GALAHAD   PRESOLVE

1 SUMMARY

Presolving consists in simplifying the formulation of a quadratic programming problem using simple transformations, in order to produce a "reduced" problem in a "standard form". This reduced problem is then passed to a solver. Once the reduced problem has been solved, it is then "restored" to obtain its solution in the context of its original formulation.

`GALAHAD_PRESOLVE` is a package that applies presolving techniques to the linear or quadratic program

$$\text{minimize } q(\mathbf{x}) = f + \mathbf{g}^T \mathbf{x} + \tfrac{1}{2} \mathbf{x}^T \mathbf{H} \mathbf{x} \tag{1.1}$$

subject to the general linear constraints

$$c_i^l \leq \mathbf{a}_i^T \mathbf{x} \leq c_i^u, \quad i = 1, \ldots, m, \tag{1.2}$$

and the simple bound constraints

$$x_j^l \leq x_j \leq x_j^u, \quad j = 1, \ldots, n, \tag{1.3}$$

where the scalar f, the n-dimensional vectors $\mathbf{g}$, $\mathbf{x}^l$ and $\mathbf{x}^u$, the m-dimensional vectors $\mathbf{c}^l$ and $\mathbf{c}^u$, the $n \times n$ symmetric matrix $\mathbf{H}$ and the $m \times n$ matrix $\mathbf{A}$ (whose rows are the vectors $\mathbf{a}_i^T$) are given. Furthermore, bounds on the Lagrange multipliers $\mathbf{y}$ associated to the general linear constraints and on the dual variables $\mathbf{z}$ associated to the bound constraints are also imposed in the form

$$y_i^l \leq \mathbf{y}_i \leq y_i^u, \quad i = 1, \ldots, m,$$

and

$$z_i^l \leq \mathbf{z}_i \leq z_i^u, \quad i = 1, \ldots, z,$$

where the m-dimensional vectors $\mathbf{y}^l$ and $\mathbf{y}^u$, as well as the n-dimensional vectors $\mathbf{x}^l$ and $\mathbf{x}^u$ are given. Any component of $\mathbf{c}^l$, $\mathbf{c}^u$, $\mathbf{x}^l$, $\mathbf{x}^u$, $\mathbf{y}^l$, $\mathbf{y}^u$, $\mathbf{z}^l$ or $\mathbf{z}^u$ may be infinite.

ATTRIBUTES — Versions: `GALAHAD_PRESOLVE_single`, `GALAHAD_PRESOLVE_double`. **Uses:** `GALAHAD_SMT`, `GALAHAD_QPT`, `GALAHAD_SPECFILE`, `GALAHAD_SORT`, `GALAHAD_SYMBOLS`. **Date:** March 2002. **Origin:** N. I. M. Gould, Rutherford Appleton Laboratory, and Ph. L. Toint, The University of Namur, Belgium. **Language:** Fortran 95 + TR 15581 or Fortran 2003.

2 HOW TO USE THE PACKAGE

Access to the package requires a `USE` statement such as

Single precision version

        USE GALAHAD_PRESOLVE_single

Double precision version

        USE GALAHAD_PRESOLVE_double

If it is required to use both modules at the same time, the derived types `SMT_problem_type`, `QPT_problem_type`, `PRESOLVE_control_type`, `PRESOLVE_inform_type` and `PRESOLVE_data_type` (Section 2.3) and the five subroutines `PRESOLVE_initialize`, `PRESOLVE_read_specfile`, `PRESOLVE_apply`, `PRESOLVE_restore`, `PRESOLVE_terminate`, (Section 2.4) must be renamed on one of the `USE` statements.

2.1 Matrix storage formats

Both the Hessian matrix $\mathbf{H}$ and the constraint Jacobian $\mathbf{A}$ may be stored in a variety of input formats.

2.1.1 Dense storage format

The matrix $\mathbf{A}$ is stored as a compact dense matrix by rows, that is, the values of the entries of each row in turn are stored in order within an appropriate real one-dimensional array. Component $n*(i-1)+j$ of the storage array `A%val` will hold the value a_{ij} for $i = 1,\ldots,m$, $j = 1,\ldots,n$. Since $\mathbf{H}$ is symmetric, only the lower triangular part (that is the part h_{ij} for $1 \leq j \leq i \leq n$) need be held. In this case the lower triangle will be stored by rows, that is component $i*(i-1)/2+j$ of the storage array `H%val` will hold the value h_{ij} (and, by symmetry, h_{ji}) for $1 \leq j \leq i \leq n$.

2.1.2 Sparse co-ordinate storage format

Only the nonzero entries of the matrices are stored. For the l-th entry of $\mathbf{A}$, its row index i, column index j and value a_{ij} are stored in the l-th components of the integer arrays `A%row`, `A%col` and real array `A%val`, respectively. The order is unimportant, but the total number of entries `A%ne` is also required. The same scheme is applicable to $\mathbf{H}$ (thus requiring integer arrays `H%row`, `H%col`, a real array `H%val` and an integer value `H%ne`), except that only the entries in the lower triangle need be stored.

2.1.3 Sparse row-wise storage format

Again only the nonzero entries are stored, but this time they are ordered so that those in row i appear directly before those in row $i+1$. For the i-th row of $\mathbf{A}$, the i-th component of a integer array `A%ptr` holds the position of the first entry in this row, while `A%ptr` $(m+1)$ holds the total number of entries plus one. The column indices j and values a_{ij} of the entries in the i-th row are stored in components $l = $ `A%ptr`(i), $\ldots$,`A%ptr` $(i+1)-1$ of the integer array `A%col`, and real array `A%val`, respectively. The same scheme is applicable to $\mathbf{H}$ (thus requiring integer arrays `H%ptr`, `H%col`, and a real array `H%val`), except that only the entries in the lower triangle need be stored.

For sparse matrices, this scheme almost always requires less storage than its predecessor.

2.1.4 Diagonal storage format

If $\mathbf{H}$ is diagonal (i.e., $h_{ij} = 0$ for all $1 \leq i \neq j \leq n$) only the diagonals entries h_{ii}, $1 \leq i \leq n$, need be stored, and the first n components of the array `H%val` may be used for the purpose. There is no sensible equivalent for the non-square $\mathbf{A}$.

2.2 The GALAHAD symbols

The following description make use of "symbols" that are publicly available in the GALAHAD_SYMBOLS module. These symbols are conventional names given to specific integer values, that allow a more natural specification of the various options and parameters of the package. Each symbol provided in the SYMBOLS module is of the form `GALAHAD_NAME`, where `NAME` is the name of the symbol. For clarify and conciseness, we will represent such a symbol by GALAHAD_NAME (in sans-serif upper case font) in what follows. See Section 5 to see how symbols may be used in the program unit that calls the PRESOLVE subroutines.

2.3 The derived data types

Six derived data types are accessible from the package.

2.3.1 The derived data type for holding matrices

The derived data type `SMT_TYPE` is used to hold the matrices **A** and **H**. The components of `SMT_TYPE` used here are:

m   is a scalar component of type default `INTEGER`, that holds the number of rows in the matrix.

n   is a scalar component of type default `INTEGER`, that holds the number of columns in the matrix.

ne   is a scalar variable of type default `INTEGER`, that either holds the number of matrix entries or is used to flag the storage scheme used.

val   is a rank-one allocatable array of type default `REAL` (double precision in `GALAHAD_PRESOLVE_double`) and dimension at least `ne`, that holds the values of the entries. Each pair of off-diagonal entries $h_{ij} = h_{ji}$ of a *symmetric* matrix **H** is represented as a single entry (see §2.1.1–2.1.3). Any duplicated entries that appear in the sparse co-ordinate or row-wise schemes will be summed.

row   is a rank-one allocatable array of type default `INTEGER`, and dimension at least `ne`, that may hold the row indices of the entries. (see §2.1.2).

col   is a rank-one allocatable array of type default `INTEGER`, and dimension at least `ne`, that may the column indices of the entries (see §2.1.2–2.1.3).

ptr   is a rank-one allocatable array of type default `INTEGER`, and dimension at least `m + 1`, that may hold the pointers to the first entry in each row (see §2.1.3).

2.3.2 The derived data type for holding the problem

The derived data type `QPT_problem_type` is used to hold the problem. The components of `QPT_problem_type` are:

new_problem_structure is a scalar variable of type default `LOGICAL`, that is `.TRUE.` if this is the first (or only) problem in a sequence of problems with identical "structure" to be attempted, and `.FALSE.` if a previous problem with the same "structure" (but different numerical data) has been solved. We say that two problems have the same structure if they differ only in their components of type `REAL`, which means that they share the same dimensions and matrix sparsity patterns. See Section 4 for a description of how the package may be applied to more than one problem with the same structure.

   When a `.TRUE.` value is specified for this component on entry in `PRESOLVE_apply` (see below), this routine performs extensive checks on the consistency of the `problem` structure and also allocates the necessary problem dependent workspace. It is thus mandatory that the `.TRUE.` value is used on the first call to `PRESOLVE_apply`, but the `.FALSE.` value should be used for any subsequent call to this routine for problems with the same structure.

n   is a scalar variable of type default `INTEGER`, that holds the number of optimization variables, *n*.

m   is a scalar variable of type default `INTEGER`, that holds the number of general linear constraints, *m*.

H   is scalar variable of type `SMT_TYPE` that holds the Hessian matrix **H**. The following components are used:

   H%type is an allocatable array of rank one and type default `CHARACTER`, that is used to indicate the storage scheme used. If the dense storage scheme (see Section 2.1.1) is used, the first five components of H%type must contain the string `DENSE`. For the sparse co-ordinate scheme (see Section 2.1.2), the first ten components of H%type must contain the string `COORDINATE`, for the sparse row-wise storage scheme (see Section 2.1.3), the first fourteen components of H%type must contain the string `SPARSE_BY_ROWS`, and for the diagonal storage scheme (see Section 2.1.4), the first eight components of H%type must contain the string `DIAGONAL`.

   For convenience, the procedure `SMT_put` may be used to allocate sufficient space and insert the required keyword into H%type. For example, if `prob` is of derived type `PRESOLVE_problem_type` and involves a Hessian we wish to store using the co-ordinate scheme, we may simply

---

```
CALL SMT_put( prob%H%type, 'COORDINATE' )
```

See the documentation for the GALAHAD package SMT for further details on the use of SMT_put.

H%ne is a scalar variable of type default INTEGER, that holds the number of entries in the **lower triangular** part of **H** in the sparse co-ordinate storage scheme (see Section 2.1.2). It need not be set for any of the other three schemes.

H%val is a rank-one allocatable array of type default REAL (double precision in GALAHAD_PRESOLVE_double), that holds the values of the entries of the **lower triangular** part of the Hessian matrix **H** in any of the storage schemes discussed in Section 2.1.

H%row is a rank-one allocatable array of type default INTEGER, that holds the row indices of the **lower triangular** part of **H** in the sparse co-ordinate storage scheme (see Section 2.1.2). It need not be allocated for any of the other three schemes.

H%col is a rank-one allocatable array variable of type default INTEGER, that holds the column indices of the **lower triangular** part of **H** in either the sparse co-ordinate (see Section 2.1.2), or the sparse row-wise (see Section 2.1.3) storage scheme. It need not be allocated when the dense or diagonal storage schemes are used.

H%ptr is a rank-one allocatable array of dimension n+1 and type default INTEGER, that holds the starting position of each row of the **lower triangular** part of **H**, as well as the total number of entries plus one, in the sparse row-wise storage scheme (see Section 2.1.3). It need not be allocated when the other schemes are used.

gradient_kind is a scalar variable of type default INTEGER, that is used to indicate whether the components of the gradient **g** have special or general values. Possible values for gradient_kind are:

0 In this case, $\mathbf{g} = 0$.

1 In this case, $g_i = 1$ for $i = 1, \ldots, n$.

$\neq$ 0,1 In this case, general values of **g** will be used, and will be provided by the user in the component G.

G is a rank-one allocatable array of dimension n and type default REAL (double precision in GALAHAD_PRESOLVE_double), that holds the gradient **g** of the linear term of the quadratic objective function. The j-th component of G, $j = 1, \ldots, n$, contains $\mathbf{g}_j$. If gradient_kind = 0, 1, G need not be allocated.

f is a scalar variable of type default REAL (double precision in GALAHAD_PRESOLVE_double), that holds the constant term, f, in the objective function.

A is scalar variable of type SMT_TYPE that holds the Jacobian matrix **A**. The following components are used:

A%type is an allocatable array of rank one and type default CHARACTER, that is used to indicate the storage scheme used. If the dense storage scheme (see Section 2.1.1) is used, the first five components of A%type must contain the string DENSE. For the sparse co-ordinate scheme (see Section 2.1.2), the first ten components of A%type must contain the string COORDINATE, while for the sparse row-wise storage scheme (see Section 2.1.3), the first fourteen components of A%type must contain the string SPARSE_BY_ROWS.

Just as for H%type above, the procedure SMT_put may be used to allocate sufficient space and insert the required keyword into A%type. Once again, if prob is of derived type PRESOLVE_problem_type and involves a Jacobian we wish to store using the sparse row-wise storage scheme, we may simply

```
CALL SMT_put( prob%A%type, 'SPARSE_BY_ROWS' )
```

A%ne is a scalar variable of type default INTEGER, that holds the number of entries in **A** in the sparse co-ordinate storage scheme (see Section 2.1.2). It need not be set for either of the other two schemes.

A%val is a rank-one allocatable array of type default REAL (double precision in GALAHAD_PRESOLVE_double),
that holds the values of the entries of the Jacobian matrix **A** in any of the storage schemes discussed in
Section 2.1.

A%row is a rank-one allocatable array of type default INTEGER, that holds the row indices of **A** in the sparse co-
ordinate storage scheme (see Section 2.1.2). It need not be allocated for either of the other two schemes.

A%col is a rank-one allocatable array variable of type default INTEGER, that holds the column indices of **A** in
either the sparse co-ordinate (see Section 2.1.2), or the sparse row-wise (see Section 2.1.3) storage scheme.
It need not be allocated when the dense storage scheme is used.

A%ptr is a rank-one allocatable array of dimension m+1 and type default INTEGER, that holds the starting po-
sition of each row of **A**, as well as the total number of entries plus one, in the sparse row-wise storage
scheme (see Section 2.1.3). It need not be allocated when the other schemes are used.

C_l is a rank-one allocatable array of dimension m and type default REAL (double precision in GALAHAD_PRESOLVE-
_double), that holds the vector of lower bounds $\mathbf{c}^l$ on the general constraints. The i-th component of C_l,
$i = 1, \ldots, m$, contains $\mathbf{c}_i^l$. Infinite bounds are allowed by setting the corresponding components of C_l to any value
smaller than -infinity, where infinity is a component of the control array control (see Section 2.3.3).

C_u is a rank-one allocatable array of dimension m and type default REAL (double precision in GALAHAD_PRESOLVE-
_double), that holds the vector of upper bounds $\mathbf{c}^u$ on the general constraints. The i-th component of C_u,
$i = 1, \ldots, m$, contains $\mathbf{c}_i^u$. Infinite bounds are allowed by setting the corresponding components of C_u to any
value larger than infinity, where infinity is a component of the control array control (see Section 2.3.3).

C_status is a rank-one allocatable array of dimension m and type default INTEGER, that holds the status of the problem
constraints (active or inactive). A constraint is said to be inactive if it is not included in the formulation of the
considered quadratic program.

X_l is a rank-one allocatable array of dimension n and type default REAL (double precision in GALAHAD_PRESOLVE_-
double), that holds the vector of lower bounds $\mathbf{x}^l$ on the the variables. The j-th component of X_l, $j = 1, \ldots, n$,
contains $\mathbf{x}_j^l$. Infinite bounds are allowed by setting the corresponding components of X_l to any value smaller
than -infinity, where infinity is a component of the control array control (see Section 2.3.3).

X_u is a rank-one allocatable array of dimension n and type default REAL (double precision in GALAHAD_PRESOLVE-
_double), that holds the vector of upper bounds $\mathbf{x}^u$ on the variables. The j-th component of X_u, $j = 1, \ldots, n$,
contains $\mathbf{x}_j^u$. Infinite bounds are allowed by setting the corresponding components of X_u to any value larger
than that infinity, where infinity is a component of the control array control (see Section 2.3.3).

X_status is a rank-one allocatable array of dimension n and type default INTEGER, that holds the status of the prob-
lem variables (active or inactive). Variable j is said to be inactive if its value is fixed to the current value of
problem%X(j), in which case it can be seen as a parameter of the quadratic program.

Y_l is a rank-one allocatable array of dimension m and type default REAL (double precision in GALAHAD_PRESOLVE_-
double), that holds the vector of lower bounds $\mathbf{y}^l$ on the the multipliers. The j-th component of Y_l, $j = 1, \ldots, m$,
contains $\mathbf{y}_j^l$. Infinite bounds are allowed by setting the corresponding components of Y_l to any value smaller
than -infinity, where infinity is a component of the control array control (see Section 2.3.3).

Y_u is a rank-one allocatable array of dimension m and type default REAL (double precision in GALAHAD_PRESOLVE-
_double), that holds the vector of upper bounds $\mathbf{y}^u$ on the multipliers. The j-th component of Y_u, $j = 1, \ldots, m$,
contains $\mathbf{y}_j^u$. Infinite bounds are allowed by setting the corresponding components of Y_u to any value larger
than that infinity, where infinity is a component of the control array control (see Section 2.3.3).

Z_l is a rank-one allocatable array of dimension n and type default REAL (double precision in GALAHAD_PRESOLVE-
_double), that holds the vector of lower bounds $\mathbf{z}^l$ on the the dual variables. The j-th component of Z_l, $j =
1, \ldots, n$, contains $\mathbf{z}_j^l$. Infinite bounds are allowed by setting the corresponding components of Z_l to any value
smaller than -infinity, where infinity is a component of the control array control (see Section 2.3.3).

Z_u   is a rank-one allocatable array of dimension n and type default REAL (double precision in GALAHAD_PRESOLVE_-double), that holds the vector of upper bounds $\mathbf{z}^u$ on the dual variables. The j-th component of Z_u, $j = 1,\ldots,n$, contains $\mathbf{z}_j^u$. Infinite bounds are allowed by setting the corresponding components of Z_u to any value larger than that infinity, where infinity is a component of the control array control (see Section 2.3.3).

X   is a rank-one allocatable array of dimension n and type default REAL (double precision in GALAHAD_PRESOLVE-_double), that holds the values $\mathbf{x}$ of the optimization variables. The j-th component of X, $j = 1,\ldots,n$, contains x_j.

Z   is a rank-one allocatable array of dimension n and type default REAL (double precision in GALAHAD_PRESOLVE_-double), that holds the values $\mathbf{z}$ of estimates of the dual variables corresponding to the simple bound constraints (see Section 4). The j-th component of Z, $j = 1,\ldots,n$, contains z_j.

C   is a rank-one allocatable array of dimension m and type default REAL (double precision in GALAHAD_PRESOLVE_-double), that holds the values $\mathbf{Ax}$ of the constraints. The i-th component of C, $i = 1,\ldots,m$, contains $\mathbf{a}_i^T\mathbf{x} \equiv (\mathbf{Ax})_i$.

Y   is a rank-one allocatable array of dimension m and type default REAL (double precision in GALAHAD_PRESOLVE-_double), that holds the values $\mathbf{y}$ of estimates of the Lagrange multipliers corresponding to the general linear constraints (see Section 4). The i-th component of Y, $i = 1,\ldots,m$, contains y_i.

2.3.3 The derived data type for holding control parameters

The derived data type PRESOLVE_control_type is used to hold controlling data. Default values may be obtained by calling PRESOLVE_initialize (see Section 2.4.1), while individual components may also be changed by calling PRESOLVE_read_specfile (see Section 2.6.1). The components of PRESOLVE_control_type are:

termination is a scalar variable of type default INTEGER, that determines the strategy for terminating the presolve analysis. Possible values are:

> GALAHAD_REDUCED_SIZE: presolving is continued as long as one of the sizes of the problem (n, m, sizes of $\mathbf{A}$ and $\mathbf{H}$) is being reduced;

> GALAHAD_FULL_PRESOLVE: presolving is continued as long as problem transformations remain possible.

> Note that the maximum number of analysis passes (max_nbr_passes) and the maximum number of problem transformations (max_nbr_transforms) set an upper limit on the presolving effort irrespective of the choice of termination. The only effect of this latter parameter is to allow for early termination. The default is termination = GALAHAD_REDUCED_SIZE.

max_nbr_transforms is a scalar variable of type default INTEGER, that determines the maximum number of problem transformations. The default is max_nbr_transforms = 1000000.

max_nbr_passes is a scalar variable of type default INTEGER, that determines the maximum number of analysis passes for problem analysis during a single call to PRESOLVE_apply. The default is max_nbr_passes = 25.

c_accuracy is a scalar variable of type default REAL (double precision in GALAHAD_PRESOLVE_double), that holds the relative accuracy at which the general linear constraints are satisfied at the exit of the solver. Note that this value is not used before the restoration of the problem. The default is c_accuracy = 10^{-4} in single precision, and c_accuracy = 10^{-6} in double precision.

z_accuracy is a scalar variable of type default REAL (double precision in GALAHAD_PRESOLVE_double), that holds the relative accuracy at which the dual feasibility constraints are satisfied at the exit of the solver. Note that this value is not used before the restoration of the problem. The default is z_accuracy = 10^{-4} in single precision, and z_accuracy = 10^{-6} in double precision.

infinity is a scalar variable of type default REAL (double precision in GALAHAD_PRESOLVE_double), that holds the value beyond which a number is deemed equal to plus infinity (minus infinity being defined as its opposite) The default is $\texttt{infinity} = 10^{19}$.

out   is a scalar variable of type default INTEGER, that holds the unit number associated with the device used for printout. The default is out = 6.

errout is a scalar variable of type default INTEGER, that holds the unit number associated with the device used for error ouput. The default is errout = 6.

print_level is a scalar variable of type default INTEGER, that holds the level of printout requested by the user. See Section 2.7. The default is print_level = GALAHAD_SILENT.

dual_transformations is a scalar variable of type default LOGICAL, that has the value .TRUE. if dual transformations of the problem are allowed. Note that this implies that the reduced problem is solved accurately (for the dual feasibility condition to hold) as to be able to restore the problem to the original constraints and variables. The value .FALSE. prevents dual transformations to be applied, thus allowing for inexact solution of the reduced problem. The setting of this control parameter overides the values of get_z, get_z_bounds, get_y, get_y_bounds, dual_constraints_freq, singleton_columns_freq, doubleton_columns_freq, z_accuracy and check_dual_feasibility. The default is dual_transformations = .TRUE..

redundant_xc is a scalar variable of type default LOGICAL, that has the value .TRUE. if redundant variables and constraints (that is variables that don't occur in the objective function and are either unbounded above with all their coefficients in **A** being positive for constraints that are unbounded above and negative for constraints that are unbounded below, or unbounded below with all their coefficients in **A** being positive for constraints that are unbounded below or negative for all constraints that are unbounded above) are to be removed from the problem with their associated constraints before any other problem transformation is attempted. The default is redundant_xc = .TRUE..

primal_constraints_freq is a scalar variable of type default INTEGER, that holds the frequency of primal constraints analysis in terms of presolving passes. A value of 2 indicates that primal constraints are analyzed every 2 presolving passes. A zero value indicates that they are never analyzed. The default is primal_constraints_freq = 1.

dual_constraints_freq is a scalar variable of type default INTEGER, that holds the frequency of dual constraints analysis in terms of presolving passes. A value of 2 indicates that dual constraints are analyzed every 2 presolving passes. A zero value indicates that they are never analyzed. The default is dual_constraints_freq = 1.

singleton_columns_freq is a scalar variable of type default INTEGER, that holds the frequency of singleton column analysis in terms of presolving passes. A value of 2 indicates that singleton columns are analyzed every 2 presolving passes. A zero value indicates that they are never analyzed. The default is singleton_columns_freq = 1.

doubleton_columns_freq is a scalar variable of type default INTEGER, that holds the frequency of doubleton column analysis in terms of presolving passes. A value of j indicates that doubleton columns are analyzed every 2 presolving passes. A zero value indicates that they are never analyzed. The default is doubleton_columns_freq = 1.

unc_variables_freq is a scalar variable of type default INTEGER, that holds the frequency of the attempts to fix linearly unconstrained variables, expressed in terms of presolving passes. A value of 2 indicates that attempts are made every 2 presolving passes. A zero value indicates that no attempt is ever made. The default is unc_variables_freq = 1.

`dependent_variables_freq` is a scalar variable of type default `INTEGER`, that holds the frequency of search for dependent variables in terms of presolving passes. A value of 2 indicates that dependent variables are searched for every 2 presolving passes. A zero value indicates that no attempt is ever made to detect such variables. The default is `dependent_variables_freq` = 1.

`sparsify_rows_freq` is a scalar variable of type default `INTEGER`, that holds the frequency of the attempts to make A sparser in terms of presolving passes. A value of 2 indicates that attempts are made every 2 presolving passes. A zero value indicates that no attempt is ever made. The default is `sparsify_rows_freq` = 1.

`max_fill` is a scalar variable of type default `INTEGER`, that holds the maximum percentage of fill in each row of **A**. Note that this is a row-wise measure: globally fill never exceeds the storage initially used for **A**, no matter how large `max_fill` is chosen. If `max_fill` is negative, no limit is put on row fill. The default is `max_fill` = -1 (no limit).

`transf_file_nbr` is a scalar variable of type default `INTEGER`, that holds the unit number to be associated with the file(s) used for saving problem transformations on a disk file. The default is `transf_file_nbr` = 52.

`transf_buffer_size` is a scalar variable of type default `INTEGER`, that holds the number of transformations that can be kept in memory at once (that is without being saved on a disk file). The default is `transf_buffer_size` = 50000.

`transf_file_status` is a scalar variable of type default `INTEGER`, that holds the exit status of the file where problem transformations are saved:

  `KEEP`: the file is not deleted after program termination,

  `DELETE`: the file is not deleted after program termination.

  The default is `transf_file_status` = GALAHAD_KEEP.

`transf_file_name` is a scalar variable of type default `INTEGER`, that holds the name of the file (to be) used for storing problem transformation on disk. Note that this parameter must be identical for all calls to `PRESOLVE` that follows `PRESOLVE_read_specfile`. It can then only be changed after calling `PRESOLVE_terminate`. The default is `transf_file_name` = transf.sav.

`y_sign` is a scalar variable of type default `INTEGER`, that determines the convention of sign used for the multipliers associated with the general linear constraints. Possible values are:

  GALAHAD_POSITIVE: all multipliers corresponding to active inequality constraints are non-negative for lower bound constraints and non-positive for upper bounds constraints;

  GALAHAD_NEGATIVE: all multipliers corresponding to active inequality constraints are non-positive for lower bound constraints and non-negative for upper bounds constraints.

  The default is `y_sign` = GALAHAD_POSITIVE.

`inactive_y` is a scalar variable of type default `INTEGER`, that determines whether or not the multipliers corresponding to general linear constraints that are inactive at the unreduced point corresponding to the reduced point on input of `PRESOLVE_restore` must be set to zero. Possible values are:

  GALAHAD_FORCE_TO_ZERO: all multipliers corresponding to inactive general linear constraints are forced to zero, possibly at the expense of deteriorating the dual feasibility condition. Note that this option is inactive unless `get_y = get_c get_c_bounds = .TRUE.`.

  GALAHAD_LEAVE_AS_IS: multipliers corresponding to inactive general linear constraints are left unaltered.

  The default is `inactive_y` = GALAHAD_LEAVE_AS_IS.

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z_sign is a scalar variable of type default INTEGER, that determines the convention of sign used for the dual variables associated with the bound constraints. Possible values are:

GALAHAD_POSITIVE: all dual variables corresponding to active lower bounds are non-negative, and non-positive for active upper bounds;

GALAHAD_NEGATIVE: all dual variables corresponding to active lower bounds are non-positive, and non-negative for active upper bounds.

The default is z_sign = GALAHAD_POSITIVE.

inactive_z is a scalar variable of type default INTEGER, that determines whether or not the dual variables corresponding to bound constraints that are inactive at the unreduced point corresponding to the reduced point on input of PRESOLVE_restore must be set to zero. Possible values are:

GALAHAD_FORCE_TO_ZERO: all dual variables corresponding to inactive bounds are forced to zero, possibly at the expense of deteriorating the dual feasibility condition. Note that this option is inactive unless get_z = get_x get_x_bounds = .TRUE..

GALAHAD_LEAVE_AS_IS: dual variables corresponding to inactive bounds are left unaltered.

The default is inactive_z = GALAHAD_LEAVE_AS_IS.

final_x_bounds is a scalar variable of type default INTEGER, that holds the type of final bounds on the variables returned by the package. This parameter can take the values:

GALAHAD_TIGHTEST: the final bounds are the tightest bounds known on the variables (at the risk of being redundant with other constraints, which may cause degeneracy);

GALAHAD_NON_DEGENERATE: the best known bounds that are known to be non-degenerate. This option implies that an additional real workspace of size 2 * problem%n must be allocated;

GALAHAD_LOOSEST: the loosest bounds that are known to keep the problem equivalent to the original problem. This option also implies that an additional real workspace of size 2 * problem%n must be allocated;

Note that his parameter must be identical for all calls to PRESOLVE following PRESOLVE_read_specfile. The default is final_x_bounds = GALAHAD_TIGHTEST.

final_z_bounds is a scalar variable of type default INTEGER, that holds the type of final bounds on the dual variables returned by the package. This parameter can take the values:

GALAHAD_TIGHTEST: the final bounds are the tightest bounds known on the dual variables (at the risk of being redundant with other constraints, which may cause degeneracy);

GALAHAD_NON_DEGENERATE: the best known bounds that are known to be non-degenerate. This option implies that an additional real workspace of size 2 * problem%n must be allocated;

GALAHAD_LOOSEST: the loosest bounds that are known to keep the problem equivalent to the original problem. This option also implies that an additional real workspace of size 2 * problem%n must be allocated;

Note that his parameter must be identical for all calls to PRESOLVE following PRESOLVE_read_specfile. The default is final_z_bounds = GALAHAD_TIGHTEST.

final_c_bounds is a scalar variable of type default INTEGER, that holds the type of final bounds on the constraints returned by the package. This parameter can take the values:

GALAHAD_TIGHTEST: the final bounds are the tightest bounds known on the constraints (at the risk of being redundant with other constraints, which may cause degeneracy);

GALAHAD_NON_DEGENERATE: the best known bounds that are known to be non-degenerate. This option implies that an additional real workspace of size 2 * problem%n must be allocated;

GALAHAD_LOOSEST: the loosest bounds that are known to keep the problem equivalent to the original problem. This option also implies that an additional real workspace of size 2 * problem%n must be allocated;

Note that his parameter must be identical for all calls to PRESOLVE following PRESOLVE_read_specfile. If different from TIGHTEST, its value must be equal to that of final_x_bounds. The default is final_c_bounds = GALAHAD_TIGHTEST.

final_y_bounds is a scalar variable of type default INTEGER, that holds the type of final bounds on the multipliers returned by the package. This parameter can take the values:

GALAHAD_TIGHTEST: the final bounds are the tightest bounds known on the multipliers (at the risk of being redundant with other constraints, which may cause degeneracy);

GALAHAD_NON_DEGENERATE: the best known bounds that are known to be non-degenerate. This option implies that an additional real workspace of size 2 * problem%n must be allocated;

GALAHAD_LOOSEST: the loosest bounds that are known to keep the problem equivalent to the original problem. This option also implies that an additional real workspace of size 2 * problem%n must be allocated;

Note that his parameter must be identical for all calls to PRESOLVE following PRESOLVE_read_specfile. The default is final_y_bounds = GALAHAD_TIGHTEST.

check_primal_feasibility is a scalar variable of type default INTEGER, that holds the level of feasibility check (on the values of **x**) at the start of the restoration phase. This parameter can take the values:

GALAHAD_NONE: no check at all;

GALAHAD_BASIC: the primal constraints are recomputed at **x** and a message issued if the computed value does not match the input value, or if it is out of bounds (if print_level ≥ GALAHAD_ACTION);

GALAHAD_SEVERE: the same as for GALAHAD_BASIC, but PRESOLVE is terminated if an incompatibilty is detected.

The default is check_primal_feasibility = GALAHAD_NONE.

check_dual_feasibility is a scalar variable of type default INTEGER, that holds the level of dual feasibility check (on the values of **x**, **y** and **z**) at the start of the restoration phase. This parameter can take the values:

GALAHAD_NONE: no check at all;

GALAHAD_BASIC: the primal constraints are recomputed at $(\mathbf{x}, \mathbf{y}, \mathbf{z})$ and a message issued if the computed value does not match the input value, or if it is out of bounds (if print_level ≥ GALAHAD_ACTION);

GALAHAD_SEVERE: the same as for GALAHAD_BASIC, but PRESOLVE is terminated if an incompatibilty is detected.

The default is check_dual_feasibility = GALAHAD_NONE.

get_q is a scalar variable of type default LOGICAL, that must be set to .TRUE. if the value of the objective function must be reconstructed by PRESOLVE_restore from the (solved) reduced problem. The default is get_q = .TRUE..

get_f is a scalar variable of type default LOGICAL, that must be set to .TRUE. if the value of the objective function's independent term is to be be reconstructed byPRESOLVE_ restore from the (solved) reduced problem. The default is get_f = .TRUE..

get_g is a scalar variable of type default LOGICAL, that must be set to .TRUE. if the values of the objective function's gradient is to be be reconstructed by PRESOLVE_restore from the (solved) reduced problem. The default is get_g = .TRUE..

get_H is a scalar variable of type default LOGICAL, that must be set to .TRUE. if the values of the objective function's
    Hessian is to be be reconstructed by PRESOLVE_restore from the (solved) reduced problem. The default is
    get_H = .TRUE..

get_A is a scalar variable of type default LOGICAL, that must be set to .TRUE. if the values of the constraints' Jacobian
    is to be be reconstructed by PRESOLVE_restore from the (solved) reduced problem. The default is get_A =
    .TRUE..

get_x is a scalar variable of type default LOGICAL, that must be set to .TRUE. if the value of the variables must be
    reconstructed by PRESOLVE_restore from the (solved) reduced problem. The default is get_x = .TRUE..

get_x_bounds is a scalar variable of type default LOGICAL, that must be set to .TRUE. if the values of the bounds on
    the problem variables must be reconstructed by PRESOLVE_restore from the (solved) reduced problem. The
    default is get_x_bounds = .TRUE..

get_z is a scalar variable of type default LOGICAL, that must be set to tt .TRUE. if the value of the dual variables must
    be reconstructed by PRESOLVE_restore from the (solved) reduced problem. The default is get_z = .TRUE..

get_z_bounds is a scalar variable of type default LOGICAL, that must be set to .TRUE. if the values of the bounds on
    the problem dual variables must be reconstructed by PRESOLVE_restore from the (solved) reduced problem. If
    set, this may require to store specific additional information on the problem transformations, therefore increasing
    the storage needed for these transformations. Note that this parameter must be identical for all calls to PRESOLVE
    following PRESOLVE_read_specfile. The default is get_z_bounds = .TRUE..

get_c is a scalar variable of type default LOGICAL, that must be set to tt .TRUE. if the values of the constraints must
    be reconstructed by PRESOLVE_restore from the (solved) reduced problem. The default is get_c = .TRUE..

get_c_bounds is a scalar variable of type default LOGICAL, that must be set to .TRUE. if the values of the bounds on
    the problem constraints must be reconstructed by PRESOLVE_restore from the (solved) reduced problem. The
    default is get_c_bounds = .TRUE..

get_y is a scalar variable of type default LOGICAL, that must be set to tt .TRUE. if the values of the multipliers must
    be reconstructed by PRESOLVE_restore from the (solved) reduced problem. The default is get_y = .TRUE..

get_y_bounds is a scalar variable of type default LOGICAL, that must be set to .TRUE. if the values of the bounds on
    the problem multipliers must be reconstructed by PRESOLVE_restore from the (solved) reduced problem. If set,
    this may require to store specific additional information on the problem transformations, therefore increasing
    the storage needed for these transformations. Note that this parameter must be identical for all calls to PRESOLVE
    following PRESOLVE_read_specfile. The default is get_y_bounds = .TRUE..

pivot_tol is a scalar variable of type default REAL (double precision in GALAHAD_PRESOLVE_double), that holds the
    relative pivot tolerance above which pivoting is considered as numerically stable in transforming the coefficient
    matrix $\mathbf{A}$. A zero value corresponds to a totally unsafeguarded pivoting strategy (potentially unstable). The
    default is pivot_tol = 10^{-6} in single precision, and pivot_tol = 10^{-10} in double precision.

min_rel_improve is a scalar variable of type default REAL (double precision in GALAHAD_PRESOLVE_double), that
    holds the minimum relative improvement in the bounds on $\mathbf{x}$, $\mathbf{y}$ and $\mathbf{z}$ for a tighter bound on these quantities to
    be accepted in the course of the analysis. More formally, if lower is the current value of the lower bound on one
    of the $\mathbf{x}$, $\mathbf{y}$ or $\mathbf{z}$, and if newlower is a tentative tighter lower bound on the same quantity, it is only accepted if

$$\text{newlower} \geq \text{lower} + \text{min\_rel\_improve} * \max(1, |\text{lower}|).$$

Similarly, a tentative tighter upper bound newupper only replaces the current upper bound upper if

$$\text{newupper} \leq \text{upper} - \text{min\_rel\_improve} * \max(1, |\text{upper}|).$$

Note that this parameter must exceed the machine precision significantly. The default is min_rel_improve =
10^{-6} in single precision, and min_rel_improve = 10^{-10} in double precision.

---

max_growth_factor is a scalar variable of type default REAL (double precision in GALAHAD_PRESOLVE_double), that
holds the maximum ratio that is allowed for the absolute value of any data item of the reduced problem compared
to the maximum absolute value of any data item of the original problem. In the course of the presolving process,
any transformation that would result in violating this bound is skipped. The default is min_growth_factor =
10^4 in single precision, and min_growth_factor = 10^8 in double precision.

2.3.4   The derived data type for holding informational parameters

The derived data type PRESOLVE_inform_type is used to hold parameters that give information about the progress and
needs of the algorithm. The components of PRESOLVE_inform_type are:

status is a scalar variable of type default INTEGER, that gives the exit status of the algorithm. See Sections 2.5 and
2.7 for details.

message is a character array of 3 lines of 80 characters each, containing a description of the exit condition on exit,
typically including more information than indicated in the description of status above. It is printed out on
device errout at the end of execution unless print_level is GALAHAD_SILENT.

nbr_transforms is a scalar variable of type default INTEGER, that gives the the final number of problem transforma-
tions, as reported to the user at exit.

2.3.5   The derived data type for holding problem data

The derived data type PRESOLVE_data_type is used to hold all the data for a particular problem, or sequences of
problems with the same structure, between calls of PRESOLVE procedures. This data should be preserved, untouched,
from the initial call to PRESOLVE_initialize to the final call to PRESOLVE_terminate.

2.4   Argument lists and calling sequences

There are five procedures for user calls (see Section 2.6 for further features):

1. The subroutine PRESOLVE_initialize is used to set default values, and initialize private data, before presolving
   one or more problems with the same sparsity and bound structure.

2. The subroutine packagename_read_specfile is used to read the packagename specfile in order to possibly
   modify the algoritmic default parameters (see Section 2.6.1).

3. The subroutine PRESOLVE_apply is called to presolve the problem, that is to reduce it by applying suitable
   problem transformations and permute it to standard form.

4. The subroutine PRESOLVE_restore restores the (solved) reduced problem to the original definition of variables
   and constraints;

5. The subroutine PRESOLVE_terminate is provided to allow the user to automatically deallocate array compo-
   nents of the private data, allocated by PRESOLVE, at the end of the solution process. It is important to do this if
   the data object is re-used for another problem **with a different structure** since PRESOLVE_initialize cannot
   test for this situation, and any existing associated targets will subsequently become unreachable.

2.4.1 The initialization subroutine

Default values for the control parameters are provided as follows:

```
CALL PRESOLVE_initialize( control, inform, data )
```

control is a scalar INTENT(OUT) argument of type PRESOLVE_control_type (see Section 2.3.3). On exit, control
contains default values for the components as described in Section 2.3.3. These values should only be changed
after calling PRESOLVE_initialize.

inform is a scalar INTENT(OUT) argument of type PRESOLVE_inform_type (see Section 2.3.4). A successful call to
the routine PRESOLVE_initialize is indicated when the component status has the value 0. For other return
values of status, see Section 2.5.

data is a scalar INTENT(INOUT) argument of type PRESOLVE_data_type (see Section 2.3.5). It is used to hold data
about the problem being solved. It should never be altered by the user.

2.4.2 The subroutine that applies presolving transformations to the problem

The presolving algorithm is called as follows:

```
CALL PRESOLVE_apply( problem, control, inform, data )
```

Such a call must always be preceded by a call to PRESOLVE_initialize.

problem is a scalar INTENT(OUT) argument of type QPT_problem_type (see Section 2.3.2) that contains the problem
statement. It is used to hold data about the problem being solved. Users are free to choose whichever of the three
matrix formats described in Section 2.1 is appropriate for **A** and **H** for their application. Some components of
the problem structure need not be allocated, in which case they will be assigned suitable default values. These
components, their size and the associated default values are given in Table 2.1. If the array problem%X_status

component	size	default	component	size	default
X_l	n	$-\infty$	C_l	m	$-\infty$
X_u	n	$+\infty$	C_u	m	$+\infty$
X	n	(problem dependent)	C	m	(problem dependent)
X_status	n	GALAHAD_ACTIVE	C_status	m	GALAHAD_ACTIVE
Z_l	n	$-\infty$	Y_l	m	$-\infty$
Z_u	n	$+\infty$	Y_u	m	$+\infty$
Z	n	(problem dependent)	Y	m	(problem dependent)

Table 2.1: Defaults for unallocated array components of problem.

is allocated on entry, then possible value of its j-th component are as follows:

GALAHAD_INACTIVE: the j-th variable is inactive in the sense that the quadratic program under consideration
ignores it (this is equivalent of fixing x_j to problem%X(j); which obviously requires problem%X to be
allocated);

GALAHAD_ACTIVE: the j-th variable is active (i.e. not inactive).

The meaning of the i-th component of problem%C_status is identical, except that it relates to the i-th constraint:

GALAHAD_INACTIVE: the i-th constraint is inactive in the sense that the quadratic program under consideration
ignores it;

GALAHAD_ACTIVE: the j-th variable is active (i.e. not inactive).

On exit, the problem structure will contain the reduced problem, **with its Hessian and Jacobian matrices stored in sparse row-wise format**. Values for **x**, **z**, **c**, **y** and q will be provided, that are feasible for the reduced problem. Note that not all the memory reserved for the original problem is typically used by the reduced one. However, crucial information that is necessary to restore the problem to its original variables/constraints remains stored in the problem structure, beyond that specified by the dimensions of the reduced problem. Thus modification (for instance by a QP algorithm) of the reduced problem data is possible (except for `problem%X_status` and `problem%C_status`, which should always remain unchanged), but no other data within the problem structure should be altered before calling `PRESOLVE_restore`.

control is a scalar `INTENT(IN)` argument of type `PRESOLVE_control_type` (see Section 2.3.3). Default values may be assigned by calling `PRESOLVE_initialize` prior to the first call to `PRESOLVE_apply`.

info is a scalar `INTENT(OUT)` argument of type `PRESOLVE_inform_type` (see Section 2.3.4). A successful call to the routine `PRESOLVE_apply` is indicated when the component `status` has the value 0. For other return values of `status`, see Section 2.5.

data is a scalar `INTENT(INOUT)` argument of type `PRESOLVE_data_type` (see Section 2.3.5). It is used to hold data about the problem being solved. It must never be altered by the user since the last call to any of the `PRESOLVE` routines.

2.4.3 The restoration subroutine

The (solved) reduced problem is restored in the original variables/constraints and matrix format by calling

        CALL PRESOLVE_restore(problem, control, inform, data)

   The choice of which components of the problem to restore is governed by the different `%get_*` components of the `control` structure (see Section 2.3.3).

problem is a scalar `INTENT(INOUT)` argument of type `QPT_problem_type` (see Section 2.3.2). On entry, it is used to hold data about the solved reduced problem. The values of `problem%X_status` and `problem%C_status` should not have been altered since the exit from `PRESOLVE_apply`.

   On exit, the problem structure will contain selected components of the solved problem restored to the original variables/constraints and/or matrix format. The selection of these elements is specified by setting the `get_*` components of the `control` dummy argument (see Section 2.3.3).

control is a scalar `INTENT(IN)` argument of type `PRESOLVE_control_type` (see Section 2.3.3). In particular, its `get_*` components specify which elements of the (solved) reduced problem must be restored to the original formulation.

info is a scalar `INTENT(OUT)` argument of type `PRESOLVE_inform_type` (see Section 2.3.4). A successful call to the routine `PRESOLVE_restoire` is indicated when the component `status` has the value 0. For other return values of `status`, see Section 2.5.

data is a scalar `INTENT(INOUT)` argument of type `PRESOLVE_data_type` (see Section 2.3.5). It is used to hold data about the problem being solved. It must not have been altered by the user since the last call to any of the `PRESOLVE` routines.

2.4.4 The termination subroutine

All previously allocated workspace arrays for PRESOLVE are deallocated as follows:

        CALL PRESOLVE_terminate(control, info, data)

control is a scalar `INTENT(IN)` argument of type `PRESOLVE_control_type` exactly as for `PRESOLVE_initialize`.

info is a scalar `INTENT(OUT)` argument of type `PRESOLVE_inform_type` exactly as for `PRESOLVE_initialize`. A successful call to `PRESOLVE_terminate` is indicated when the component `status` has the value 0. For other return values of `status`, see Section 2.5.

data is a scalar `INTENT(INOUT)` argument of type `PRESOLVE_data_type` exactly as for `PRESOLVE_solve`, which must not have been altered by the user since the last call to `PRESOLVE_initialize`. On exit, array components will have been deallocated.

Note that a call to this routine is mandatory before `PRESOLVE_apply` is called for a new quadratic program whose structure differs from the current one.

2.5 Warning and error messages

A negative value of `info%status` on exit from `PRESOLVE_initialize`, `PRESOLVE_read_specfile`, `PRESOLVE_apply`, `PRESOLVE_restore`, or `PRESOLVE_terminate` indicates that an error has occurred. No further calls should be made to the four three of these routines until the error has been corrected. Possible values are:

   1. The maximum number of problem transformation has been reached. Note that this exit is not really an error, since the problem can nevertheless be permuted and solved. It merely signals that further problem reduction could possibly be obtained with a larger value of the parameter `max_nbr_transforms`.

  -1. The memory allocation failed.

  -2. A file intended for saving problem transformations could not be opened.

  -3. An IO error occurred while saving transformations on the relevant disk file.

  -4. The machine/compiler only supports less than 8 bits in a single integer (this error is thus very unlikely).

 -21. The problem appears to be primal infeasible.

 -22. The problem appears to be dual infeasible.

 -23. The dimension of the gradient `problem%G` is not equal to the number of variables in the problem `problem%n`.

 -24. The dimension of the vector `problem%H_val` containing the entries of the Hessian is erroneously specified.

 -25. The dimension of the vector `problem%H_ptr` containing the addresses of the first entry of each Hessian row is erroneously specified.

 -26. The dimension of the vector `problem%H_col` containing the column indices of the nonzero Hessian entries is erroneously specified.

 -27. The dimension of the vector `problem%H_row` containing the row indices of the nonzero Hessian entries is erroneously specified.

 -28. The dimension of the vector `problem%A_val` containing the entries of the Jacobian is erroneously specified.

 -29. The dimension of the vector `problem%A_ptr` containing the addresses of the first entry of each Jacobian row is erroneously specified.

 -30. The dimension of the vector `problem%A_col` containing the column indices of the nonzero Jacobian entries is erroneously specified.

 -31. The dimension of the vector `problem%A_row` containing the row indices of the nonzero Jacobian entries is erroneously specified;

-32. The dimension of the vector `problem%X` of variables is incompatible with the problem dimension `problem%n`.

-33. The dimension of the vector `problem%X_l` of lower bounds on the variables is incompatible with the problem dimension `problem%n`.

-34. The dimension of the vector `problem%X_u` of upper bounds on the variables is incompatible with the problem dimension `problem%n`.

-35. The dimension of the vector `problem%Z` of dual variables is incompatible with the problem dimension `problem%n`.

-36. The dimension of the vector `problem%Z_l` of lower bounds on the dual variables is incompatible with the problem dimension `problem%n`.

-37. The dimension of the vector `problem%Z_u` of upper bounds on the dual variables is incompatible with the problem dimension `problem%n`.

-38. The dimension of the vector `problem%C` of constraints values is incompatible with the problem dimension `problem%m`.

-39. The dimension of the vector `problem%C_l` of lower bounds on the constraints is incompatible with the problem dimension `problem%m`.

-40. The dimension of the vector `problem%C_u` of upper bounds on the constraints is incompatible with the problem dimension `problem%m`.

-41. The dimension of the vector `problem%Y` of multipliers values is incompatible with the problem dimension `problem%m`.

-42. The dimension of the vector `problem%Y_l` of lower bounds on the multipliers is incompatible with the problem dimension `problem%m`.

-43. The dimension of the vector `problem%Y_u` of upper bounds on the multipliers is incompatible with the problem dimension `problem%m`.

-44. The problem structure has not been set or has been cleaned up before an attempt to apply `PRESOLVE_apply`.

-45. The problem has not been analyzed before an attempt to permute it.

-46. The problem has not been permuted or fully reduced before an attempt to restore it.

-47. The column indices of a row of the sparse Hessian are not in increasing order, in that they specify an entry above the diagonal.

-48. One of the files containing saved problem transformations has been corrupted between writing and reading.

-49. The dimension of the vector `problem%X_status` of variables' status is incompatible with the problem dimension `problem%n`.

-50. The dimension of the vector `problem%C_status` of constraints' status is incompatible with the problem dimension `problem%m`.

-52. The problem does not contain any (active) variable ($problem\%n \leq 0$).

-53. The problem contains a negative number of constraints ($problem\%m < 0$).

-54. The vectors are too long for the quicksort sorting routine (see the GALAHAD SORT module).

-55. The value of a variable that is obtained in `PRESOLVE_restore` by substitution from a constraint is incoherent with the variable's bounds. This may be due to a relatively loose accuracy on the linear constraints. Try to increase `control%c_accuracy`.

-56. The value of a constraint that is obtained by recomputing its value on input of `PRESOLVE_restore` from the current **x** is incompatible with its declared value or its bounds. This may caused the restored problem to be infeasible.

-57. The value of a dual variable that is obtained by recomputing its value on input of `PRESOLVE_restore` (assuming dual feasibility) from the current values of $(\mathbf{x}, \mathbf{y}, \mathbf{z})$ is incompatible with its declared value. This may caused the restored problem to be infeasible or suboptimal.

-58. A dual variable whose value is nonzero because the corresponding primal is at an artificial bound cannot be zeroed while maintaining dual feasibility (in `PRESOLVE_restore`). This can happen when $(\mathbf{x}, \mathbf{y}, \mathbf{z})$ on input of this routine are not (sufficiently) optimal.

-60. A keyword was not recognized in the analysis of the specification file.

-61. A value was not recognized in the analysis of the specification file.

-63. The vector `problem%G` has not been allocated although it has general values.

-65. The vector `problem%A_val` has not been allocated although `problem%m` > 0.

-66. The vector `problem%A_ptr` has not been allocated although `problem%m` > 0 and **A** is stored in row-wise sparse format.

-67. The vector `problem%A_col` has not been allocated although `problem%m` > 0 and **A** is stored in row-wise sparse format or sparse coordinate format.

-68. The vector `problem%A_row` has not been allocated although `problem%m` > 0 and **A** is stored in sparse coordinate format.

-69. The vector `problem%H_val` has not been allocated although `problem%H_ne` $= -2$ or `problem%H_ne` $= -1$ or `problem%H_ne` > 0.

-70. The vector `problem%H_ptr` has not been allocated although **H** is stored in row-wise sparse format.

-71. The vector `problem%H_col` has not been allocated although **H** is stored in row-wise sparse format or `problem%H_ne` > 0 and **H** is stored sparse coordinate format.

-72. The vector `problem%H_row` has not been allocated although `problem%H_ne` > 0 and **H** is stored in sparse coordinate format.

-73. The value of problem%A_ne is erroneously specified.

-74. The value of problem%H_ne is erroneously specified.

2.6 Further features

In this section, we describe an alternative means of setting control parameters, that is components of the variable `control` of type `PRESOLVE_control_type` (see Section 2.3.3), by reading an appropriate data specification file using the subroutine `PRESOLVE_read_specfile`. This facility is useful as it allows a user to change `PRESOLVE` control parameters without editing and recompiling programs that call `PRESOLVE`.

A specification file, or specfile, is a data file containing a number of "specification commands". Each command occurs on a separate line, and comprises a "keyword", which is a string (in a close-to-natural language) used to identify

a control parameter, and an (optional) "value", which defines the value to be assigned to the given control parameter. All keywords and values are case insensitive, keywords may be preceded by one or more blanks but values must not contain blanks, and each value must be separated from its keyword by at least one blank. Values must not contain more than 30 characters, and each line of the specfile is limited to 80 characters, including the blanks separating keyword and value.

The portion of the specification file used by PRESOLVE_read_specfile must start with a "BEGIN PRESOLVE" command and end with an "END" command. The syntax of the specfile is thus defined as follows:

```
( .. lines ignored by PRESOLVE_read_specfile .. )
  BEGIN PRESOLVE
     keyword    value
     .......    .....
     keyword    value
  END
( .. lines ignored by PRESOLVE_read_specfile .. )
```

where keyword and tt value are two strings separated by (at least) one blank. The "BEGIN PRESOLVE" and "END" delimiter command lines may contain additional (trailing) strings so long as such strings are separated by one or more blanks, so that lines such as

```
  BEGIN PRESOLVE SPECIFICATION
```

and

```
  END PRESOLVE SPECIFICATION
```

are acceptable. Furthermore, between the "BEGIN PRESOLVE" and "END" delimiters, specification commands may occur in any order. Blank lines and lines whose first non-blank character is ! or * are ignored. The content of a line after a ! or * character is also ignored (as is the ! or * character itself). This provides an easy manner to "comment out" some specification commands, or to comment specific values of certain control parameters.

The value of a control parameters may be of five different types, namely integer, logical, real, string or symbol. Integer and real values may be expressed in any relevant Fortran integer and floating-point formats (respectively). Permitted values for logical parameters are "ON", "TRUE", ".TRUE.", "T", "YES", "Y", or "OFF", "NO", "N", "FALSE", ".FALSE." and "F". Empty values are also allowed for logical control parameters, and are interpreted as "TRUE". String are specified as a sequence of characters. A symbolic value is a special string obtained from one of the predefined symbols of the SYMBOLS module by deleting the leading GALAHAD_ characters in its name. Thus, the specification command

```
  termination REDUCED_SIZE
```

im plies that the value GALAHAD_REDUCED_SIZE is assigned to control%termination. This technique is intended to help expressing an (integer) control parameter for an algorithm in a "language" that is close to natural (see Section 2.2).

The specification file must be open for input when PRESOLVE_read_specfile is called, and the associated device number passed to the routine in device (see below). Note that the corresponding file is REWINDed, which makes it possible to combine the specifications for more than one program/routine. For the same reason, the file is not closed by PRESOLVE_read_specfile.

2.6.1   To read control parameters from a specification file

Control parameters may be read from a file as follows:

```
  CALL PRESOLVE_read_specfile( device, control, inform )
```

device is a scalar `INTENT(IN)` argument of type default `INTEGER`, that must be set to the unit number on which the specfile has been opened. If device is not open, control will not be altered and execution will continue, but an error message will be printed on unit `control%error`.

control is a scalar `INTENT(INOUT)` argument of type `PRESOLVE_control_type` (see Section 2.3.3). Default values should have already been set, perhaps by calling `PRESOLVE_initialize`. On exit, individual components of control may have been changed according to the commands found in the specfile. Specfile commands and the component (see Section 2.3.3) of control that each affects are given in Tables 2.2–2.3.

inform is a scalar `INTENT(OUT)` argument of type `PRESOLVE_inform_type` (see Section 2.3.4).

2.7 Information printed

The meaning of the various `control%print_level` values is defined as follows:

GALAHAD_SILENT: no printout is produced,

GALAHAD_TRACE: only reports the major steps in the analysis, that is headers of the main preprocessing phases and, for each pass, the number of transformations of each type applied,

GALAHAD_ACTION: reports the nature of each problem transformation,

GALAHAD_DETAILS: reports more details on each of the main presolving loop constituents,

GALAHAD_DEBUG: reports LOTS of information, including information on unsuccessful attempts to apply presolving transformations,

GALAHAD_CRAZY: reports a completely silly amount of information.

3 GENERAL INFORMATION

Use of common: None.

Workspace: Provided automatically by the module.

Other routines called directly: None.

Other modules used directly: PRESOLVE calls the GALAHAD modules `GALAHAD_SMT`, `GALAHAD_QPT`, `GALAHAD_SPECFILE`, `GALAHAD_SORT`, and `GALAHAD_SYMBOLS`.

Input/output: Output is under control of the arguments `control%error`, `control%out` and `control%print_level`.

Restrictions: $prob\%n > 0$, $prob\%m \geq 0$, $prob\%A\_type$ and $prob\%H\_type \in \{\,'DENSE', 'COORDINATE', 'SPARSE\_BY\_ROWS'\,\}$.

Portability: ISO Fortran 95 + TR 15581 or Fortran 2003. The package is thread-safe.

4 METHOD

The required solution **x** of the problem necessarily satisfies the primal optimality conditions

$$\mathbf{A}\mathbf{x} = \mathbf{c}$$

and

$$\mathbf{c}^l \leq \mathbf{c} \leq \mathbf{c}^u, \ \ \mathbf{x}^l \leq \mathbf{x} \leq \mathbf{x}^u,$$

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the dual optimality conditions

$$\mathbf{Hx} + \mathbf{g} = \mathbf{A}^T\mathbf{y} + \mathbf{z}, \ \ \mathbf{y} = \mathbf{y}^l + \mathbf{y}^u \ \text{ and } \ \mathbf{z} = \mathbf{z}^l + \mathbf{z}^u,$$

and

$$\mathbf{y}^l \geq 0, \ \mathbf{y}^u \leq 0, \ \mathbf{z}^l \geq 0 \ \text{ and } \ \mathbf{z}^u \leq 0,$$

and the complementary slackness conditions

$$(\mathbf{Ax} - \mathbf{c}^l)^T\mathbf{y}^l = 0, \ (\mathbf{Ax} - \mathbf{c}^u)^T\mathbf{y}^u = 0, \ (\mathbf{x} - \mathbf{x}^l)^T\mathbf{z}^l = 0 \ \text{ and } \ (\mathbf{x} - \mathbf{x}^u)^T\mathbf{z}^u = 0,$$

where the vectors $\mathbf{y}$ and $\mathbf{z}$ are known as the Lagrange multipliers for the general linear constraints, and the dual variables for the bounds, respectively, and where the vector inequalities hold componentwise. The purpose of presolving is to exploit these equations in order to reduce the problem to the standard form defined as follows:

- The variables are ordered so that their bounds appear in the order

free			$\mathbf{x}$	
non-negativity	0	$\leq$	$\mathbf{x}$	
lower	$\mathbf{x}^l$	$\leq$	$\mathbf{x}$	
range	$\mathbf{x}^l$	$\leq$	$\mathbf{x}$	$\leq$ $\mathbf{x}^u$
upper			$\mathbf{x}$	$\leq$ $\mathbf{x}^u$
non-positivity			$\mathbf{x}$	$\leq$ 0

  Fixed variables are removed. Within each category, the variables are further ordered so that those with non-zero diagonal Hessian entries occur before the remainder.

- The constraints are ordered so that their bounds appear in the order

non-negativity	0	$\leq$	$\mathbf{Ax}$	
equality	$\mathbf{c}^l$	$=$	$\mathbf{Ax}$	
lower	$\mathbf{c}^l$	$\leq$	$\mathbf{Ax}$	
range	$\mathbf{c}^l$	$\leq$	$\mathbf{Ax}$	$\leq$ $\mathbf{c}^u$
upper			$\mathbf{Ax}$	$\leq$ $\mathbf{c}^u$
non-positivity			$\mathbf{Ax}$	$\leq$ 0

  Free constraints are removed.

- In addition, constraints may be removed or bounds tightened, to reduce the size of the feasible region or simplify the problem if this is possible, and bounds may be tightened on the dual variables and the multipliers associated with the problem.

The presolving algorithm proceeds by applying a (potentially long) series of simple transformations to the problem, each transformation introducing a further simplification of the problem. These involve the removal of empty and singleton rows, the removal of redundant and forcing primal constraints, the tightening of primal and dual bounds, the exploitation of linear singleton, linear doubleton and linearly unconstrained columns, the merging dependent variables, row sparsification and split equalities. Transformations are applied in successive passes, each pass involving the following actions:

1. remove empty and singletons rows,

2. try to eliminate variables that are linearly unconstrained,

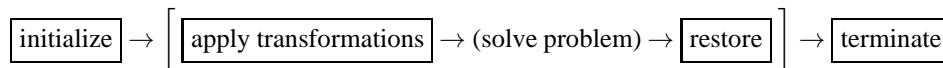3. attempt to exploit the presence of linear singleton columns,

4. attempt to exploit the presence of linear doubleton columns,

5. complete the analysis of the dual constraints,

6. remove empty and singletons rows,

7. possibly remove dependent variables,

8. analyze the primal constraints,

9. try to make *A* sparser by combining its rows,

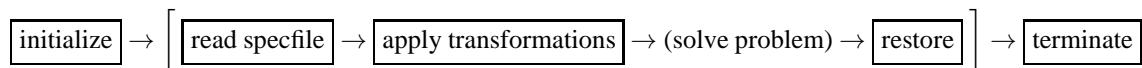10. check the current status of the variables, dual variables and multipliers.

All these transformations are applied on the structure of the original problem, which is only permuted to standard form after all transformations are completed. *Note that the Hessian and Jacobian of the resulting reduced problem are always stored in sparse row-wise format.* The reduced problem is then solved by a quadratic or linear programming solver, thus ensuring sufficiently small primal-dual feasibility and complementarity. Finally, the solution of the simplified problem is re-translated in the variables/constraints/format of the original problem formulation by a "restoration" phase.

If the number of problem transformations exceeds `control%transf_buffer_size`, the transformation buffer size (see Section 2.3.3), then they are saved in a "history" file, whose name may be chosen by specifying the `control%transf_file_name` control parameter (see Section 2.3.3). When this is the case, this file is subsequently reread by `PRESOLVE_restore`. It must not be altered by the user.

At the overall level, the presolving process follows one of the two sequences:

$$\boxed{\text{initialize}} \rightarrow \left[\boxed{\text{apply transformations}} \rightarrow (\text{solve problem}) \rightarrow \boxed{\text{restore}} \right] \rightarrow \boxed{\text{terminate}}$$

or

$$\boxed{\text{initialize}} \rightarrow \left[\boxed{\text{read specfile}} \rightarrow \boxed{\text{apply transformations}} \rightarrow (\text{solve problem}) \rightarrow \boxed{\text{restore}} \right] \rightarrow \boxed{\text{terminate}}$$

where the procedure's control parameter may be modified by reading the specfile (see Section 2.6), and where (solve problem) indicates that the reduced problem is solved. Each of the "boxed" steps in these sequences corresponds to calling a specific routine of the package (see Section 2.4). In the above diagrams, brackated subsequence of steps means that they can be repeated with problem having the same structure. The value of the `new_problem_structure` component of `problem` must be `.TRUE.` on entry of `PRESOLVE_apply` on the first time it is used in this repeated subsequence. Such a subsequence must be terminated by a call to `PRESOLVE_terminate` before presolving is applied to a problem with a different structure.

Note that the values of the multipliers and dual variables (and thus of their respective bounds) depend on the functional form assumed for the Lagrangian function associated with the problem. This form is given by

$$L(\mathbf{x},\mathbf{y},\mathbf{z}) = q(\mathbf{x}) - \texttt{y\_sign} * \mathbf{y}^T(\mathbf{Ax} - \mathbf{c}) - \texttt{z\_sign} * \mathbf{z},$$

(considering only active constraints $\mathbf{Ax} = \mathbf{c}$), where the parameters `y_sign` and `z_sign` are +1 or -1 and can be chosen by the user. Thus, if `y_sign = +1`, the multipliers associated to active constraints originally posed as inequalities are non-negative if the inequality is a lower bound and non-positive if it is an upper bound. Obvioulsy they are not constrained in sign for constraints originally posed as equalities. These sign conventions are reversed if `y_sign = -1`. Similarly, if `z_sign = +1`, the dual variables associated to active bounds are non-negative if the original bound is an lower bound, non-positive if it is an upper bound, or unconstrained in sign if the variables is fixed; and this

---

convention is reversed in z_sign = -1. The values of z_sign and y_sign may be chosen by setting the corresponding components of the control structure to GALAHAD_POSITIVE or GALAHAD_NEGATIVE (see Section 2.3.3).

References:

The algorithm is described in more detail in

N. I. M. Gould and Ph. L. Toint (2004). Presolving for quadratic programming. Mathematical Programming **100**(1), pp 95–132.

5 EXAMPLE OF USE

Suppose that we wish to solve the quadratic program (1.1)–(1.3) with the data $n = 6$, $m = 5$, $f = 1$, $\mathbf{g} = (1\ 1\ 1\ 1\ 1\ 1)^T$,

$$
\mathbf{H} = \begin{pmatrix}
1 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0
\end{pmatrix}, \qquad
\mathbf{A} = \begin{pmatrix}
0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 1 & 1 & 1 & 0 \\
0 & 0 & 1 & 0 & 0 & 1 \\
0 & 0 & 0 & 1 & 1 & 1
\end{pmatrix},
$$

$\mathbf{x}^l = (0\ 0\ 0\ 0\ 0\ 0)^T$, $\mathbf{x}^u = (1\ 1\ 1\ 1\ 1\ 1)^T$, $\mathbf{c}^l = (0\ 0\ 2\ 1\ 3)^T$ and $\mathbf{c}^u = (1\ 1\ 3\ 3\ 3)^T$, using the quadratic programming solver QPSOLVER after applying the PRESOLVE package and then restoring the final solution to the original variable formulation. We may use the following code—note that we require some output from PRESOLVE by setting control%print_level to the GALAHAD_TRACE symbol, and that calling QPSOLVER is actually unnecessary since the problem of our example is completely reduced to a single feasible point (which must then be the solution) after presolving.

```
PROGRAM GALAHAD_PRESOLVE_EXAMPLE
USE GALAHAD_QPT_double                            ! Double precision
USE GALAHAD_PRESOLVE_double                       ! Double precision
USE GALAHAD_SYMBOLS                               ! The GALAHAD symbols
IMPLICIT NONE
INTEGER, PARAMETER :: wp = KIND( 1.0D0 )          ! Set precision
REAL ( KIND = wp ), PARAMETER  :: infinity = 10._wp ** 20
REAL ( KIND = wp ), PARAMETER  :: r0 = 0.0_wp, r1 = 1.0_wp
REAL ( KIND = wp ), PARAMETER  :: r2 = 2.0_wp, r3 = 3.0_wp
TYPE ( QPT_problem_type )      :: problem
TYPE ( PRESOLVE_control_type ) :: control
TYPE ( PRESOLVE_inform_type )  :: inform
TYPE ( PRESOLVE_data_type )    :: data
INTEGER :: j, n, m, a_ne, h_ne
! start problem data
n = 6; m = 5; h_ne = 1; a_ne = 8
problem%new_problem_structure = .TRUE.
problem%n   = n; problem%m = m; problem%f = r1
ALLOCATE( problem%G( n )  , problem%X_l( n ), problem%X_u( n ) )
ALLOCATE( problem%C_l( m ), problem%C_u( m ) )
problem%gradient_kind = 1
problem%C_l = (/  r0, r0, r2, r1, r3  /)
problem%C_u = (/  r1, r1, r3, r3, r3  /)
problem%X_l = (/ -r3, r0, r0, r0, r0, r0 /)
problem%X_u = (/  r3, r1, r1, r1, r1, r1 /)
! sparse coordinate format
```

```
  CALL SMT_put( problem%H%type, 'COORDINATE' )
  CALL SMT_put( problem%A%type, 'COORDINATE' )
  ALLOCATE( problem%H%val( h_ne ) )
  ALLOCATE( problem%H%col( h_ne ), problem%H%row( h_ne ) )
  ALLOCATE( problem%A%val( a_ne ) )
  ALLOCATE( problem%A%col( a_ne ), problem%A%row( a_ne ) )
  problem%H%val = (/ r1  /)
  problem%H%row = (/  1  /)
  problem%H%col = (/  1  /)
  problem%A%val = (/ r1, r1, r1, r1, r1, r1, r1, r1 /)
  problem%A%row = (/  3,  3,  3,  4,  4,  5,  5,  5 /)
  problem%A%col = (/  3,  4,  5,  3,  6,  4,  5,  6 /)
  problem%a_ne  = a_ne; problem%h_ne = h_ne
! problem data complete
! write the original formulation
  CALL QPT_write_problem( 6, problem )
! set the default PRESOLVE control parameters
  CALL PRESOLVE_initialize( control, inform, data )
  IF ( inform%status /= 0 ) STOP
  control%print_level = GALAHAD_TRACE           ! Ask for some output
! apply presolving to reduce the problem
  CALL PRESOLVE_apply( problem, control, inform, data )
  IF ( inform%status /= 0 ) STOP
! write the reduced problem
  CALL QPT_write_problem( 6, problem )
! solve the reduced problem
  ! CALL QPSOLVER (unnecessary here, because the reduced problem has a
  ! single feasible point in this example)
! restore the solved reduced problem to the original formulation
  CALL PRESOLVE_restore( problem, control, inform, data )
  IF ( inform%status /= 0 ) STOP
! write the final solution in the original variables
  WRITE( 6, * ) ' '
  WRITE( 6, * ) '  The problem solution X is'
  WRITE( 6, * ) ' '
  DO j = 1, n
     WRITE( 6, '(3x,''x('',I1,'') = '', ES12.4)' ) j, problem%X( j )
  END DO
! deallocate internal workspace
  CALL PRESOLVE_terminate( control, inform, data )
  END PROGRAM GALAHAD_PRESOLVE_EXAMPLE
```

This produces the following output:

```
  =============== PROBLEM ====================

  n =  6

  variables

                lower        upper

  x(   1) =   -3.0000E+00  3.0000E+00
  x(   2) =    0.0000E+00  1.0000E+00
  x(   3) =    0.0000E+00  1.0000E+00
```

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```
x(   4) =     0.0000E+00  1.0000E+00
x(   5) =     0.0000E+00  1.0000E+00
x(   6) =     0.0000E+00  1.0000E+00

 m =  5

 constraints

               lower       upper

c(   1) =     0.0000E+00  1.0000E+00
c(   2) =     0.0000E+00  1.0000E+00
c(   3) =     2.0000E+00  3.0000E+00
c(   4) =     1.0000E+00  3.0000E+00
c(   5) =     3.0000E+00  3.0000E+00

 Jacobian

A(   3,   3) =   1.0000E+00
A(   3,   4) =   1.0000E+00
A(   3,   5) =   1.0000E+00
A(   4,   3) =   1.0000E+00
A(   4,   6) =   1.0000E+00
A(   5,   4) =   1.0000E+00
A(   5,   5) =   1.0000E+00
A(   5,   6) =   1.0000E+00


 objective function constant term =   1.0000E+00


 gradient

g(   1) =     1.0000E+00
g(   2) =     1.0000E+00
g(   3) =     1.0000E+00
g(   4) =     1.0000E+00
g(   5) =     1.0000E+00
g(   6) =     1.0000E+00

 Hessian

H(   1,   1) =   1.0000E+00

 ============ END OF PROBLEM =================


*******************************************
*                                         *
*        GALAHAD presolve for QPs         *
*                                         *
*             problem analysis            *
*                                         *
*******************************************
```

```
============ starting problem analysis ============

checking bounds on x, y, z, and c: 0 transformations
redundant variables and constraints: 0 transformations

============= main processing loop 1  =============
  ( n = 6 , m = 5 , a_ne = 8 , h_ne = 1 )

removing empty and singleton rows: 2 transformations
analyzing special linear columns: 3 transformations
analyzing dual constraints: 0 transformations
removing empty and singleton rows: 0 transformations
checking dependent variables: 2  transformations
analyzing primal constraints: 5 transformations
checking bounds on x, y, z, and c: 0 transformations

============= main processing loop 2  =============
  ( n = 1 , m = 2 , a_ne = 2 , h_ne = 0 )

removing empty and singleton rows: 2 transformations
analyzing special linear columns: 2 transformations

======== end of the main processing loop ( loop = 2 ) ========

all variables and constraints have been eliminated!

No permutation necessary.

******************** Bye ********************


  =============== PROBLEM ====================

  n =  0

  m =  0

  current objective function value =   3.5000E+00


  objective function constant term =   3.5000E+00


  ============ END OF PROBLEM ================


*******************************************
*                                         *
*         GALAHAD PRESOLVE for QPs         *
*                                         *
*            problem restoration           *
*                                         *
*******************************************
```

```
verifying user-defined presolve control parameters
===  starting historical loop
===  end of the historical loop

Problem successfully restored.

******************* Bye *******************


  The problem solution X is

 x(1) =  -1.0000E+00
 x(2) =   0.0000E+00
 x(3) =   0.0000E+00
 x(4) =   1.0000E+00
 x(5) =   1.0000E+00
 x(6) =   1.0000E+00


 *******************************************
 *                                         *
 *         GALAHAD PRESOLVE for QPs         *
 *                                         *
 *              workspace cleanup          *
 *                                         *
 *******************************************



 ******************* Bye *******************
```

The same problem may be solved holding the data in a sparse row-wise storage format by replacing the lines

```
! sparse coordinate format
  ......
! problem data complete
```

by

```
! sparse row-wise storage format
  CALL SMT_put( problem%H%type, 'SPARSE_BY_ROWS' )
  CALL SMT_put( problem%A%type, 'SPARSE_BY_ROWS' )
  ALLOCATE( problem%H%val( h_ne ) )
  ALLOCATE( problem%H%ptr( n+1 ), problem%H%col( h_ne ) )
  ALLOCATE( problem%A%val( a_ne ) )
  ALLOCATE( problem%A%ptr( m+1 ), problem%A%col( a_ne ) )
  problem%H%val = (/ r1  /)
  problem%H%ptr = (/  1,  2,  2,  2,  2,  2,  2 /)
  problem%H%col = (/  1  /)
  problem%A%val = (/ r1, r1, r1, r1, r1, r1, r1, r1 /)
  problem%A%ptr = (/  1,  1,  1,  4,  6,  9  /)
  problem%A%col = (/  3,  4,  5,  3,  6,  4,  5,  6 /)
! problem data complete
```

or using a dense storage format with the replacement lines

```
! dense storage format
```

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```
   CALL SMT_put( problem%H%type, 'DENSE' )
   CALL SMT_put( problem%A%type, 'DENSE' )
   ALLOCATE( problem%H%val( n*(n+1)/2 ) )
   ALLOCATE( problem%A%val( n*m ) )
   problem%H%val = (/ r1,                            &
                      r0, r0,                        &
                      r0, r0, r0,                    &
                      r0, r0, r0, r0,                &
                      r0, r0, r0, r0, r0,            &
                      r0, r0, r0, r0, r0, r0  /)
   problem%A%val = (/ r0, r0, r0, r0, r0, r0,        &
                      r0, r0, r0, r0, r0, r0,        &
                      r0, r0, r1, r1, r1, r0,        &
                      r0, r0, r1, r0, r0, r1,        &
                      r0, r0, r0, r1, r1, r1  /)
! problem data complete
```

respectively. (If instead **H** had been the diagonal matrix

$$\mathbf{H} = \begin{pmatrix} 1 & & \\ & 0 & \\ & & 3 \end{pmatrix}$$

but the other data is as before, the diagonal storage scheme might be used for **H**, and in this case we would instead

```
   CALL SMT_put( prob%H%type, 'DIAGONAL' )  ! Specify dense storage for H
   ALLOCATE( p%H%val( n ) )
   p%H%val = (/ r1, r0, r0, r0, r0, r0, r0 /) ! Hessian values
```

Notice here that zero diagonal entries are stored.) We could also make use of the PRESOLVE_read_specfile routine to set the printing level, in which case the statement

```
   control%print_level = GALAHAD_TRACE             ! Ask for some output
```

is replaced by

```
! open specfile
   OPEN( 57, FILE = 'PRESOLVE.SPC', STATUS = 'OLD' )
! read its content (asking for some output)
   CALL PRESOLVE_read_specfile( 57, control, inform )
! close it
   CLOSE( 57 )
```

where we assume that the file PRESOLVE.SPC exists in the current directory and contains the lines

```
BEGIN PRESOLVE SPECIFICATION
   print-level TRACE
END PRESOLVE SPECIFICATION
```

---

command	component of control	value type/ symbolic value
error-printout-device	%error	integer
printout-device	%out	integer
print-level	%print_level	SILENT, TRACE, ACTION, DETAILS, DEBUG, CRAZY
presolve-termination-strategy	%termination	REDUCED_SIZE, FULL_PRESOLVE
maximum-number-of-transformations	%max_nbr_transforms	integer
maximum-number-of-passes	%max_nbr_passes	integer
constraints-accuracy	%c_accuracy	real
dual-variables-accuracy	%z_accuracy	real
allow-dual-transformations	%dual_transformations	logical
remove-redundant-variables-constraints	%redundant_xc	logical
primal-constraints-analysis-frequency	%primal_constraints_freq	integer
dual-constraints-analysis-frequency	%dual_constraints_freq	integer
singleton-columns-analysis-frequency	%singleton_columns_freq	integer
doubleton-columns-analysis-frequency	%doubleton_columns_freq	integer
unconstrained-variables-analysis-frequency	%unc_variables_freq	integer
dependent-variables-analysis-frequency	%dependent_variables_freq	integer
row-sparsification-frequency	%sparsify_rows_freq	integer
maximum-percentage-row-fill	%max_fill	integer
transformations-buffer-size	%transf_buffer_size	integer
transformations-file-device	%transf_file_nbr	integer
transformations-file-status	%transf_file_status	KEEP, DELETE
transformations-file-name	%transf_file_name	string
primal-feasibility-check	%check_primal_feasibility	NONE, BASIC, SEVERE
dual-feasibility-check	%check_dual_feasibility	NONE, BASIC, SEVERE
active-multipliers-sign	%y_sign	POSITIVE, NEGATIVE
inactive-multipliers-value	%inactive_y	LEAVE_AS_IS, FORCE_TO_ZERO
active-dual-variables-sign	%z_sign	POSITIVE, NEGATIVE
inactive-dual-variables-value	%inactive_z	LEAVE_AS_IS, FORCE_TO_ZERO
primal-variables-bound-status	%final_x_bounds	TIGHTEST, NON_DEGENERATE, LOOSEST

Table 2.2: Specfile commands and associated components of control (part 1).

command	component of `control`	value type/ symbolic value
`dual-variables-bound-status`	`%final_z_bounds`	TIGHTEST, NON_DEGENERATE, LOOSEST
`constraints-bound-status`	`%final_c_bounds`	TIGHTEST, NON_DEGENERATE, LOOSEST
`multipliers-bound-status`	`%final_y_bounds`	TIGHTEST, NON_DEGENERATE, LOOSEST
`infinity-value`	`%infinity`	real
`pivoting-threshold`	`%pivot_tol`	real
`minimum-relative-bound-improvement`	`%min_rel_improve`	real
`maximum-growth-factor`	`%max_growth_factor`	real
`compute-quadratic-value`	`%get_q`	logical
`compute-objective-constant`	`%get_f`	logical
`compute-gradient`	`%get_g`	logical
`compute-Hessian`	`%get_H`	logical
`compute-constraints-matrix`	`%get_A`	logical
`compute-primal-variables-values`	`%get_x`	logical
`compute-primal-variables-bounds`	`%get_x_bounds`	logical
`compute-dual-variables-values`	`%get_z`	logical
`compute-dual-variables-bounds`	`%get_z_bounds`	logical
`compute-contraints-values`	`%get_c`	logical
`compute-constraints-bounds`	`%get_c_bounds`	logical
`compute-multipliers-values`	`%get_y`	logical
`compute-multipliers-bounds`	`%get_y_bounds`	logical

Table 2.3: Specfile commands and associated components of `control` (part 2).