

Note that the error occurs in the 17th significant digit of `y("toolarge")`. However, after the `$offdigit` line, y("ignored") is accepted without any errors even though there are more than 16 significant digits.

[on|off]dollar `($offdollar)`

This option controls the echoing of dollar control option lines in the listing file.

Consider running the following slice of code,

```
$hidden this line will not be displayed
$ondollar
$hidden this line will be displayed
$offdollar
$hidden this line will not be displayed
```

The listing file that results looks like,

```
2  $ondollar
3  $hidden this line will be displayed
```

Note that all lines between the `$ondollar` and `$offdollar` are echoed in the listing file. Also note that this action of this option is immediate, i.e. the `$ondollar` line is itself echoed on the listing file, while the `$offdollar` line is not.

[on|off]empty `($offempty)`

This option allows empty data statements for list or table formats. By default, data statements cannot be empty.

Consider running the following slice of code,

```
set i /1,2,3/ ;
set j(i) /  / ;
parameter x(i) empty parameter /  / ;
table y(i,i) headers only
     1   2   3
;
$onempty
set k(i) /  / ;
parameter xx(i) empty parameter /  / ;
table yy(i,i)
     1   2   3
;
```

The listing file that results looks like,

```
    1  set i /1,2,3/ ;
    2  set j(i) /  / ;
****              $460
    3  parameter x(i) empty parameter /  / ;
****                                    $460
    4  table y(i,i) headers only
    5       1   2   3
    6  ;
****   $462
    8  set k(i) /  / ;
    9  parameter xx(i) empty parameter /  / ;
   10  table yy(i,i)
   11       1   2   3
   12  ;

Error Messages

460  Empty data statements not allowed. You may want to use $ON/OFFEMPTY
462  The row section in the previous table is missing
```

Note that empty data statements are not allowed for `sets`, `parameters` or `tables`. These are most likely to occur when data is being entered into the GAMS model by an external program. Using the `$onempty` dollar control option allows one to overcome this problem.

☞ *The empty data statement can only be used with symbols, which have a known dimension. If the dimension is also derived from the data, the* `$phantom` *dollar control option should be used to generate* 'phantom' *set elements.*

[on|off]end (`$offend`)

Offers alternative syntax for flow control statements. `Endloop`, `endif`, `endfor`, and `endwhile` are introduced as key-words with the use of the `$onend` option that then serves the purpose of closing the `loop`, `if`, `for`, and `while` language constructs respectively.

The following example provides the alternate syntax for the four language constructs mentioned above (standard syntax as `eolcomment`).

```
set i/1*3/ ; scalar cond /0/;
parameter a(i)/1 1.23, 2 2.65, 3 1.34/;
$maxcol 40
$onend
loop i do                                 loop (i,
  display a;                                display a;
endloop;                                  );

if (cond) then                            if (cond,
  display a;                                display a;
else                                      else
  a(i) = a(i)/2;                            a(i) = a(i)/2;
  display a;                                display a;
endif;                                    );

for cond = 1 to 5 do                      for (cond = 1 to 5,
  a(i) = 2 * a(i);                          a(i) = 2 * a(i);
endfor;                                   );

while cond < 2 do                         while (cond < 2,
   a(i) = a(i) / 2;                          a(i) = a(i) / 2;
 endwhile;                                 );
```

Note that the alternate syntax is more in line with syntax used in some of the popular programming languages.

☞ *Both forms of the syntax will never be valid simultaneously. Setting the* `$onend` *option will make the alternate syntax valid, but makes the standard syntax invalid.*

[on|off]eolcom ($offeolcom)

Switch to control the use of end-of-line comments. By default, the end-of-line comments are set to '`!!`' but the processing is disabled.

Consider running the following slice of code,

```
$oneolcom
set i /1*2/ ;     !! set declaration
parameter a(i) ;  !! parameter declaration
```

Note that comments can now be entered on the same line as GAMS code.

☞ *`$eolcom` automatically sets `$oneolcom`.*

Consider the following example,

```
$eolcom ->
set i /1*2/ ;     -> set declaration
parameter a(i) ;  -> parameter declaration
```

The character set `->` serves as the end-of-line-comment indicator.

[on|off]eps ($offeps)

This option is used to treat a zero as an `EPS` in a parameter or table data statement. This can be useful if one overloads the value zero with existence interpolation.

Consider running the following slice of code,

```
set i/one,two,three,four/ ;
parameter a(i) /
$oneps
      one     0
$offeps
      two     0
      three   EPS   /;
display a ;
```

The result of the display statement in the listing file is as follows,

```
----      8 PARAMETER A

one   EPS,    three EPS
```

Note that only those entries specifically entered as 0 are treated as `EPS`.

[on|off]global ($offglobal)

When an include file is inserted, it inherits the dollar control options from the higher level file. However, the dollar control option settings specified in the include file do not affect the higher level file. This convention is common among most scripting languages or command processing shells. In some cases, it may be desirable to break this convention. This option allows an include file to change options of the parent file as well.

Consider running the following slice of code,

```
$include 'inc.inc'
$hidden after first call to include file
$onglobal
$include 'inc.inc'
$hidden after second call to include file
```

where the file `inc.inc` contains the lines,

```
$ondollar
$hidden text inside include file
```

The resulting listing file is as follows,

```
INCLUDE    D:\GAMS\INC.INC
    2  $ondollar
    3  $hidden text inside include file
INCLUDE    D:\GAMS\INC.INC
    7  $ondollar
    8  $hidden text inside include file
    9  $hidden after second call to include file
```

Note that the effect of the `$ondollar` dollar control option inside the include file does not affect the parent file until `$onglobal` is turned on. The `$hidden` text is then echoed to the listing file.

[on|off]include (`$oninclude`)

Controls the listing of the expanded include file name in the listing file.

Consider running the following slice of code,

```
$include 'inc.inc'
$offinclude
$include 'inc.inc'
```

where the file inc.inc contains the line,

```
$ondollar
$hidden text inside include file
```

The resulting listing file is as follows,

```
INCLUDE    D:\GAMS\INC.INC
   2  $ondollar
   3  $hidden text inside include file
   6  $ondollar
   7  $hidden text inside include file
```

Note that the include file name is echoed the first time the include file is used. However, the include file name is not echoed after `$offinclude` is set.

[on|off]inline (`$offinline`)

Switch to control the use of in-line comments. By default, the in-line comments are set to the two character pairs '`/*`' and '`*/`' but the processing is disabled. These comments can span lines till the end-of-comment characters are encountered.

Consider running the following slice of code,

```
$oninline
/* the default comment symbols are now
   active. These comments can continue
   to additional lines till the closing
   comments are found  */
```

☞ *`$inlinecom` automatically sets `$oninline`.*

Consider running the following slice of code,

```
$inlinecom << >>
<< the in-line comment characters have been
   changed from the default. >>
```

☞ *Nested in-line comments are illegal unless `$onnestcom` is set.*

[on|off]listing (`$onlisting`)

Controls the echoing of input lines to the listing file. Note that suppressed input lines do not generate entries in the symbol and reference sections appearing at the end of the compilation listing. Lines with errors will always be listed.

Consider running the following slice of code,

```
set i /0234*0237/
    j /a,b,c/     ;
table x(i,j) very long table
        a   b   c
 0234   1   2   3
$offlisting
 0235   4   5   6
 0236   5   6   7
$onlisting
 0237   1   1   1
```

The resulting listing file looks as follows,

```
      1  set i /0234*0237/
      2      j /a,b,c/     ;
      3  table x(i,j) very long table
      4          a   b   c
      5   0234   1   2   3
     10   0237   1   1   1
```

Note that the lines in the source file between the `$offlisting` and `$onlisting` settings are not echoed to the listing file.

[on|off]margin (`$offmargin`)

Controls the margin marking. The margins are set with `$mincol` and `$maxcol`.

Consider running the following slice of code,

```
$onmargin mincol 20 maxcol 45
Now we have         set i plant /US, UK/     This defines I
turned on the       scalar x / 3.145 /       A scalar example.
margin marking.     parameter a, b;          Define some
                                             parameters.
$offmargin
```

Any statements between columns 1 and 19, and anything beyond column 45 are treated as comments.

[on|off]multi (`$offmulti`)

Controls multiple data statements or tables. By default, GAMS does not allow data statements to be redefined. If this option is enabled, the second or subsequent data statements are merged with entries of the previous ones. Note that all multiple data statements are executed before any other statement is executed.

Consider running the following slice of code,

```
$eolcom !
set i / 1*10 /;
parameter x(i) / 1*3  1 /   ! 1=1,2=1,3=1
$onmulti
parameter x(i) / 7*9  2 /   ! 1=1,2=1,3=1,7=2,8=2,9=2
parameter x(i) / 2*6  3 /   ! 1=1,2=3,3=3,4=3,5=3,6=3,7=2,8=2,9=2
parameter x(i) / 3*5  0 /   ! 1=1,2=3,6=3,7=2,8=2,9=2
display x;
```

This would have been illegal without the presence of the `$onmulti` option. The result of the display statement in the listing file is as follows,

```
----      8 PARAMETER X

1 1.000,    2 3.000,    6 3.000,    7 2.000,    8 2.000,    9 2.000
```

Note that `x("1")` has a value of 1 after the first data statement since none of the subsequent data statements affect it. `x("2")` on the other hand is reset to 3 by the third data statement.

☞ *The two-pass processing of a GAMS file can lead to seemingly unexpected results. Both the dollar control options and the data initialization is done in the first pass, and assignments in the second, irrespective of their relative locations. This is an issue particularly with `$onmulti` since it allows data initializations to be performed more than once.*

Consider the following example,

```
scalar a /12/ ;
a=a+1;
$onmulti
scalar a /20/ ;
display a ;
```

The two `scalar` data initialization statements and the `$onmulti` option are processed before the assignment statement `a=a+1`. In the order that it is processed, the example above is read by GAMS as,

```
* compilation step
scalar a /12/ ;
$onmulti
scalar a /20/ ;
* execution step
a=a+1;
display a ;
```

The example results in a taking a value of 21. The display statement in the resulting listing file is as follows,

```
----      5 PARAMETER A                    =       21.000
```

[on|off]nestcom `($offnestcom)`

Controls nested in-line comments. Make sure that the open-comment and close-comment characters have to match.

Consider running the following slice of code,

```
$inlinecom { } onnestcom
{ nesting is now possible in comments { braces
  have to match } }
```

[on|off]symlist `($offsymlist)`

Controls the complete listing of all symbols that have been defined and their text, including pre-defined functions and symbols, in alphabetical order grouped by symbol type.

The symbol listing in the listing file generated by running [TRNSPORT] with `$onsymlist` is as follows,

```
Symbol Listing

FUNCTIONS
**********
ABS
ARCTAN
CEIL


SETS
I           canning plants
J           markets

PARAMETERS
A           capacity of plant i in cases
B           demand at market j in cases
C           transport cost in thousands of dollars per case
D           distance in thousands of miles
F           freight in dollars per case per thousand miles

VARIABLES
X           shipment quantities in cases
Z           total transportation costs in thousands of dollars

EQUATIONS
COST        define objective function
DEMAND      satisfy demand at market j
SUPPLY      observe supply limit at plant i

MODELS
TRANSPORT

FILES
FILE        Current file name for FILE.xxx use

PREDEFINED
DIAG
SAMEAS
```

This serves as a simple description of the symbols used in a model, and can be used in reports and other documentation.

[on|off]symxref `($onsymxref)`

This option controls the following,

- ➢ Collection of cross references for identifiers like sets, parameters, and variables.
- ➢ Cross-reference report of all collected symbols in listing file
- ➢ Listing of all referenced symbols and their explanatory text by symbol type in listing file. This is also reported by using `$onsymlist`.

Consider the following slice of code,

```
$offsymxref
set j(i) will not show / 1*3 /
display i;
$onsymxref
k('1') = yes;
```

The resulting listing file will contain the following symbol reference reports,

```
SYMBOL      TYPE   REFERENCES
I           SET    DECLARED      1  DEFINED      1      REF      1
K           SET    DECLARED      1  ASSIGNED     6
SETS
I           this is set declaration
K           some more
```

[on|off]text

The `$ontext` - `$offtext` pair encloses comment lines. Line numbers in the compiler listing are suppressed to mark skipped lines.

Consider the following,

```
* standard comment line
$ontext
Everything here is a comment
until we encounter the closing $offtext
like the one below
$offtext
* another standard comment line
```

The resulting listing file is as follows,

```
    1  * standard comment line
       Everything here is a comment
       until we encounter the closing $offtext
       like the one below
    7  * another standard comment line
```

☞ *GAMS requires that every `$ontext` has a matching `$offtext`, and vice versa.*

[on|off]uellist   (`$offuellist`)

This option controls the complete listing of all set elements that have been entered, in the listing file.

The unique element listing in the listing file generated by running [TRNSPORT] with `$onuellist` is as follows,

```
Unique Element Listing

Unique Elements in Entry Order
    1   SEATTLE     SAN-DIEGO   NEW-YORK    CHICAGO     TOPEKA
Unique Elements in Sorted Order
1   CHICAGO     NEW-YORK    SAN-DIEGO   SEATTLE     TOPEKA
```

Note that the sorted order is not the same as the entry order. This is explained in Section 12.2.

[on|off]uelxref   (`$offuelxref`)

This option controls the collection and listing (in the listing file) of cross references of set elements.

Consider the following slice of code,

```
$onuelxref
set i this is set declaration / one, two, three /, k(i)
$offuelxref
set j(i) will not show / two /;
$onuelxref
k('one') = yes;
```

The resulting listing file will contain the following unique element reference reports,

```
ELEMENT           REFERENCES
ONE          DECLARED        2    INDEX        6
THREE        DECLARED        2
TWO          DECLARED        2
```

[on|off]upper   (`$offupper`)

This option controls the upper casing of input lines when echoed to the listing file.

Consider the following slice of code,

```
$onupper
* now we list everything in upper case
$offupper
* now we are back to list lines as entered
```

The resulting listing file is as follows,

```
   2  * NOW WE LIST EVERYTHING IN UPPER CASE
   4  * now we are back to list lines as entered
```

Note that all the characters in the lines between `$onupper` and `$offupper` are capitalized.

[on|off]warning (`$offwarning`)

Switch for data domain checking. In some cases it may be useful to accept domain errors in data statements that are imported from other systems and report warnings instead of errors. Data will be accepted and stored, even though it is outside the domain.

☞ *This switch affects three types of domain errors usually referred to as error numbers 116, 170 and 171.*

☞ *This can have serious side affects and one has to exercise great care when using this feature.*

Consider the following slice of code,

```
set i    / one,two,three /
$onwarning
    j(i) / four, five /;
parameter x(i) Messed up Data /  one 1.0,  five 2.0 /;
x('six') = 6;  x(j) = 10;  x('two') = x('seven');
$offwarning
display i,j,x;
```

Note that the set `j`, although specified as a subset of `i`, contains elements not belonging to its domain. Similarly, the parameter `x` contains data elements outside its domain. The skeleton listing file that results from running this code is as follows,

```
    1  set i    / one,two,three /
    3      j(i) / four, five /;
****                 $170  $170
    4  parameter x(i) Messed up Data /  one 1.0,  five 2.0 /;
****                                                $170
    5  x('six') = 6;  x(j) = 10;  x('two') = x('seven');
****         $170                               $116,170
    7  display i,j,x;

 Error Messages
116  Label is unknown
170  Domain violation for element
**** 0 ERROR(S)   6 WARNING(S)

E x e c u t i o n

----      7 SET       I
one  ,    two  ,    three

----      7 SET       J
four,    five

----      7 PARAMETER X             Messed up Data
one   1.000,    four 10.000,    five 10.000,    six   6.000
```

The domain violations are marked like normal compilation errors but are only treated as warnings and one can execute the code.

phantom `id`

Used to designate `id` as a phantom set element. Syntactically, a phantom element is handled like any other set element. Semantically, however, it is handled like it does not exist. This is sometimes used to specify a data template that initializes the phantom records to default values.

Consider the following example,

```
$phantom null
set i / null/
    j / a,b,null/ ;
display i,j ;
```

The resulting section of the listing file is shown below,

```
----      4 SET       I
                      (EMPTY)

----      4 SET       J
a,    b
```

Note that null does not appear in the listing file.

☞ *Assignment statements on the phantom label are ignored.*

Consider the following extension to the previous example,

```
Parameter p(j) / a 1, null 23 / ;
display p ;
```

The resulting section of the listing file is shown below,

```
----      6 PARAMETER P

a 1.000
```

shift

The `$shift` option is similar to the DOS batch shift operator. It shifts the order of all parameters passed once to the '*left*'. This effectively drops the lowest numbered parameter in the list.

Consider the following example,

```
scalar a, b, c ; a = 1 ;
$batinclude inc.inc a b c
display a, b, c ;
```

where the batch include file `inc.inc` is as follows,

```
%2 = %1 + 1 ;
$shift
%2 = %1 + 1 ;
```

The resulting listing file is,

```
    1  scalar a, b, c ; a = 1 ;
BATINCLUDE C:\PROGRAM FILES\GAMSIDE\INC.INC
    3  b = a + 1 ;
    5  c = b + 1 ;
    6  display a, b, c ;
```

In the first statement in the include file, `%1` is the first argument in the `$batinclude` call and is interpreted in this case as `a`. `%2` is the second argument in the `$batinclude` call and is interpreted as `b`. This leads to the overall assignment being interpreted as `b=a+1`.

The `$shift` option shifts the arguments to the left. So now, `%1` is interpreted as `b`, and `%2` is interpreted as `c`. This leads to the second assignment being interpreted as `c=b+1`.

The result of the display statement in the input file is therefore,

```
----      6 PARAMETER A                  =        1.000
            PARAMETER B                  =        2.000
            PARAMETER C                  =        3.000
```

single

The lines following a `$single` option will be echoed single spaced on the compiler listing. This option is the default, and is only useful as a switch to turn off the `$double` option.

Consider the following example,

```
set i /1*2/ ;
scalar a /1/ ;
$double
set j /10*15/ ;
scalar b /2/ ;
$single
set k /5*10/ ;
scalar c /3/ ;
```

The resulting listing file looks as follows,

```
     1  set i /1*2/ ;
     2  scalar a /1/ ;

     4  set j /10*15/ ;

     5  scalar b /2/ ;
     7  set k /5*10/ ;
     8  scalar c /3/ ;
```

Note that lines between the `$double` and `$single` options are listed double spaced, while the lines after the `$single` option revert back to being listed singly spaced.

stars (`****`)

This option is used to redefine the '`****`' marker in the GAMS listing file. By default, important lines like those denote errors, and the solver/model status are prefixed with '`****`'.

Consider the following example,

```
$stars ####
garbage
```

The resulting listing file looks as follows,

```
     2  garbage
####         $140
####  $36,299  UNEXPECTED END OF FILE (1)

Error Messages
 36  '=' or '..' or ':=' or '$=' operator expected
     rest of statement ignored
140  Unknown symbol
299  Unexpected end of file
```

stitle

This option sets the subtitle in the page header of the listing file to '`text`' which follows immediately the keyword `stitle`. The next output line will appear on a new page in the listing file.

Consider the following example,

```
$stitle data tables for input/output
```

sysinclude

Equivalent to `$batinclude`:

```
$sysinclude file arg1 arg2 ...
```

However, if an incomplete path is given, the file name is completed using the system include directory. By default, the system include directory is set to the GAMS system directory. The default directory can be reset with the `sdir` command line parameter.

Consider the following example,

```
$sysinclude abc x y
```

This call first looks for the include file `[GAMS System Directory]/abc`, and if this file does not exist, looks for `[GAMS System Directory]/abc.gms`. The arguments `x` and `y` are passed on to the include file to interpret as explained for the `$batinclude` option.

Consider the following example,

```
$sysinclude c:\abc\myinc.inc x y
```

This call first looks specifically for the include file `c:\abc\myfile.inc`.

title

This option sets the title in the page header of the listing file to '`text`' which follows immediately the keyword `title`. The next output line will appear on a new page in the listing file.

Consider the following example,

```
$title  Production Planning Model
$stitle Set Definitions
```

use205

This option sets the GAMS syntax to that of Release 2.05. This is mainly used for backward compatibility. New keywords have been introduced in the GAMS language since Release 2.05. Models developed earlier that use identifiers that have since become keywords will cause errors when run with the latest version of GAMS. This option will allow one to run such models.

Consider the following example,

```
$use205
set if /1.2.3/; scalar x ;
```

The word `if` is a keyword in GAMS introduced with the first version of Release 2.25. The setting of the `$use205` option allows if to be used as an identifier since it was not a keyword in Release 2.05.

use225

This option sets the GAMS syntax to that of first version of Release 2.25. This is mainly used for backward compatibility. New keywords have been introduced in the GAMS language since the first version of Release 2.25. Models developed earlier that use identifiers that have since become keywords will cause errors when run with the latest version of GAMS. This option will allow one to run such models.

Consider the following example,

```
$use225
set for /1.2.3/; scalar x ;
```

The word `for` is a keyword in GAMS introduced with the later versions of Release 2.25. The setting of the `$use225` option allows `for` to be used as an identifier since it was not a keyword in the first version of Release 2.25.

use999

This option sets the GAMS syntax to that of the latest version of the compiler. This option is the default.

Consider the following example,

```
$use225
set for /1.2.3/; scalar x ;
$use999
for (x=1 to 3, display x) ;
```

The word `for` is used as a set identifier by setting the option `$use225`, and later the keyword `for` is used as a looping construct by setting the language syntax to that of the latest version by setting `$use999`.

E

The Option Statement

E.1 Introduction

The `option` statement is used to set various global system parameters that control output detail, solution process and the layout of displays. They are processed at execution time unlike the dollar control options discussed in Appendix D. They are provided to give flexibility to the user who would like to change the way GAMS would normally do things. GAMS does provide default values that are adequate for the most purposes, but there are always cases when the user would like to maintain control of aspects of the run.

E.1.1 The Syntax

The general form of an option statement is

```
option 'keyword1' [ = 'value1'] { ,|EOL  'keyword2' [ = 'value2'] } ;
```

where the `'keyword1'` and `'keyword2'` are recognized option names (but not reserved words) and the `'value1'` and `'value2'` are valid values for each of the respective options. Note that commas or end-of-line characters are both legal separators between options.

☞ *Option names are not reserved words and therefore do not conflict with other uses of their name.*

There are five possible formats:

1. a `display` specifier.
2. a recognized name, number following = sign or value
3. a recognized name, number following an = sign, then an unsigned integer value.
4. a recognized name, number following an = sign, then an unsigned real number.
5. a recognized name, number following an = sign, then either of two recognized words.

☞ *An option statement is executed by GAMS in sequence with other instructions. Therefore, if an option statement comes between two solve statements, the new values are assigned between the solves and thus apply only to the second one.*

☞ *The values associated with an option can be changed as often as necessary, with the new value replacing the older one each time.*

An example of a list of option statements is shown below,

```
option profit:0:3:2;
option eject
       iterlim = 100 , solprint = off ;
solve mymodel using lp maximizing profit ;
display profit.l ;
input("val1") = 5.3 ;
option iterlim = 50 ;
solve mymodel using lp maximizing profit ;
```

The `option` statement in the second line affects the display format of the identifier `profit`. More details on this option can be found under the heading `<identifier>` in the following section. The option on the second line has no value associated with it, and serves to advance the output in the listing file to the next page. The third line contains two options - `iterlim`, and `solprint`. The values associated with the two options on the fourth line are of different types - `iterlim` has an integer value while `solprint` requires a character string as a value. Note also that the end of line and the comma serve as legal separators between two options.

The `option iterlim` serves to limit the number of iterations taken by the solver while attempting to solve the `lp` model `mymodel`. After `mymodel` is solved for the first time, some of the input data is changed and the model is solved again. However, before the second solve statement, the `option iterlim` is changed to 50. The effect of the sequence above is to limit the first solve to less than 100 iterations and the second to less than 50.

E.2 List of Options

The options available through the option statement are grouped into the following functional categories affecting

output detail	solver specific parameters
input program control	choice of solver

Table E.1 briefly describes the various options in each of the categories. Section E.3 contains a reference list of all options available through the `option` statement in alphabetical order with detailed description for each.

Options controlling output detail:			
`<identifier>`	controls print format	`profile`	lists program execution profile
`decimals`	global control of print format	`profiletol`	sets tolerance for execution profile
`eject`	advances output to next page	`solprint`	controls printing of solution
`limcol`	number of columns listed	`solslack`	controls type of equation information
`limrow`	number of rows listed	`sysout`	controls printing of solver status file
Options controlling solver specific parameters:			
`bratio`	use of advanced basis	`optca`	sets absolute optimality tolerance
`domlim`	limits number of domain errors	`optcr`	sets relative optimality tolerance
`iterlim`	limits number of solver iterations	`reslim`	limits amount of solver time
Options controlling choice of solver:			
`cns`	sets solver for `cns` model type	`mip`	sets solver for `mip` model type
`dnlp`	sets solver for `dnlp` model type	`mpec`	sets solver for `mpec` model type
`lp`	sets solver for `lp` model type	`nlp`	sets solver for `nlp` model type
`mcp`	sets solver for `mcp` model type	`rminlp`	sets solver for `rminlp` model type
`minlp`	sets solver for `minlp` model type	`rmip`	sets solver for `rmip` model type
Options affecting input program control:			
`seed`	resets seed for pseudo random number generator		
`solveopt`	controls return of solution values to GAMS		

Table E.1: GAMS options

E.3 Detailed Description of Options

This section describes each of the options in detail. The options are listed in alphabetical order for easy reference. In each of the following options, the default value, if available, is bracketed.

`<identifier>`
: Display specifier: `identifier:d`, `identifier:d:r:c` Defines print formats for `identifier` when used in a display statement. `d` is the number of decimal places, `r` is the number of index positions printed as row labels, `c` is the number of index positions printed as column labels; the remaining index positions (if any) will be used to index the planes (index order: plane, row, column); if `r` is zero list format will be used. The default setting is described in Section 14.4.

`bratio (0.25)`
: Certain solution procedures can restart from an advanced basis that is constructed automatically. This option is used to specify whether or not basis information (probably from an earlier solve) is used. The use of this basis is rejected if the number of basic variables is smaller than bratio times the size of the basis. Setting `bratio` to 1 will cause all existing basis information to be discarded, which is sometimes needed with nonlinear problems. A `bratio` of 0 accepts any basis, and a `bratio` of 1 always rejects the basis. Setting `bratio` to 0 forces GAMS to construct a basis using whatever information is available. If `bratio` has been set to 0 and there was no previous solve, an '*all slack*' (sometimes called '*all logical*') basis will be provided. This option is not useful for MIP solvers.

  Range:
  `0-1`

`cns (default)`
: The default `cns` solver is set during installation. The user can change this default by setting this option to the required solver. The list of `cns` solvers available with your system can be obtained by reading the `gamscomp.txt` file that is present in the GAMS system directory. A value of `default` will change the `cns` solver back to the default one as specified in `gamscomp.txt`.

`decimals (3)`
: Number of decimals printed for symbols not having a specific print format attached.

  Range:
  `0-8`

`dnlp (default)`
: This option controls the solver used to solve `dnlp` models. For details cf. option `cns`.

`domlim (0)`
: This controls the number of domain errors (undefined operations like division by zero) a nonlinear solver will perform, while calculating function and derivative values, before it terminates the run. Nonlinear solvers have difficulty recovering after attempting an undefined operation.

`eject`
: Advances output in the listing file to the next page.

`iterlim (1000)`
: This option will cause the solver to interrupt the solution process after iterlim iterations and return the current solution values to GAMS.

`limcol (3)`
: This controls the number of columns that are listed for each variable in the `COLUMN LISTING` section of the listing file. Specify zero to suppress the `COLUMN LISTING` altogether.

`limrow (3)`
: This controls the number of rows that are listed for each equation in the `EQUATION LISTING` section of the listing file. Specify zero to suppress the `EQUATION LISTING` altogether.

`lp (default)`
: This option controls the solver used to solve `lp` models. For details cf. option `cns`.

`mcp (default)`
: This option controls the solver used to solve `mcp` models. For details cf. option `cns`.

`minlp (default)`
This option controls the solver used to solve `minlp` models. For details cf. option `cns`.

`mip (default)`
This option controls the solver used to solve `mip` models. For details cf. option `cns`.

`miqcp (default)`
This option controls the solver used to solve `miqcp` models. For details cf. option `cns`.

`nlp (default)`
This option controls the solver used to solve `nlp` models. For details cf. option `cns`.

`optca (0.0)`
This option is only used with problems containing discrete variables (i.e. the GAMS model type `mip`). General mixed integer problems are often extremely difficult to solve, and proving that a solution found is the best possible can use enormous amounts of resources. This option sets an absolute termination tolerance, which means that the solver will stop and report on the first solution found whose objective value is within `optca` of the best possible solution.

`optcr (0.1)`
This option sets a *relative termination tolerance* for problems containing discrete variables, which means that the solver will stop and report on the first solution found whose objective value is within `100*optcr` of the best possible solution.

`profile (0)`
This option is used to generate more information on program execution profiles. This option is equivalent in function to the profile command line parameter.

0	No execution profile is generated in listing file
1	The listing file reports execution times for each statement and the number of set elements over which the particular statement is executed.
2	Specific times for statements inside control structures like loops.

`profiletol (0.0)`
This option sets profile tolerance in seconds. All statements that take less time to execute than this tolerance are not reported in the listing file.

`qcp (default)`
This option controls the solver used to solve `qcp` models. For details cf. option `cns`.

`reslim (1000)`
This option causes the solver to terminate the solution process after `reslim` units of processor time have been used, and the current solution values are returned to GAMS. The units are seconds on the '*wall clock*' for PCs, or CPU seconds for larger machines. The `SOLUTION SUMMARY` part of the listing file shows the limit was used.

`rmip (default)`
This option controls the solver used to solve `rmip` models. For details cf. option `cns`.

`rminlp (default)`
This option controls the solver used to solve `rminlp` models. For details cf. option `cns`.

`seed (3141)`
This option resets the seed for the pseudo random number generator.

`solprint (on)`
This option controls the printing of the model solution in the listing file. Using this specification suppresses the list of the solution following a `solve`.

on	The solution is printed one line per row and column in the listing file.
off	Solution details are not printed. Although this saves paper, we do not recommend it unless you understand your model very well and solve it often.

`solslack (0)`

This option causes the equation output in the listing file to contain slack variable values instead of level values.

0	Equation output in listing file contains level values between lower and upper bound values
1	Equation output in listing file contains slack values between lower and upper bound values

`solveopt (merge)`

Controls the way solution values from a solve are returned to GAMS.

merge	Old and new values merged together, and new values over-write old ones
replace	All old values associated with a variable or equation are reset to default values before new solution values are returned

`sysout (off)`

This option controls the printing of the solver status file as part of the listing file. The contents of the solver status file are useful if you are interested in the behavior of the solver. If the solver crashes or encounters any difficulty, the contents of the solver status file will be automatically sent to the listing file.

on	Prints the system output file of the solver
off	No subsystem output appears on output file unless a subsystem error has occurred.

F

The Save and Restart Feature

F.1 Introduction

GAMS saves the information provided in the input files in intermediate, mostly binary, files. These files are referred to as *work files* or *scratch files*. Some of these files are used to exchange information between GAMS and the various solvers. Just before a GAMS run is complete, these files are usually deleted.

Input files can be processed in parts through the use of these intermediate files. This is an extremely powerful feature that can reduce the time needed when several runs of the same model are being made with different data.

It may be clearer if the process is described in a different way. Imagine taking a large GAMS program and running it, producing one output file. Then think of splitting the program into two pieces. The first piece is run and the resulting work file is saved along with the resulting listing file. Then the second piece is run after reading in the data from the work file saved previously. A new listing file is generated for the second piece. The content of the output that results is the same, though slightly rearranged, as the case when the large file was run. Splitting the files allows one to interrupt a GAMS task and restart it later without loss of information. Furthermore, changes could be made or errors corrected to the later parts.

F.2 The Save and Restart Feature

Using the save and restart command line parameters provides a mechanism to break up the compilation of a large input file into many components and stages. Some of the reasons for using these features and running a model in pieces are explained in Section F.3. The next two sub-sections explain the save and restart mechanisms in GAMS. The save and restart command line parameters, described in Appendix C, are used for this purpose.

[TRNSPORT] is used for the purposes of illustration. Consider the following file, containing code extracted from this model called `file1.gms`,

```
Sets
   i   "canning plants"   / seattle, san-diego /
   j   "markets"          / new-york, chicago, topeka / ;
Parameters
   a(i)  "capacity of plant i in cases"
      /    seattle     350
           san-diego   600  /

   b(j)  "demand at market j in cases"
      /    new-york    325
           chicago     300
           topeka      275  / ;

Table d(i,j)  "distance in 1000 miles"
                  new-york       chicago      topeka
   seattle          2.5           1.7          1.8
```

```
     san-diego        2.5          1.8         1.4  ;

   Scalar f  "freight in dollars/case per 1000 miles" /90/ ;

   Parameter c(i,j)  "transport cost in $1000/case" ;
                c(i,j) = f * d(i,j) / 1000 ;

   Variables
       x(i,j)  "shipment quantities in cases"
       z       "total transportation costs in 1000$" ;

   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/ ;
```

Consider the following file (say `file2.gms`),

```
   Solve transport using lp minimizing z ;
   Display x.l, x.m ;
```

Note that [TRNSPORT] results from appending `file2.gms` at the end of `file1.gms`.

F.2.1 Saving The Work File

The information in `file1.gms` can be stored by using the following call to GAMS,

```
   gams file1 s=trans
```

One work file called `trans.g00` is created in the working directory.

☞ *The Work file preserves all information (including declarations, values, option settings and compiler dollar directives) known to GAMS at the end of the run that created them.*

☞ *The work file is not machine specific, it is portable between platforms. For example, a work file generated on a PC running Windows can be re-used on a Sun machine running Solaris.*

F.2.2 Restarting from the Work File

Consider the following call,

```
   gams file2 r=trans
```

GAMS reads the work file named `trans.g00` and regenerates the information stored in `file1.gms`. Then `file2.gms` is run and the result is as if the two files were concatenated.

A restarted run also requires a continuation input file. The restart does not alter work files. They can be used repeatedly to continue a particular run many times, possibly with many different continuation input files.

The most common mistake that occurs in using the save and restart feature is running GAMS on the same file twice, so all the data and equation definitions get repeated which causes compilation errors during restart. The following calls will cause errors:

```
$gams trnsport s=trans
$gams trnsport r=trans
```

In general, definitions of data constructs should not be repeated either in the same file or across files used in the Save and Restart operation. GAMS works as if the two files are actually concatenated. In order to avoid any syntax problems, one needs to understand the GAMS syntax regarding data entry. By default GAMS requires that each data item be entered only once. Once the elements that form the set have been defined, the set cannot be redefined through the data statment. For example, the following set of statements are all invalid:

```
set i /seattle, san-diego / ;
set i /seattle, san-diego, portland / ;
```

Similar rules apply to Scalar, Parameter, and Table declarations. One can only use assignment statments to change values of scalars, parameters and tables once they have been specified by the data statement. For example,

```
parameter a(i) /
seattle    20
san-diego  50  / ;

a("seattle")   =  10 ;
a("san-diego") = 100 ;
```

One can, however, separate the definition of the data type from the actual data entry. For example, the following succession of statements is valid:

```
Set i ;
Set i /seattle, san-diego / ;
```

This is true with the other data types as well. This last feature is very useful in completely separating the model definition from the data, and leads to the development of a good runtime GAMS model.

☞ *It is the responsibility of the modeler to ensure that the contents of the input file matches that of the work file, although the compiler will issue errors if it detects any inconsistencies, such as references to symbols not previously declared.*

☞ *A Work file can be used only by GAMS tasks requesting a restarted run.*

☞ *A Work file can be saved following a restarted run, thus producing another work file that reflects the state of the job following completion of the statements in the continuation file.*

F.3 Ways in which a Work File is Useful

The basic function of a work file is to preserve information that has been expensive to produce. Several reasons for wanting to do this are described in this section.

F.3.1 Separation of Model and Data

The separation of model and data is one of the core principles of the GAMS modeling paradigm. The use of save and restart features helps to exploit this separation.

Let us re-arrange the contents of `file1.gms` and `file2.gms` to separate the model from the data. The modified version of `file1.gms` is shown below,

```
Sets i   canning plants
     j   markets

Parameters  a(i)    "capacity of plant i in cases"
```

```
            b(j)    "demand at market j in cases"
            c(i,j)  "transport cost in 1000$/case"
            d(i,j)  "distance in 1000 miles"  ;

Scalar f  "freight in $/case per 1000 miles"

Variables   x(i,j)  "shipment quantities in cases"
            z       "total transportation costs in 1000$"  ;

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/ ;
```

Note that this representation does not contain any data, and is a purely algebraic representation of the transportation problem. Running this model and saving the resulting work file will allow the model to be used with the data stored in a separate file (`file2.gms`).

```
Sets   i   / seattle, san-diego /
       j   / new-york, chicago, topeka / ;

Parameters  a(i)  / seattle     350
                    san-diego   600  /
            b(j)  / new-york    325
                    chicago     300
                    topeka      275  /

Table d(i,j)
                  new-york       chicago      topeka
    seattle          2.5           1.7          1.8
    san-diego        2.5           1.8          1.4  ;

Scalar f / 90 / ;

c(i,j) = f * d(i,j) / 1000 ;

Solve transport using lp minimizing z ;
Display x.l, x.m ;
```

This file contains the data for the model and the `solve` statement.

F.3.2 Incremental Program Development

GAMS programs are often developed in stages. A typically style is to put the sets first, followed by tables and data manipulations, then equations, and finally the assignments used to generate reports. As each piece of the model is built, it should be run and checked for errors by inserting diagnostic display and abort statements. As confidence mounts in the correctness of what has been done, it is useful to save the completed parts in a work file. Then by restarting it is possible to work only on the piece under active development, thereby minimizing computer costs and the amount of output produced in each of the developmental runs. This approach is especially useful when entering the statements needed for reporting. The solution is much more expensive than the report, but the report is likely to involve many details of content and layout that have to be tried several times before they are satisfactory. The model can be solved and the result saved in a work file. One can then restart from the work file when developing the report. It is a great relief not to have to solve the model every time.

F.3.3 Tacking Sequences of Difficult Solves

In many cases where solves are known to be difficult and expensive, it may be too risky to ask GAMS to process a job containing many solve statements. The risk is that if one solve does not proceed to normal completion, then the following one will be started from a bad initial point, and much time and effort will be wasted.

An alternative is to request one solve at a time and save the work file. Then the output is carefully inspected before proceeding. If everything is normal, the job is restarted with the next solve requested. If not, the previous solve can be repeated, probably with a different initial point, or continued if the cause of the trouble was an iteration limit, for example.

This approach is common when doing repeated solves of a model that successively represent several consecutive time periods. It uses a work file in a sequential rather than a tree-structure way.

It also produces many files, which can be difficult to manage, if the solves are especially difficult, it is possible to lose track of exactly what was done. Great care is needed to avoid losing control of this process.

F.3.4 Multiple Scenarios

The majority of modeling exercises involves a *base case*, and the point of the study is to see how the system changes when circumstances change, either naturally or by design. This is often done by making many different changes to the base case and separately considering the effects; it is sometimes called '*what if*' analysis.

The point is that the base can be saved using a work file, and as many different scenarios as may be interesting can then be run separately by restarting. Each scenario probably involves only making a change in data or in bounds, solving the changed model (the base solution is automatically used as a starting point), and reporting. This procedure is an example of how a work file is used in a tree-structured way: one work file is used with many different (but probably very small) input files to produce many different output files. File handling is less likely to be a problem than in the sequential case above.

F.3.5 The GAMS Runtime License

We assume the model and the data have been completely separated as shown above, with `file1.gms` containing only the model, and `file2.gms` containing only the data.

The developer of the model can run the first model with the following command:

```
gams file1 s=trans
```

and then distribute the file `trans.g00` file that result, along with the example `file2.gms`.

If the end-user has a run-time license for GAMS, they will not be able to see the model, nor change it by adding any new variables or equations. The end-user will only be able to change the data, and run the model developed during the save process. However, the end-user will have full control of the data, and will be able to manipulate the number of elements in the set, and the values of the various scalars, parameters, and tables.

The end user will run the model with the following command:

```
gams file2 r=trans
```

G

Secure Work Files

G.1 Introduction

When models are distributed to users other than the original developers or embedded in applications to be deployed by other developers, issues of privacy, security, data integrity and ownership arise. We may have to hide, protect or purge some parts of the model before it can be released. The information to be protected can be of numeric or symbolic nature. For example:

Privacy
A Social Accounting Matrix supplied by a Statistical Office is required in a general equilibrium model to be used by the Ministry of Finance. The data from the statistical office needs to be protected for obvious privacy reasons and the model experiments are used to evaluate policy options that are highly confidential. Most of the model structure is public, most of the data however is private and model results need to be transformed in such a way as to prohibit the discovery of the original data.

Security
Components of a model contain proprietary information that describes mathematically a chemical reaction. The associated algebra and some of the data are considered of strategic importance and need to be hidden completely. The final model however, will be used at different locations around the world.

Integrity
Data integrity safeguards are needed to assure the proper functioning of a model. Certain data and symbolic information needs to be protected from accidental changes that would compromise the operation of the model.

To address these issues, access control at a symbol level and secure restart files have been added to the GAMS system.

Access Control
The access to GAMS symbols like sets, variables, parameters and equations can be changed once with the compile time commands $purge, $hide, $protect and $expose. $Purge will remove any information associated with this symbol. $Hide will make the symbol and all its information invisible. $Protect prevents changes to information. $Expose will revert the symbol to its original state.

Secure Restart Files
The GAMS licensing mechanism can be used to save a secure model in a secure work file. A secure work file[1] behaves like any other work file but is locked to a specific users license file. A privacy license, the license file of the target users, is required to create a secure work file. The content of a secure work file is disguised and protected against unauthorized access via the GAMS license mechanism.

A special license is required to set the access controls and to create a corresponding secure work file. Reporting features have been added to allow audits and traces during generation and use of secure work files.

[1]Work files are used to save and restart the state of a GAMS program. Depending on the context, we refer to those files as work files, save files or restart files.

G.2 A First Example

The model TRNSPORT from the GAMS model library will be used to illustrate the creation and deployment of a secure work file. Assume we want to distribute this model but have concerns about proprietary formulations and data. In addition we would like to protect the user from making unintentional modifications to the model. We assume that the objective function and the supply constraints are to be hidden from other users and only the demand figures can be changed. Data that is not needed any more will be purged as well. This will be demonstrated below using the command line interface to GAMS[2]. First we will copy the model from the GAMS model library, run the model and save a normal work file:

```
> gamslib trnsport
> gams trnsport s=t1
```

We continue to enter access control commands in a file called `t2.gms` and create a secure work file with the name `t2.g00`:

```
     > type t2.gms

        $eolcom //
        $protect all            // make all symbol read only
        $purge   d f            // remove items d and f
        $hide    cost supply a  // make objective invisible
        $expose  transport b    // allow changes to b

  > gams t2 r=t1 s=t2 plicense=target

        GAMS Rev 124  Copyright (C) 1987-2001 GAMS Development...
        Licensee: Source User Name
                  Source Company Name
        *** Creating a Secure Restart File for:
        ***       Target User Name
        ***       Target Company Name
        --- Starting continued compilation
        --- T2.GMS(6) 1 Mb
        --- Starting execution
        *** Status: Normal completion
```

The access control commands are activated by the use of the privacy GAMS license option PLICENSE. This option specifies the name of the target user license file. The save/restart file `t2.g00` can only be read with the target license file.

The three lines starting with '***' are a recap of the content of the target license file. From now on, the source and the target licensees are 'burned into' this file and all its descendants. We are ready to send the restart file to the target user or system.

The target user can now run the model with new data, add new GAMS statements, and make new save/restart files. The only restrictions are that some of the symbols are hidden and that this model can only be executed using the target license file. For example, the target user may want to half the demand and compare the original solution with the new one. We will call this program `t3.gms` and it will be executed on the target system:

```
> type t3.gms

   parameter rep summary report;
   rep(i,j,'base') = x.l(i,j);
   b(j) = b(j)*0.5; solve transport minimizing z using lp;
   rep(i,j,'half') = x.l(i,j);
   display rep;

> gams t3 r=t2
```

[2]When using the GAMS/IDE interface, the GAMS parameters are entered and mainened in the text window just right to the *Run GAMS (F9)* button.

```
      GAMS Rev 124 Copyright (C) 1987-2001 GAMS Development...
      Licensee: Target User Name
                Target User Company
      *** Restarting from a Secure Restart File created by:
      ***       Source User Name
      ***       Source Company Name
      --- Starting continued compilation
      --- T3.GMS(5) 1 Mb
      ...
```

Note that the originator/owner of the secure work file is mentioned by name on the log file. A similar message is contained in the listing file:

```
   > type t3.lst
   ...
   EXECUTION TIME    =    0.000 SECONDS   1.1 Mb   WIN201-124

   **** Secure Save/Restart File Source:
          Source User Name
          Source Company Name
   **** Secure Save/Restart File Target:
          Target User Name
       Target User Company
...
```

A more detailed inspection of the listing file will show that the hidden variables and equations do not appear in the usual equation/variable listings and the solution print. The hidden items can only be accessed via a public (exposed) model and a solve statement.

In the following two sections we will describe secure work files and the access control commands in more detail.

G.3 Secure Work Files

Secure Work Files control access to symbolic and numeric information and can only be read by a specific GAMS user. The initial creation or additions to access control requires a special GAMS license. Saving Secure Work Files without new access controls does not require a special GAMS license. The creation or addition of access control is signaled by the use of the GAMS parameter PLICENSE, which gives the name of a privacy license file. The shortcut 'PLICENSE=LICENSE' sets the privacy license to the current license file. This is convenient when experimenting with access controls.

When a secure work file is written the first time, the first and second lines of the current license file and the privacy license file are inserted into the work file. This information cannot be changed any more and the original source and the intended target users are locked into the work file.

A secure work file can be used just like any other work file and new work files can be derived from secure files. However, their use is restricted to the 'target' user specified with the PLICENSE parameter. The target user can, if licensed, add access controls to an existing secure file by using the PLICENSE=LICENSE parameter but cannot change the original information about source and target users.

Secure work files can be tested on any GAMS system by specifying a non-default license file with the LICENSE=target parameter.

G.4 Access Control Commands

There are four Access Control Commands (ACC) that are processed during the compilation phase. These commands can be inserted anywhere and are processed in chronological order and have the following syntax:

```
$acc ident1 ident2 ...
$acc ALL
```

Where *acc* is one of the four ACC's:

PURGE	remove the objects and all data associated
HIDE	hide the objects but allow them to be used in model calculations
PROTECT	the objects cannot be modified but used in model calculations
EXPOSE	removes all restrictions

The keyword ALL applies the ACC to all identifiers defined up to this point in the GAMS source code. ACC's can be changed and redefined within the same GAMS program. Identifiers inherited from a restart file cannot be changed, however.

G.5 Advanced Use of Access Control

We will again use the transport model to show how to hide input data and results from the target user. The target user is only allowed to view percentage changes from an unknown base case. In addition to the original model we will introduce a data initialization and a report model.

First we will define a new model to calculate input data. The previous parameter c is now the variable newc and the model getc does the calculations:

```
$include trnsport.gms
variable newc(i,j)    new tansport data;
equation defnewc(i,j) definition of new transport data;
model getc            compute new transport data / defnewc /;
defnewc(i,j).. newc(i,j) =e= f*d(i,j)/1000;
solve getc using cns;
```

Next, we change the objective function of the original model to a more complicated nonlinear function. Furthermore, we will compute a base case value to be used later in the reporting model. Note the reference to `newc.l(i,j)`, since `nexc` is a variable we have to specify that we only want the level value:

```
scalar   beta scale coefficient / 1.1 /;
equation newcost definition of new objective function;
model newtrans / newcost,supply,demand /;
newcost.. z =e= sum((i,j), newc.l(i,j)*x(i,j)**beta);
solve newtrans using nlp minimizing z;
parameter basex(i,j) base values of x;
basex(i,j) = x.l(i,j);
```

Finally we transform the result by using a third model:

```
variable delta(i,j)    percentage change from base values;
equation defdelta(i,j) definition of delta;
model rep / defdelta /;
defdelta(i,j)$basex(i,j)..
    delta(i,j) =e= 100*(x.l(i,j)- basex(i,j))/basex(i,j);
solve rep using cns;
```

We will save the above GAMS code under the name `p1.gms`, execute and make a save/restart file with the name `p1.g00` as follows:

```
> gams p1 s=p1
```

Now we are ready to make some test runs similar to those we expect to be defined by the target user. We will define three scenarios to be solved in a loop and name the file `u1.gms`:

```
set s / one,two,three /;
parameter sbeta(s) / one 1.25, two 1.5, three 2.0 /
          sf(s)    / one 85,   two 75,  three 50 /;
```

```
parameter report summary report;
loop(s,
   beta = sbeta(s);
   f    = sf(s);
   solve getc using cns;
   solve newtrans using nlp minmizing z;
   solve rep using cns;
   report(i,j,s) = delta.l(i,j);
   report('','beta',s) = beta;
   report('','f',s)    = f;
   report('obj','z',s) = z.l ) ;
display report;
```

When executing the above GAMS code together with the original transport model from the GAMS model library we will get the following results.

```
> gams u1 r=p1

   ----    109 PARAMETER report summary report

                            one         two       three

   seattle  .new-york      -4.050      -6.967      -8.083
   seattle  .chicago      -18.797     -27.202     -31.550
   seattle  .topeka       233.958     348.468     404.187
   san-diego.new-york       3.605       6.201       7.194
   san-diego.chicago       28.138      40.719      47.228
   san-diego.topeka       -15.512     -23.104     -26.799
            .beta           1.250       1.500       2.000
            .f             85.000      75.000      50.000
   obj      .z            526.912    1652.963   13988.774
```

Note that all symbols are still completely exposed. We need to add access controls to the model p1.gms before we can ship it to the target client. The information to be protected is the original distance matrix and derived information. We start out by hiding everything and then give access to selected parts of the model. We collect the access control information in the file `s1.gms` shown below and save the secure work file under the name s1.g00. Since we are still testing, we use our own license as target user. This will allows us to test the system the same way the target user will use it:

```
   $hide all
   $expose getc newtrans rep
   $expose i j z delta
   $expose f beta a b

> gams s1 r=p1 s=s1 plicense=license
```

To test the new secure file, we run again the problem u1.gms. When doing so you will observe that equation, variable and solution listings related to the hidden variables are not shown any more. Any attempt to reference a hidden variable will case a compilation error.

```
> gams u1 r=s1
```

Before we can ship a secure work file we need a copy of the target user license file. We then will restart again from `p1.gms`, zip the resulting secure files and we are ready to distribute the model:

```
> gams s1 r=p1 plicense=target.txt s=target
> zip target target.g00
```

G.6 Limitations and Future Requirements

One of the design goals for secure work files has been to minimize the impact on other components of the GAMS system. Solvers used out of a secure environment should work as if called out of a normal environment. This implies that, in principle, certain information could be recovered, if one has knowledge of GAMS solvers internals and is willing to expand considerable programming effort. In this section we will discuss current limitations and possible extension to the security features.

The following limitations exist:

- Solvers are not security aware and it would be possible to write a special GAMS solver that extracts information about a specific model instance. Primal and duals values as well as first partial derivatives could be extracted and displayed.
- The names and explanatory text of all GAMS symbols are retained in the work file and could be accessed by a special GAMS solver.
- The source and target license files locked to the secure work file cannot be changed. If the target user upgrades the GAMS system and receives a new license file, the secure work file cannot be read any more.

H

Compressed and Encrypted Input Files

H.1 Introduction

When models are distributed to users other than the original developers, issues of privacy, security, data integrity and ownership arise. Besides using secure work files, one can compress and encrypt GAMS input files. The compression and decompression of files is available to any GAMS user. The encryption follows the work file security model and requires special licensing. Three new Dollar Control Options have been introduced:

`$Encrypt`	`<source> <target>`	Encrypts into a GAMS system file
`$Compress`	`<source> <target>`	Compresses into a GAMS system file
`$Decompress`	`<source> <target>`	Decompresses a GAMS system file

Encryption is only available if a system is licensed for secure work files and usually requires a target license file which will contain the user or target encryption key. Once a file has been encrypted it cannot be decrypted any more.

The use of a `PLICENSE` parameter will specify the target or privacy license to be used as a user key for encrypting. Decompression and encrypting is done on the fly into memory when reading the GAMS system files. GAMS will recognize if a file is just plain text or compressed and/or encrypted and will validate and process the files accordingly.

Finally, all compressed and encrypted files are, of course, platform independent as any other GAMS input file.

H.2 A First Example

The model TRNSPORT from the GAMS model library will be used to illustrate the creation of a compressed input file. First we will copy the model from the GAMS model and create a compressed version. Spaces are recognized as separators between the source and target file names which means you have to use quotes (single or double) if the filenames contain spaces:

```
> gamslib trnsport
> echo $compress trnsport.gms t1.gms > t2.gms
> gams t2

...
--- Compress Source: C:\support\28Dec\trnsport.gms
--- Compress Target: C:\support\28Dec\t1.gms.gms
--- Compress Time  : 0msec
...
```

Now we can treat the compressed input files like any other GAMS input file and the listing files will be identical because the decompressed input is echoed just like any normal input line:

```
> gams transport
> gams t1
```

We can decompress the file and compare it to the original file:

```
> echo $Decompress .t1.gms. .t3.org. > t4.gms
> gams t4
> diff t1.gms t3.org
```

Finally, we may want to encrypt the input file in a way to hide the equation definitions. To do this we just insert $Offlisting and $Onlisting around the blocks of GAMS code we want to hide. We now can encrypt the modified model file by using a privacy or target license file to lock the new encrypted file to this license key.

```
> echo $encrypt trnsport.gms t1.gms > t2.gms
> gams t2 plicense=target
```

This new version of t1.gms can only be used with the target license file. To simulate the target environment we can force the target license to be used instead of the installed one.

```
> gams t1 license=target dumpopt=19
```

Note the use of `dumopt=19` which is sometimes used for debugging and maintenance, writes a clean copy of the input to the file `t1.dmp` (all include files and macros are expanded). In the file `t1.dmp` you will see that the input text between $offlisting and $onlisting is suppressed.

An attempt to $Decompress and decrypt the file will fail as well. Once a file has been encrypted, it cannot be decrypted any more. For example, trying to decompress as in the example before will fail:

```
> gams t4

...
--- Decompress Source: C:\support\28Dec\t1.gms
--- Decompress Target: C:\support\28Dec\t3.org
--- Decompress Error : Security violation
```

H.3 The CEFILES Gamslib Model

The CEFILES model from the GAMS Model Library contains a more elaborate example that can be easily modified to test the use of compressed files. This example will also show how to use the `PLICENSE=LICENSE` parameter to test the creation and use without having a target license file available.

```
$title Compressed Input Files (CEFILES,SEQ=317)

$ontext
This model demonstrates the use of compressed input files.
Remember, if the file names contain spaces you need
to use single or double quotes around the file names.
$offtext

* --- get model
$ondollar
$call gamslib -q trnsport

* --- compress and run model
$compress   trnsport.gms t1.gms
$decompress t1.gms       t1.org
$call       diff trnsport.gms t1.org > %system.nullfile%
$if         errorlevel 1 $abort files trsnport and t1 are different

* --- check to see if we get the same result
```

```
$call gams trnsport gdx=trnsport lo=%gams.lo%
$if   errorlevel 1 $abort model trnsport failed
$call gams t1       gdx=t1       lo=%gams.lo%
$if   errorlevel 1 $abort model t1 failed
$call gdxdiff trnsport t1 %system.redirlog%
$if   errorlevel 1 $abort results for trnsport and t1 are not equal

* --- also works with include files
$echo $include t1.gms > t2.gms
$call gams t2 gdx=t2 lo=%gams.lo%
$if   errorlevel 1 $abort model t2 failed
$call gdxdiff trnsport t2 %system.redirlog%
$if   errorlevel 1 $abort results for trnsport and t2 are not equal
$terminate
```

H.4 The ENCRYPT GAMSLIB Model

The ENCRYPT model from the GAMS Model Library contains a more elaborate example of the use of encrypted files. Note the use of LICENSE=DEMO which overrides the currently installed license with a demo license which has the secure file option enabled.

```
$Title Input file encryption demo (ENCRYPT,SEQ=318)

$ontext
Input files can be encrypted and use the save/privacy license
file mechanism for managing the user password. Similar to
compression, we offer an $encrypt utility to lock any file to a
specific target license file. Once a file has been encrypted it
can only be read by a gams program that has the matching license
file.  There is no inverse operation possible: you cannot recover
the original GAMS file from the encrypted version.

To create an encrypted file, we need a license file which has the
security option enabled. To allow easy testing and demonstration
a special temporary demo license can be created internally and
will be valid for a limited time only, usually one to two hours.

In the following example we will use the GAMS option license=DEMO to
use a demo license with secure option instead of our own license
file. Also note that we use the same demo license file to read the
locked file by specifying the GAMS parameter plicence=LICENSE.
$offtext

* --- get model
$ondollar
$call gamslib -q trnsport

* --- encrypt and try to decrypt
$call rm -f t1.gms
$echo $encrypt trnsport.gms t1.gms > s1.gms
$call gams s1 license=DEMO plicense=LICENSE lo=%gams.lo%
$if   errorlevel 1     $abort encryption failed

$eolcom  //
$if NOT errorfree $abort pending errors
$decompress t1.gms t1.org  // this has to fail
$if      errorfree $abort decompress did not fail
$clearerror

* --- execute original and encrypted model
$call gams trnsport gdx=trnsport lo=%gams.lo%
$if   errorlevel 1 $abort model trnsport failed
* Although this reads license=DEMO this license file is the one
* specified with plicense from the s1 call
$call gams t1 license=DEMO gdx=t1 lo=%gams.lo%
$if   errorlevel 1 $abort model t1 failed
$call gdxdiff trnsport t1 %system.redirlog%
```

```
$if   errorlevel 1 $abort results for trnsport and t1 are not equal

* --- use the encrypted file as an include file
$onecho > t2.gms
$offlisting
* this is hidden
option limrow=0,limcol=0,solprint=off;
$include t1.gms
$onlisting
* this will show
$offecho
$call gams t2 license=DEMO lo=%gams.lo%
$if   errorlevel 1 $abort model t2 failed

* --- protect against viewing
*     now we will show how to protect parts of an input
*     file from viewing and extracting original source
*     via the gams DUMPOPT parameter. We just need to
*     encrypt again

* --- encrypt new model
$call rm -f t3.gms
$echo $encrypt t2.gms t3.gms > s1.gms
$call gams s1 license=DEMO plicense=LICENSE lo=%gams.lo%
$if   errorlevel 1  $abort encryption failed
$call gams t3 license=DEMO gdx=t3 dumpopt=19 lo=%gams.lo%
$if   errorlevel 1 $abort model t3 failed
$call gdxdiff trnsport t3 %system.redirlog%
$if   errorlevel 1 $abort results for trnsport and t3 are not equal

* --- check for hidden output
$call   grep "this is hidden" t3.lst > %system.nullfile%
$if not errorlevel 1 $abort did not hide in listing
$call   grep "this is hidden" t3.dmp > %system.nullfile%
$if not errorlevel 1 $abort did not hide in dump file
```

I

The GAMS Grid Computing Facility

I.1 Introduction

As systems with multiple CPUs and High Performance Computing Grids are becoming available more widely, the GAMS language has been extended to take advantage of these new environments. New language features facilitate the management of asynchronous submission and collection of model solution tasks in a platform independent fashion. A simple architecture, relying on existing operating system functionality allows for rapid introduction of new environments and provides for an open research architecture.

A typical application uses a coarse grain approach involving hundreds or thousands of model solutions tasks which can be carried out in parallel. For example:

- Scenario Analysis
- Monte Carlo Simulations
- Lagrangian Relaxation
- Decomposition Algorithms
- Advanced Solution Approaches

The grid features work on all GAMS platforms and have been tailored to many different environments, like the Condor Resource Manager, a system for high throughput computing from the University of Wisconsin or the Sun Grid Engine. Researchers using Condor reported a delivery of 5000 CPU hours in 20 hours wall clock time.

Disclaimer. The use of the term grid computing may be offensive to some purists in the computer science world. We use it very loosely to refer to a collection of computing components that allow us to provide high throughput to certain applications. One may also think of it as a resurrection of the commercial service bureau concept of some 30 years ago.

Caution. Although these features have been tested on all platforms and are part of our standard release we may change the approach and introduce alternative mechanisms in the future.

Acknowledgments. Prof. Monique Guignard-Spielberg from the Wharton School at U Penn introduced us to parallel Lagrangian Relaxation on the SUN Grid Environment. Prof. Michael Ferris from the University of Wisconsin at Madison adopted our original GAMS grid approach to the high throughput system Condor and helped to make this approach a practical proposition.

I.2 Basic Concepts

The grid facility separates the solution into several steps which then can be controlled separately. We will first review what happens during the synchronous solution step and then introduce the asynchronous or parallel solution steps.

When GAMS encounters a solve statement during execution it proceeds in three basic steps:

1. **Generation.** The symbolic equations of the model are used to instantiate the model using the current state of the GAMS data base. This instance contains all information and services needed by a solution method to attempt a solution. This representation is independent of the solution subsystem and computing platform.

2. **Solution.** The model instance is handed over to a solution subsystem and GAMS will wait until the solver subsystem terminates.

3. **Update.** The detailed solution and statistics are used to update the GAMS data base.

In most cases, the time taken to generate the model and update the data base with the solution will be much smaller than the actual time spent in a specific solution subsystem. The model generation takes a few seconds, whereas the time to obtain an optimal solution may take a few minutes to several hours. If sequential model solutions do not depend on each other, we can solve in parallel and update the data base in random order. All we need is a facility to generate models, submit them for solution and continue. At a convenient point in our GAMS program we will then look for the completed solution and update the data base accordingly. We will term this first phase the submission loop and the subsequent phase the collection loop:

Submission Loop. In this phase we will generate and submit models for solutions that can be solved independently.

Collection Loop. The solutions of the previously submitted models are collected as soon a solution is available. It may be necessary to wait for some solutions to complete by putting the GAMS program to 'sleep'.

Note that we have assumed that there will be no errors in any of those steps. This, of course, will not always be the case and elaborate mechanisms are in place to make the operation fail-safe.

I.3 A First Example

The model QMEANVAR form the GAMS model library will be used to illustrate the use of the basic grid facility. This model traces an efficiency frontier for restructuring an investment portfolio. Each point on the frontier requires the solution of independent quadratic mixed integer models. The original solution loop is shown below:

```
Loop(p(pp),
   ret.fx = rmin + (rmax-rmin)/(card(pp)+1)*ord(pp) ;
   Solve minvar min var using miqcp ;
   xres(i,p)         = x.l(i);
   report(p,i,'inc') = xi.l(i);
   report(p,i,'dec') = xd.l(i) );
```

This loop will save the solutions to the model MINVAR for different returns RET. Since the solutions do not depend on the order in which they are carried out, we can rewrite this loop to operate in parallel. The first step is to write the submit loop:

```
parameter h(pp) model handles;
minvar.solvelink=3;
Loop(p(pp),
   ret.fx = rmin + (rmax-rmin)/(card(pp)+1)*ord(pp) ;
   Solve minvar min var using miqcp;
   h(pp) = minvar.handle );
```

The model attribute **.solvelink** controls the behavior of the solve statement. A value of '**3**' tells GAMS to generate and submit the model for solution and continue without waiting for the completion of the solution step. There is a new model attribute **.handle** which provides a unique identification of the submitted solution request. We need to store those handle values, in this case in the parameter h, to be used later to collect the solutions once completed. This is then done with a collection loop:

```
   loop(pp$handlecollect(h(pp)),
      xres(i,pp)          = x.l(i);
      report(pp,i,'inc') = xi.l(i);
      report(pp,i,'dec') = xd.l(i) );
```

The function **handlecollect** interrogates the solution process. If the solution process has been completed the results will be retrieved and the function returns a value of 1. If the solution is not ready to be retrieved the value zero will be returned.

The above collection loop has one big flaw. If a solution was not ready it will not be retrieved. We need to call this loop several times until all solutions have been retrieved or we get tired of it and quit. We will use a repeat-until construct and the handle parameter h to control the loop to look only for the not yet loaded solutions as shown below:

```
Repeat
   loop(pp$handlecollect(h(pp)),
         xres(i,pp)          = x.l(i);
         report(pp,i,'inc') = xi.l(i);
         report(pp,i,'dec') = xd.l(i);
         display$handledelete(h(pp)) 'trouble deleting handles' ;
         h(pp) = 0 ) ;
   display$sleep(card(h)*0.2) 'sleep some time';
until card(h) = 0 or timeelapsed > 100;
xres(i,pp)$h(pp) = na;
```

Once we have extracted a solution we will set the handle parameter to zero. In addition, we want to remove the instance from the system by calling the function **handledelete** which returns zero if successful (see definition). No harm is done if it fails but we want to be notified via the conditional display statement. Before running the collection loop again, we may want to wait a while to give the system time to complete more solution steps. This is done with the sleep command that sleeps some time. The final wrinkle is to terminate after 100 seconds elapsed time, even if we did not get all solutions. This is important, because if one of the solution steps fails our program would never terminate. The last statement sets the results of the missed solves to NA to signal the failed solve. The parameter h will now contain the handles of the failed solvers for later analysis.

Alternatively, we could have used the function **handlestatus** and collect the solution which is stored in a GDX file. For example we could write:

```
loop(pp$(handlestatus(h(pp))=2),
   minvar.handle = h(pp);
   execute_loadhandle minvar;
   xres(i,pp)          = x.l(i);
   report(pp,i,'inc') = xi.l(i);
   report(pp,i,'dec') = xd.l(i) );
```

The function **handlestatus** interrogates the solution process and returns '2' if the solution process has been completed and the results can be retrieved. The solution is stored in a GDX file which can be loaded in a way similar to other gdx solution points. First we need to tell GAMS what solution to retrieve by setting the minvar.handle to the appropriate value. Then we can use `execute_loadhandle` to load the solution for model minvar back into the GAMS data base. Using **handlestatus** and **loadhandle** instead of the simpler **handlecollect** adds one more layer of control to the final collection loop. We now need one additional if statement inside the above collection loop:

```
Repeat
   loop(pp$h(pp),
      if(handlestatus(h(pp))=2,
         minvar.handle = h(pp);
         execute_loadhandle minvar;
         xres(i,pp)          = x.l(i);
         report(pp,i,'inc') = xi.l(i);
         report(pp,i,'dec') = xd.l(i);
         display$handledelete(h(pp)) 'trouble deleting handles' ;
         h(pp) = 0 ) ) ;
      display$sleep(card(h)*0.2) 'sleep some time';
   until card(h) = 0 or timeelapsed > 100;
   xres(i,pp)$h(pp) = na;
```

Now we are ready to run the modified model. The execution log will contain some new information that may be useful on more advanced applications:

```
--- LOOPS pp = p1
---   46 rows 37 columns 119 non-zeroes
---   311 nl-code 7 nl-non-zeroes
---   14 discrete-columns
--- Submitting model minvar with handle grid137000002
--- Executing after solve
...
--- GDXin=C:\answerv5\gams_srcdev\225j\grid137000003\gmsgrid.gdx
--- Removing handle grid137000003
```

The log will now contain some additional information about the submission, retrieval and removal of the solution instance. In the following sections we will make use of this additional information. You can find a complete example of a grid enabled transport model in the GAMS model library.

At a final note, we have made no assumptions about what kind of solvers and what kind of computing environment we will operate. The above example is completely platform and solver independent and it runs on your Windows laptop or on a massive grid network like the Condor system without any changes in the GAMS source code.

I.4 Advanced use of Grid Features

In this section we will describe a few special application requirements and show how this can be handled with the current system. Some of those applications may involve thousands of model instances with solution times of many hours each. Some may fail and require resubmission. More complex examples require communication and the use of GAMS facilities like the BCH (Branch&Cut&Heuristic) which submit other models from within a running solver.

I.4.1 Very Long Job Durations

Imagine a situation with thousands of model instances each taking between minutes and many hours to solve. We will break the master program into a submitting program, an inquire program and a final collection program. We will again use the previous example to demonstrate the principle. We will split the GAMS code of the modified QMEANVAR GAMS code into three components: qsubmit, qcheck and qreport.

The file qsubmit.gms file will include everything up to and including the new submit loop. To save the instances we will need a unique Grid Directory and to restart the problem we will have to create a save file. The first job will then look a follows.

```
> gams qsubmit s=submit gdir=c:\test\grid
```

The solution of all the model instances may take hours. From time to time I can then run a quick inquiry job to learn about the stats. The following program qcheck.gms will list the current status:

```
parameter status(pp,*); scalar handle;
acronym BadHandle,Waiting,Ready;
loop(pp,
   handle := handlestatus(h(pp));
   if(handle=0,
      handle := BadHandle
   elseif handle=2,
      handle := Ready;
      minvar.handle = h(pp);
      execute_loadhandle minvar;
      status(pp,'solvestat') = minvar.solvestat;
```

```
         status(pp,'modelstat') = minvar.modelstat;
         status(pp,'seconds') = minvar.resusd;
      else
         handle := Waiting );
      status(pp,'status') = handle );
   display status;
```

To run the above program we will restart from the previous save file by using the restart or r parameter.

```
> gams qcheck r=submit gdir=c:\test\grid
```

The output may then look like:

```
----   173 PARAMETER status

    solvestat   modelstat   seconds     status

p1      1.000       1.000     0.328      Ready
p2      1.000       1.000     0.171      Ready
p3                                     Waiting
p4                                     Waiting
p5      1.000       1.000     0.046      Ready
```

You may want to do some more detailed analysis on one of the solved model instances. Then we may have a qanalyze.gms program that may look like and be called using the double dash option, which sets a GAMS environment variable:

```
$if not set instance $abort --instance is missing
if(not handlestatus(h('%instance%')),
    abort$yes 'model instance %instance% not ready');
minvar.handle = h('%instance%');
execute_loadhandle minvar;
display x.l,xi.l,xd.l;
. . .
```

```
> gams qanalyze r=submit gdir=c:\test\grid --instance=p4
```

Once all jobs are completed we can continue with the second part which will contain the collection loop, for simplicity without the repeat loop because we would not run the final collection program unless we are satisfied that we got most of what we wanted. Then the qreport.gms file could look like:

```
loop(pp$handlestatus(h(pp)),
   minvar.handle = h(pp);
   execute_loadhandle minvar;
   xres(i,pp)         = x.l(i);
   report(pp,i,'inc') = xi.l(i);
   report(pp,i,'dec') = xd.l(i);
   display$handledelete(h(pp)) 'trouble deleting handles' ;
   h(pp) = 0 );
xres(i,pp)$h(pp) = na;
. . .
```

We would restart the above program from the save file that was created by the submitting job like:

```
> gams qreport r=submit gdir=c:\test\grid
```

Note that it would not be necessary to run the job out of the same directory we did the initial submission. We don't even have to run the same operating system.

I.5 Summary of Grid Features

To facilitate the asynchronous or parallel execution of the solve solution steps we have introduced three new functions, a new model attribute, a new gdx load procedure and a new GAMS option GridDir.

I.5.1 Grid Handle Functions

HandleCollect(handle) collects (loads) the solution if ready.

0	the model instance was not ready or could not be loaded
1	**the model instance solution has been loaded**

HandleStatus(handle) returns the status of the solve identified by handle. An execution error is triggered if GAMS cannot retrieve the status of the handle.

0	the model instance is not known to the system
1	the model instance exists but no solution process is complete
2	**the solution process has terminated and the solution is ready for retrieval**
3	the solution process signaled completion but the solution cannot be retrieved

HandleDelete(handle) returns the status of the deletion of the handle model instance. In case of a nonzero return an execution error is triggered.

0	**the model instance has been removed**
1	the argument is not a legal handle
2	the model instance is not known to the system
3	the deletion of the model instance encountered errors

HandleSubmit(handle) resubmits a previously created instance for solution. In case of a nonzero return an execution error is triggered.

0	**the model instance has been resubmitted for solution**
1	the argument is not a legal handle
2	the model instance is not known to the system
3	the completion signal could not be removed
4	the resubmit procedure could not be found
5	the resubmit process could not be started

In addition, GAMS will issue execution errors which will give additional information that may help to identify the source of problems. The property execerror can be used to get and set the number of execution errors.

I.5.2 Grid Model Attributes

mymodel.solvelink specifies the solver linking conventions

0	automatic save/restart, wait for completion, the default
1	start the solution via a shell and wait
2	start the solution via spawn and wait
3	**start the solution and continue**
4	**start the solution and wait (same submission process as 3)**
5	start the solution via shared library and wait

mymodel.handle specifies the current instance handle

This is used to identify a specific model instance and to provide additional information needed for the process signal management.

mymodel.number specifies the current instance number

Any time a solve is attempted for mymodel, the instance number is incremented by one and the handle is update accordingly. The instance number can be reset by the user which then resyncs the handle.

I.5.3 Grid Solution Retrieval

Execute_loadhandle *mymodel*;

This will update the GAMS data base with the status and solution for the current instance of *mymodel*. The underlying mechanism is a gdx file and operates otherwise like the execute_loadpoint procedure. Additional arguments can be used to retrieve information from the gdx solution file.

I.5.4 Grid Directory

The instantiated (generated) models and their corresponding solution are kept in unique directories, reachable from your submitting system. Each GAMS job can have only one Grid Directory. By default, the grid directory is assumed to be the scratch directory. This can be overwritten by using the GAMS parameter GridDir, or short GDir. For example:

```
>gams myprogram ...  GDir=gridpath
```

If *gridpath* is not a fully qualified name, the name will be completed using the current directory. If the grid path does not exist, an error will be issued and the GAMS job will be terminated. A related GAMS parameter is the DcrDir (SDir for short). Recall the following default mechanism:

When a GAMS job starts, a unique process directory is created in the current (job submitting), directory. These directories are named 225a to 225z. When a GAMS job terminates it will remove the process directory at the completion of a GAMS job. Any file that has not been created by the GAMS core system will be flagged.

Using the program *gamskeep* instead of *gams* will call another exit script which (the default script) will do nothing and the process directory will not be removed.

If we do not specify a scratch directory, the scratch directory will be the same as the process directory. If we do not specify a grid directory, the grid directory will be the same as the scratch directory.

If there is a danger that some of the model instances may fail or we want to break the GAMS program into several pieces to run as separate jobs, we need to be careful not to remove the model instance we have not completely processed. In such cases, we have to use the GridDir option in order to be able to access previously created model instances.

I.6 Architecture and Customization

The current Grid Facility relies on very basic operating system features and does not attempt to offer real and direct job or process control. The file system is used to signal the completion of a submitted task and GAMS has currently no other way to interact with the submitted process directly, like forcing termination or change the priority of a submitted task. This approach has its obvious advantages and disadvantages. There are a number of attempts to use grid computing to provide value added commercial remote computing services, notably is SUN's recent commercial entry. Commercial services require transparent and reliable charge approaches and related accounting and billing features which are still missing or inadequate.

When GAMS executes a solve under solvelink=3 it will perform the following steps:

1. Create a subdirectory in the GridDir with the name gridnnn. Where nnn stands for the numeric value of the handle. The handle value is the internal symbol ID number x 1e6 + the model instance number. For example, in the QMEANVAR example the first grid subdirectory was **grid137000002**.

2. Remove the completion signal in case the file already exists. Currently the signal is a file called finished. For example, **grid137000002/finished**.

3. Create or replace a gdx file called **gmsgrid.gdx** which will contain a dummy solution with failed model and solver status. This file will be overwritten by the final step of the solution process and will be read when calling execute_loadhandle.

4. Place all standard GAMS solver interface files into the above instance directory.

5. Execute the submission wrapper called **gmsgrid.cmd** under Windows or **gmsgrid.run** under Unix. These submission scripts are usually located in the GAMS system directory but are found via the current path if not found in the GAMS system directory.

The grid **submission script gmsgrid.cmd** or **gmsgrid.run** is called with three arguments needed to make a standard GAMS solver call:

1. The solver executable file name
2. The solver control file name
3. The solver scratch directory

The submission script then does the final submission to the operating system. This final script will perform the following steps:

```
call the solver
call a utility that will create the final gdx file gmsgrid.gdx
set the completion signal finished
```

If we want to use the function handlesubmit() we also have to create the **gmsrerun.cmd** or **gmsrerun.run** script which could later be used to resubmit the job.

For example, the default submission script for Windows is shown below:

```
@echo off
: gams grid submission script
:
: arg1 solver executable
:    2 control file
:    3 scratch directory
:
: gmscr_nx.exe processes the solution and produces 'gmsgrid.gdx'
:
: note: %3 will be the short name because START cannot
:       handle spaces and/or "...". We could use the original
:       and use %~s3 which will strip ".." and makes the name :
:       short
: gmsrerun.cmd will resubmit runit.cmd
echo @echo off                > %3runit.cmd
echo %1 %2                   >> %3runit.cmd
echo gmscr_nx.exe %2   >> %3runit.cmd
echo echo OK ^> %3finished    >> %3runit.cmd
echo exit                    >> %3runit.cmd
echo @start /b %3runit.cmd ^> nul > %3gmsrerun.cmd
start /b %3runit.cmd > nul
exit
```

I.6.1 Grid Submission Testing

The grid submission process can be tested on any GAMS program without having to change the source text. The **solvelink=4** option instructs the solve statement to use the grid submission process and then wait until the results are available and then loads the solution into the GAMS data base. The **solvelink** option can be set via a GAMS command line parameter or via assignment to a the model attribute. Once the model instance has been submitted for solution, GAMS will check if the job has been completed. It will keep checking twice the reslim seconds allocated for this optimization job and report a failure if this limit has been exceed. After successful or failed retrieval of the solution gams will remove the grid directory, unless we have used gamskeep or have set the gams keep parameter.

I.7 Glossary and Definitions

BCH	Branch & Cut & Heuristic
Condor	High throughput computing system
GAMS	General Algebraic Modeling System
GDX	GAMS Data Exchange
HPC	High Performance Computing
SUN Grid Compute Utility	

J

Extrinsic Functions

J.1 Introduction

Functions play an important part in the GAMS language, especially for non-linear models. Similar to other programming languages, GAMS provides a number of built-in (intrinsic) functions. However, GAMS is used in an extremely diverse set of application areas and this creates frequent requests for the addition of new and often sophisticated and specialized functions. There is a trade-off between satisfying these requests and avoiding complexity not needed by most users. The GAMS Function Library Facility (6.3.3) provides the means for managing that trade-off. In this Appendix the extrisic function libraries which are included in the GAMS distribution are described.

In the tables that follow, the Model Function Type (first column) specifies in which models the function can legally appear with endogenous (non-constant) arguments. In order of least to most restrictive, the choices are `any`, `NLP`, `DNLP` or `none`.

The following conventions are used for the function arguments. Lower case indicates that an endogenous variable is allowed. Upper case indicates that a constant argument is required. The arguments in square brackets can be omitted and default values will be used.

J.2 Fitpack Library

FITPACK by Paul Dierckx[1] is a FORTRAN based library for one and two dimensional spline interpolation. This library has been repackaged to work with the GAMS Function Library Facility. As it can be seen in the GAMS Test Library model `fitlib01` the function data needs to be stored in a GDX file `fit.gdx` containing a three dimensional parameter `fitdata`. The first argument of that parameter contains the function index, the second argument is the index of the supporting point and the last one needs to be one of `w` (weight), `x` (x-value), `y` (y-value) or `z` (z-value).

Function	*Endogenous Classification*	*Description*
`fitFunc(FUNIND,x[,y])`	DNLP	Evalute Spline
`fitParam(FUNIND,PARAM[,VALUE])`	none	Read or set parameters

Table J.1: Fitpack functions

[1] Paul Dierckx, Curve and Surface Fitting with Splines, Oxford University Press, 1993, http://www.netlib.org/dierckx/

The function `FitParam` can be used to change certain parameters used for the evaluation:

- 1: Smoothing factor (S)
- 2: Degree of spline in direction x (Kx)
- 3: Degree of spline in direction y (Ky)
- 4: Lower bound of function in direction x (LOx)
- 5: Lower bound of function in direction y (LOy)
- 6: Upper bound of function in direction x (UPx)
- 7: Upper bound of function in direction y (UPy)

This library is made available by the following directive:

```
$FuncLibIn <InternalLibName> fitfclib
```

J.3 Piecewise Polynomial Library

This library can be used to evaluate piecewise polynomial functions. The functions which should be evaluated need to be defined and stored in a GDX file like it is done in the GAMS Test Library model `pwplib01`:

```
* Define two piecewise polynomial functions
Table pwpdata(*,*,*) '1st index: function number, 2nd index: segment number, 3rd index: degree'
                 leftBound       0          1         2
       1.1       1               2.4       -2.7       0.3
       1.2       4               5.6       -4.3       0.5
       2.1       0               0         -6.3333    0
       2.2       0.3333          1.0370   -12.5554    9.3333
       2.3       0.6667          9.7792   -38.7791   29
;
* Write pwp data to gdx file read by external library
$gdxout pwp.gdx
$unload pwpdata
$gdxout
```

On each row of the Table pwpdata we have

```
FuncInd.SegInd    leftBound    Coef0    Coef1    Coef2    ...
```

`FuncInd` sets the function index. `SegInd` defines the index of the segment (or interval) which is decribed here. `LeftBound` gives the lower bound of the segment. The upper bound is the lower bound on the next row, or the upper bound for the variable if this is the last segment. `CoefX` defines the Xth degree coefficient of the polynomial corresponding to this segment.

This library is made available by the following directive:

```
$FuncLibIn <InternalLibName> pwpcclib
```

Function	*Endogenous Classification*	*Description*
`pwpFunc(FUNIND,x)`	DNLP	Piecewise Polynomials

Table J.2: Piecewise polynomial functions

J.4 Stochastic Library

The stochastic library provides random deviates, probability density functions, cumulative density functions and inverse cumulative density functions for certain distributions. This library is made available by the following directive:

```
$FuncLibIn <InternalLibName> stodclib
```

Function	*Description*
`SetSeed(SEED)`	defines the seed for random number generator
Continous distributions	
`beta(SHAPE_1,SHAPE_2)`	Beta distribution with shape parameters SHAPE_1 and SHAPE_2, see MathWorld
`cauchy(LOCATION,SCALE)`	Cauchy distribution with location parameter LOCATION and scale parameter SCALE, see MathWorld
`ChiSquare(DF)`	Chi-squared distribution with degrees of freedom DF, see MathWorld
`exponential(LAMBDA)`	Exponential distribution with rate of changes LAMBDA, see MathWorld
`f(DF_1,DF_2)`	F-distribution with degrees of freedom DG_1 and DG_2, see MathWorld
`gamma(SHAPE,SCALE)`	Gamma ditribution with shape parameter SHAPE and scale parameter SCALE, see MathWorld
`gumbel(LOCATION,SCALE)`	Gumbel distribution with location parameter LOCATION and scale parameter SCALE, see MathWorld
`invGaussian(MEAN,SHAPE)`	Inverse Gaussian distribution with mean MEAN and scaling parameter SHAPE, see MathWorld
`laplace(MEAN,SCALE)`	Laplace distribution with mean MEAN and scale parameter SCALE, see MathWorld
`logistic(LOCATION,SCALE)`	Logistic distribution with location parameter LOCATION and scale parameter SCALE, see MathWorld
`logNormal(MEAN,STD_DEV)`	Log Normal distribution with mean MEAN and standard deviation STD_DEV, see MathWorld
`normal(MEAN,STD_DEV)`	Normal distribution with mean MEAN and standard deviation STD_DEV, see MathWorld
`pareto(SCALE,SHAPE)`	Pareto distribution with scaling parameter SCALE and shape parameter SHAPE, see MathWorld
`rayleigh(SIGMA)`	Rayleigh ditribution with parameter SIGMA, see MathWorld
`studentT(DF)`	Student's t-distribution with degrees of freedom DF, see MathWorld
`triangular(LOW,MID,HIGH)`	Triangular distribution between LOW and HIGH, MID is the most probable number, see MathWorld
`uniform(LOW,HIGH)`	Uniform distribution between LOW and HIGH, see MathWorld
`weibull(SHAPE,SCALE)`	Weibull distribution with shape parameter SHAPE and scaling parameter SCALE, see MathWorld

Discrete distributions	
`binomial(N,P)`	Binomial distribution with number of trials N and succes probability P in each trial, see MathWorld
`geometric(P)`	Geometric distribution with succes probability P in each trial, see MathWorld
`hyperGeo(TOTAL,GOOD,TRIALS)`	Hypergeometric distribution with total number of elements TOTAL, number of good elements GOOD and number of trials TRIALS, see MathWorld
`logarithmic(P-FACTOR)`	Logarithmic distribution with parameter P-FACTOR, also called log-series distribution, see MathWorld
`negBinomial(FAILURES,P)`	Negative Binomial distribution with the number of failures until the experiment is stopped FAILURES and succes probability P in each trial, see MathWorld
`poisson(LAMBDA)`	Poisson distribution with mean LAMBDA, see MathWorld
`uniformInt(LOW,HIGH)`	Integer Uniform distribution between LOW and HIGH, see MathWorld

Table J.3: Random number generators

For each distribution in table J.3, the library offers four functions:

Function	*Endogenous Classification*	*Description*
`d<DistributionName>`	none	generates a random number
`pdf<DistributionName>`	DNLP (none for discrete distributions)	probability density function
`cdf<DistributionName>`	DNLP (none for discrete distributions)	cumulative distribution function
`icdf<DistributionName>`	DNLP (none for discrete distributions)	inverse cumulative distribution function

Table J.4: Distribution functions

J.5 Trigonometric Library

This library comes in three versions. They come with the GAMS Test Library models `trilib01`, `trilib02` and `trilib03` and can be found compiled and as source code written in C, Delphi and FORTRAN respectively.

Function	*Endogenous Classification*	*Description*
`setMode(MODE)`	none	sets mode globally, could still be overwritten by MODE at (Co)Sine call, possible values are 0=radians and 1=degree
`cosine(x[,MODE])`	NLP	returns the cosine of the argument x, default setting: MODE = 0
`sine(x[,MODE])`	NLP	returns the sine of the argument x, default setting: MODE = 0
`pi`	any	value of $\pi = 3.141593...$

Table J.5: Trigonometric functions

K

Installation and System Notes

Windows

INSTALLATION

1. Run `windows_x86_32.exe` (Windows 32bit) or `windows_x64_64.exe` (Windows 64bit): Both files are either available on the GAMS web site or on the distribution DVD (in the directory `windows`). The 32 bit version works both on a 32bit and on a 64bit operating system. Please note that the installation may require administrative privileges on your machine. The installer will first prompt you for the name of the directory in which to install GAMS. We call this directory the '`GAMS directory`'. You may accept the default choice or pick another directory. Please remember: if you want to install two different versions of GAMS, they must be in separate directories.

2. Copy the GAMS license file: You will be asked for the GAMS license file (`gamslice.txt`) during the installation. If you are not sure, if you have a license file, choose 'No' when asked if you wish to copy a license file. You can always do this later. If no valid license file is found, GAMS will still function in the demonstration mode, but will only solve small problems. All demonstration and student systems do not include a license file. If you have a license file you wish to copy to the GAMS directory at this time, answer '`Yes`'. You will now be given the opportunity to browse the file system and find the license file `gamslice.txt`. When you have found the correct file, choose '`open`' to perform the copy.

3. Create a project file: If this is the first installation of GAMS on your system, the installation program will create a default GAMS project in a subdirectory of your home folder. Otherwise your existing GAMS projects will be preserved.

4. Choose the default solvers: Run the GAMS IDE by double clicking `gamside.exe` from the GAMS directory. To view or edit the default solvers, choose File → Options → Solvers from the IDE. You can accept the existing defaults if you wish, but most users want to select new default solvers for each model type.

5. Run a few models to test the GAMS system: The on-line help for the IDE (`Help → GAMS IDE Help Topics → Guided Tour`) describes how to copy a model from the GAMS model library, run it and view the solution. To test your installation, run the following models from the GAMS model library:

```
LP:    trnsport (objective value:  153.675)
NLP:   chenery  (objective value:  1058.9)
MIP:   bid      (optimal solution: 15210109.512)
MINLP: procsel  (optimal solution: 1.9231)
MCP:   scarfmcp (no objective function)
MPSGE: scarfmge (no objective function)
```

COMMAND LINE INSTALLATION

Users wishing to use GAMS from the command line (aka the console mode) may want to perform the following steps after they have installed the system as described above. These steps are not necessary to run GAMS via the IDE.

1. Run the program `gamsinst`: `gamsinst` is a command line program used to install and configure GAMS. It prompts the user for default solvers to be used for each model type. If possible choose solvers you have licensed, since unlicensed solvers will only run in demonstration mode. The solver defaults can be changed by:

   (a) rerunning `gamsinst` and resetting the default values
   (b) setting a command line default, e.g. `gams trnsport lp=bdmlp`
   (c) by an option statement in the GAMS model, e.g: `option lp=bdmlp;`

   If you have to support different operating systems from the same installation, please use '`gamsinst -sys all`'. A complete log of the installation is stored in `gamsinst.log`. The system wide solver defaults are shared by the command line and the GAMS IDE, so you can also choose to set these defaults using the GAMS IDE.

2. Add the GAMS directory to your path. To avoid having to type in an absolute path name each time you run GAMS, we recommend adding the GAMS directory to your `PATH` when using the console mode (not the GAMS IDE) version of GAMS. In case more than one GAMS system is installed on the machine, separate paths have to be set before invoking each version. Under Windows XP/Vista the following procedure must be applied to add the GAMS directory to your path:

   - Open the `System Properties` under the `Control Panel`.
   - On the `Advanced` tab click on the `Environment Variables` button and select the existing variable `Path`. Click `Edit`.
   - In the `Value Box` add the GAMS directory to the path as the following example illustrates: `c:\your\current\path\setting;C:\gams` and click `OK`.

Unix

INSTALLATION

To install GAMS, please follow the steps below as closely as possible. We advise you to read this entire document before beginning the installation procedure:

1. Choose a location for the GAMS system directory (the directory where the GAMS system files should reside). We recommend to choose a name that indicates the distribution of GAMS you are installing. For example, if you are installing the 23.3 distribution, a good choice for the GAMS system directory would be `/usr/gams/23.3`. If the directory where you want to install GAMS is not below your home directory, you may need to have root privileges on the machine.

2. Create the GAMS system directory, for instance `/usr/gams/23.3`. Go to this directory. Make sure `pwd` returns the name of this directory correctly.

3. Transfer the distribution file into the GAMS system directory. This file is available from the GAMS DVD or via the web in one large self-extracting zip archive with a `_sfx.exe` file extension. You can run the archive (e.g. `linux_x86_32_sfx.exe` on a Linux 32bit system) directly from the DVD to extract the necessary files to the system directory. For example, you might execute the following commands:

```
mkdir /usr/gams/23.3
cd    /usr/gams/23.3
/dev/dvd/linux/linux_x86_32_sfx.exe
```

4. To mount the GAMS DVD, you may need to be logged in as root. We assume you want to mount the DVD over the directory `/dvd`. If the directory you want to mount over does not exist, you must create it now. Once this directory is created, mount the DVD, using the appropriate command. The correct arguments for the mount command vary from machine to machine. After mounting the DVD, view the `README.TXT` file on it to find the subdirectory containing the GAMS system for your machine.

5. If you transferred the distribution file via the web, check that it has the execute permission set. If you are not sure how to do this, just type in the command, e.g. `chmod 755 linux_x86_32_sfx.exe`.
6. Check if the file `gamslice.txt` exists in the GAMS system directory. The license files is nowadays sent via email. If no license file is present, GAMS will still function in the demonstration mode but can only solve small problems. Student and demonstration systems do not include a license file. A license file can easily be added later, so if you cannot find a license file, you can safely proceed without one.
7. Run the program `./gamsinst`. This will unpack files if necessary. It will also prompt you for default solvers to be used for each class of models. If possible, choose solvers you have licensed since unlicensed solvers will only run in demonstration mode. These solver defaults can be changed or overridden by:
   (a) rerunning `./gamsinst` and resetting the default values
   (b) setting a command line default, e.g. `gams trnsport lp=bdmlp`
   (c) an option statement in the GAMS model, e.g: `option lp=bdmlp;`
8. Add the GAMS system directory to your path (see 'ACCESS TO GAMS' below).
9. To test the installation, log in as a normal user and run a few models from your home directory, but not the GAMS system directory:

```
LP:    trnsport (objective value:  153.675)
NLP:   chenery  (objective value:  1058.9)
MIP:   bid      (optimal solution: 15210109.512)
MINLP: procsel  (optimal solution: 1.9231)
MCP:   scarfmcp (no objective function)
MPSGE: scarfmge (no objective function)
```

10. If you move the GAMS system to another directory, remember to rerun `./gamsinst`. It is also good practice to rerun `./gamsinst` when you add or change your license file if this has changed the set of licensed solvers.

ACCESS TO GAMS

To run GAMS you must be able to execute the GAMS programs located in the GAMS system directory. There are several ways to do this. Remember that the GAMS system directory in the examples below may not correspond to the directory where you have installed your GAMS system.

1. If you are using the C shell (`csh`) and its variants you can modify your `.cshrc` file by adding the second of the two lines given below:

```
set path = (/your/previous/path/setting )
set path = ( $path /usr/gams/23.3 ) # new
```

2. Those of you using the Bourne (`sh`) or Korn (`ksh`) shells and their variants can modify their `.profile` file by adding the second of the three lines below:

```
PATH=/your/previous/path/setting
PATH=$PATH:/usr/gams/23.3  # new
export PATH
```

   You should log out and log in again after you have made any changes to your path.

3. You may prefer to use an alias for the names of the programs instead of modifying the path as described above. C shell users can use the following commands on the command line or in their `.cshrc` file:

```
alias gams /usr/gams/23.3/gams
alias gamslib /usr/gams/23.3/gamslib
alias gamsbatch /usr/gams/23.3/gamsbatch
```

   The correct Bourne or Korn shell syntax (either command line or `.profile`) is:

```
alias gams=/usr/gams/23.3/gams
alias gamslib=/usr/gams/23.3/gamslib
alias gamsbatch=/usr/gams/23.3/gamsbatch
```

Again, you should log out and log in in order to put the alias settings in `.cshrc` or `.profile` into effect.

4. Casual users can always type the absolute path names of the GAMS programs, e.g.:
   `/usr/gams/23.3/gams trnsport`

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