



## C interfaces to GALAHAD EQP

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# Chapter 1

## GALAHAD C package eqp

### 1.1 Introduction

#### 1.1.1 Purpose

This package uses an iterative method to solve the **equality-constrained quadratic programming problem**

$$\text{minimize } q(x) = \frac{1}{2}x^T Hx + g^T x + f$$

subject to the linear constraints

$$(1) \quad Ax + c = 0,$$

where the  $n$  by  $n$  symmetric matrix  $H$ , the  $m$  by  $n$  matrix  $A$ , the vectors  $g$  and  $c$ . Full advantage is taken of any zero coefficients in the matrices  $H$  and  $A$ .

The package may alternatively be used to minimize the (shifted) squared- least-distance objective

$$\frac{1}{2} \sum_{j=1}^n w_j^2 (x_j - x_j^0)^2 + g^T x + f,$$

subject to the linear constraint (1), for given vectors  $w$  and  $x^0$ .

#### 1.1.2 Authors

N. I. M. Gould, STFC-Rutherford Appleton Laboratory, England.

C interface, additionally J. Fowkes, STFC-Rutherford Appleton Laboratory.

#### 1.1.3 Originally released

March 2006, C interface January 2021.

### 1.1.4 Terminology

The required solution  $x$  necessarily satisfies the primal optimality conditions

$$(2) \quad Ax + c = 0$$

and the dual optimality conditions

$$Hx + g - A^T y = 0 \quad (\text{or } W^2(x - x^0) + g - A^T y = 0 \text{ for the shifted-least-distance type objective})$$

where the diagonal matrix  $W^2$  has diagonal entries  $w_j^2$ ,  $j = 1, \dots, n$ , and where the vector  $y$  is known as the Lagrange multipliers for the linear constraints.

### 1.1.5 Method

A solution to the problem is found in two phases. In the first, a point  $x_F$  satisfying (2) is found. In the second, the required solution  $x = x_F + s$  is determined by finding  $s$  to minimize  $q(s) = \frac{1}{2}s^T Hs + g_F^T s + f_F$  subject to the homogeneous constraints  $As = \text{zero}$ , where  $g_F = Hx_F + g$  and  $f_F = \frac{1}{2}x_F^T Hx_F + g^T x_F + f$ . The required constrained minimizer of  $q(s)$  is obtained by implicitly applying the preconditioned conjugate-gradient method in the null space of  $A$ . Any preconditioner of the form

$$K_G = \begin{pmatrix} G & A^T \\ A & 0 \end{pmatrix}$$

is suitable, and the GALAHAD package SBLS provides a number of possibilities. In order to ensure that the minimizer obtained is finite, an additional, precautionary trust-region constraint  $\|s\| \leq \Delta$  for some suitable positive radius  $\Delta$  is imposed, and the GALAHAD package GLTR is used to solve this additionally-constrained problem.

### 1.1.6 Reference

The preconditioning aspects are described in detail in

H. S. Dollar, N. I. M. Gould and A. J. Wathen. "On implicit-factorization constraint preconditioners". In Large Scale Nonlinear Optimization (G. Di Pillo and M. Roma, eds.) Springer Series on Nonconvex Optimization and Its Applications, Vol. 83, Springer Verlag (2006) 61-82

and

H. S. Dollar, N. I. M. Gould, W. H. A. Schilders and A. J. Wathen "On iterative methods and implicit-factorization preconditioners for regularized saddle-point systems". SIAM Journal on Matrix Analysis and Applications, **28(1)** (2006) 170-189,

while the constrained conjugate-gradient method is discussed in

N. I. M. Gould, S. Lucidi, M. Roma and Ph. L. Toint, Solving the trust-region subproblem using the Lanczos method. SIAM Journal on Optimization **9:2** (1999), 504-525.

### 1.1.7 Call order

To solve a given problem, functions from the eqp package must be called in the following order:

- `eqp_initialize` - provide default control parameters and set up initial data structures
- `eqp_read_specfile` (optional) - override control values by reading replacement values from a file
- `eqp_import` - set up problem data structures and fixed values
- `eqp_reset_control` (optional) - possibly change control parameters if a sequence of problems are being solved
- solve the problem by calling one of
  - `eqp_solve_qp` - solve the quadratic program
  - `eqp_solve_sldqp` - solve the shifted least-distance problem
- `eqp_resolve_qp` (optional) - resolve the problem with the same Hessian and Jacobian, but different  $g$ ,  $f$  and/or  $c$

possibly change control parameters if a sequence of problems are being solved

- `eqp_information` (optional) - recover information about the solution and solution process
- `eqp_terminate` - deallocate data structures

See Section 4.1 for examples of use.

### 1.1.8 Unsymmetric matrix storage formats

The unsymmetric  $m$  by  $n$  constraint matrix  $A$  may be presented and stored in a variety of convenient input formats.

Both C-style (0 based) and fortran-style (1-based) indexing is allowed. Choose `control.f_indexing` as `false` for C style and `true` for fortran style; the discussion below presumes C style, but add 1 to indices for the corresponding fortran version.

Wrappers will automatically convert between 0-based (C) and 1-based (fortran) array indexing, so may be used transparently from C. This conversion involves both time and memory overheads that may be avoided by supplying data that is already stored using 1-based indexing.

#### 1.1.8.1 Dense storage format

The matrix  $A$  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. In this case, component  $n * i + j$  of the storage array `A_val` will hold the value  $A_{ij}$  for  $0 \leq i \leq m - 1$ ,  $0 \leq j \leq n - 1$ .

#### 1.1.8.2 Sparse co-ordinate storage format

Only the nonzero entries of the matrices are stored. For the  $l$ -th entry,  $0 \leq l \leq ne - 1$ , of  $A$ , its row index  $i$ , column index  $j$  and value  $A_{ij}$ ,  $0 \leq i \leq m - 1$ ,  $0 \leq j \leq n - 1$ , are stored as the  $l$ -th components of the integer arrays `A_row` and `A_col` and real array `A_val`, respectively, while the number of nonzeros is recorded as `A_ne = ne`.

### 1.1.8.3 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  $A$  the  $i$ -th component of the integer array  $A\_ptr$  holds the position of the first entry in this row, while  $A\_ptr(m)$  holds the total number of entries plus one. The column indices  $j$ ,  $0 \leq j \leq n-1$ , and values  $A_{ij}$  of the nonzero entries in the  $i$ -th row are stored in components  $l = A\_ptr(i), \dots, A\_ptr(i+1)-1$ ,  $0 \leq i \leq m-1$ , of the integer array  $A\_col$ , and real array  $A\_val$ , respectively. For sparse matrices, this scheme almost always requires less storage than its predecessor.

## 1.1.9 Symmetric matrix storage formats

Likewise, the symmetric  $n$  by  $n$  objective Hessian matrix  $H$  may be presented and stored in a variety of formats. But crucially symmetry is exploited by only storing values from the lower triangular part (i.e., those entries that lie on or below the leading diagonal).

### 1.1.9.1 Dense storage format

The matrix  $H$  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. Since  $H$  is symmetric, only the lower triangular part (that is the part  $h_{ij}$  for  $0 \leq j \leq i \leq n-1$ ) need be held. In this case the lower triangle should be stored by rows, that is component  $i * i/2 + j$  of the storage array  $H\_val$  will hold the value  $h_{ij}$  (and, by symmetry,  $h_{ji}$ ) for  $0 \leq j \leq i \leq n-1$ .

### 1.1.9.2 Sparse co-ordinate storage format

Only the nonzero entries of the matrices are stored. For the  $l$ -th entry,  $0 \leq l \leq ne-1$ , of  $H$ , its row index  $i$ , column index  $j$  and value  $h_{ij}$ ,  $0 \leq j \leq i \leq n-1$ , are stored as the  $l$ -th components of the integer arrays  $H\_row$  and  $H\_col$  and real array  $H\_val$ , respectively, while the number of nonzeros is recorded as  $H\_ne = ne$ . Note that only the entries in the lower triangle should be stored.

### 1.1.9.3 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  $H$  the  $i$ -th component of the integer array  $H\_ptr$  holds the position of the first entry in this row, while  $H\_ptr(n)$  holds the total number of entries plus one. The column indices  $j$ ,  $0 \leq j \leq i$ , and values  $h_{ij}$  of the entries in the  $i$ -th row are stored in components  $l = H\_ptr(i), \dots, H\_ptr(i+1)-1$  of the integer array  $H\_col$ , and real array  $H\_val$ , respectively. Note that as before only the entries in the lower triangle should be stored. For sparse matrices, this scheme almost always requires less storage than its predecessor.

### 1.1.9.4 Diagonal storage format

If  $H$  is diagonal (i.e.,  $H_{ij} = 0$  for all  $0 \leq i \neq j \leq n-1$ ) only the diagonal entries  $H_{ii}$ ,  $0 \leq i \leq n-1$  need be stored, and the first  $n$  components of the array  $H\_val$  may be used for the purpose.

### 1.1.9.5 Multiples of the identity storage format

If  $H$  is a multiple of the identity matrix, (i.e.,  $H = \alpha I$  where  $I$  is the  $n$  by  $n$  identity matrix and  $\alpha$  is a scalar), it suffices to store  $\alpha$  as the first component of  $H\_val$ .

### 1.1.9.6 The identity matrix format

If  $H$  is the identity matrix, no values need be stored.



## Chapter 2

# File Index

### 2.1 File List

Here is a list of all files with brief descriptions:

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## Chapter 3

# File Documentation

### 3.1 eqp.h File Reference

```
#include <stdbool.h>
#include "galahad_precision.h"
#include "fdc.h"
```

#### Data Structures

- struct [eqp\\_control\\_type](#)
- struct [eqp\\_time\\_type](#)
- struct [eqp\\_inform\\_type](#)

#### Functions

- void [eqp\\_initialize](#) (void \*\*data, struct [eqp\\_control\\_type](#) \*control, int \*status)
- void [eqp\\_read\\_specfile](#) (struct [eqp\\_control\\_type](#) \*control, const char specfile[])
- void [eqp\\_import](#) (struct [eqp\\_control\\_type](#) \*control, void \*\*data, int \*status, int n, int m, const char H\_type[], int H\_ne, const int H\_row[], const int H\_col[], const int H\_ptr[], const char A\_type[], int A\_ne, const int A\_row[], const int A\_col[], const int A\_ptr[])
- void [eqp\\_reset\\_control](#) (struct [eqp\\_control\\_type](#) \*control, void \*\*data, int \*status)
- void [eqp\\_solve\\_qp](#) (void \*\*data, int \*status, int n, int m, int h\_ne, const real\_wp\_ H\_val[], const real\_wp\_ g[], const real\_wp\_ f, int a\_ne, const real\_wp\_ A\_val[], real\_wp\_ c[], real\_wp\_ x[], real\_wp\_ y[])
- void [eqp\\_solve\\_sldqp](#) (void \*\*data, int \*status, int n, int m, const real\_wp\_ w[], const real\_wp\_ x0[], const real\_wp\_ g[], const real\_wp\_ f, int a\_ne, const real\_wp\_ A\_val[], real\_wp\_ c[], real\_wp\_ x[], real\_wp\_ y[])
- void [eqp\\_resolve\\_qp](#) (void \*\*data, int \*status, int n, int m, const real\_wp\_ g[], const real\_wp\_ f, real\_wp\_ c[], real\_wp\_ x[], real\_wp\_ y[])
- void [eqp\\_information](#) (void \*\*data, struct [eqp\\_inform\\_type](#) \*inform, int \*status)
- void [eqp\\_terminate](#) (void \*\*data, struct [eqp\\_control\\_type](#) \*control, struct [eqp\\_inform\\_type](#) \*inform)

#### 3.1.1 Data Structure Documentation

##### 3.1.1.1 struct eqp\_control\_type

control derived type as a C struct

## Data Fields

bool	f_indexing	use C or Fortran sparse matrix indexing
int	error	error and warning diagnostics occur on stream error
int	out	general output occurs on stream out
int	print_level	the level of output required is specified by print_level
int	factorization	the factorization to be used. Possible values are 0 automatic 1 Schur-complement factorization 2 augmented-system factorization (OBSOLETE
int	max_col	the maximum number of nonzeros in a column of A which is permitted with the Schur-complement factorization (OBSOLE
int	indmin	an initial guess as to the integer workspace required by SBLS (OBSOL
int	valmin	an initial guess as to the real workspace required by SBLS (OBSOL
int	len_ulsmin	an initial guess as to the workspace required by ULS (OBSOL
int	itref_max	the maximum number of iterative refinements allowed (OBSOL
int	cg_maxit	the maximum number of CG iterations allowed. If cg_maxit < 0, this number will be reset to the dimension of the system + 1
int	preconditioner	the preconditioner to be used for the CG is defined by precon. Possible values are 0 automatic 1 no preconditioner, i.e, the identity within full factorization 2 full factorization 3 band within full factorization 4 diagonal using the barrier terms within full factorization (OBSOLETE 5 optionally supplied diagonal, G = D
int	semi_bandwidth	the semi-bandwidth of a band preconditioner, if appropriate (OBSOL
int	new_a	how much has A changed since last problem solved: 0 = not changed, 1 = values changed, 2 = structure changed
int	new_h	how much has H changed since last problem solved: 0 = not changed, 1 = values changed, 2 = structure changed
int	sif_file_device	specifies the unit number to write generated SIF file describing the current problem
real_wp_	pivot_tol	the threshold pivot used by the matrix factorization. See the documentation for SBLS for details (OBSOLE
real_wp_	pivot_tol_for_basis	the threshold pivot used by the matrix factorization when finding the ba See the documentation for ULS for details (OBSOLE
real_wp_	zero_pivot	any pivots smaller than zero_pivot in absolute value will be regarded to zero when attempting to detect linearly dependent constraints (OBSOLE
real_wp_	inner_fraction_opt	the computed solution which gives at least inner_fraction_opt times the optimal value will be found (OBSOLE
real_wp_	radius	an upper bound on the permitted step (-ve will be reset to an appropriat large value by eqp_solve)
real_wp_	min_diagonal	diagonal preconditioners will have diagonals no smaller than min_diagona (OBSOLETE)

## Data Fields

real_wp_	max_infeasibility_relative	if the constraints are believed to be rank deficient and the residual at a "typical" feasible point is larger than $\max(\text{max\_infeasibility\_relative} * \text{norm A}, \text{max\_infeasibility\_absolute})$ the problem will be marked as infeasible
real_wp_	max_infeasibility_absolute	see max_infeasibility_relative
real_wp_	inner_stop_relative	the computed solution is considered as an acceptable approximation to the minimizer of the problem if the gradient of the objective in the preconditioning(inverse) norm is less than $\max(\text{inner\_stop\_relative} * \text{initial preconditioning(inverse) gradient norm}, \text{inner\_stop\_absolute})$
real_wp_	inner_stop_absolute	see inner_stop_relative
real_wp_	inner_stop_inter	see inner_stop_relative
bool	find_basis_by_transpose	if .find_basis_by_transpose is true, implicit factorization precondition will be based on a basis of A found by examining A's transpose (OBSOLETE)
bool	remove_dependencies	if .remove_dependencies is true, the equality constraints will be preprocessed to remove any linear dependencies
bool	space_critical	if .space_critical true, every effort will be made to use as little space as possible. This may result in longer computation time
bool	deallocate_error_fatal	if .deallocate_error_fatal is true, any array/pointer deallocation error will terminate execution. Otherwise, computation will continue
bool	generate_sif_file	if .generate_sif_file is true. if a SIF file describing the current problem is to be generated
char	sif_file_name[31]	name of generated SIF file containing input problem
char	prefix[31]	all output lines will be prefixed by .prefix(2:LEN(TRIM(.prefix))-1) where .prefix contains the required string enclosed in quotes, e.g. "string" or 'string'
struct fdc_control_type	fdc_control	control parameters for FDC
struct sbls_control_type	sbls_control	control parameters for SBLS
struct gltr_control_type	gltr_control	control parameters for GLTR

## 3.1.1.2 struct eqp\_time\_type

time derived type as a C struct

## Data Fields

real_wp_	total	the total CPU time spent in the package
real_wp_	find_dependent	the CPU time spent detecting linear dependencies
real_wp_	factorize	the CPU time spent factorizing the required matrices
real_wp_	solve	the CPU time spent computing the search direction
real_wp_	solve_inter	see solve
real_wp_	clock_total	the total clock time spent in the package

## Data Fields

real_wp_	clock_find_dependent	the clock time spent detecting linear dependencies
real_wp_	clock_factorize	the clock time spent factorizing the required matrices
real_wp_	clock_solve	the clock time spent computing the search direction

## 3.1.1.3 struct eqp\_inform\_type

inform derived type as a C struct

## Data Fields

int	status	return status. See EQP_solve for details
int	alloc_status	the status of the last attempted allocation/deallocation
char	bad_alloc[81]	the name of the array for which an allocation/deallocation error occurred
int	cg_iter	the total number of conjugate gradient iterations required
int	cg_iter_inter	see cg_iter
int	factorization_integer	the total integer workspace required for the factorization
int	factorization_real	the total real workspace required for the factorization
real_wp_	obj	the value of the objective function at the best estimate of the solution determined by QPB_solve
struct <a href="#">eqp_time_type</a>	time	timings (see above)
struct <a href="#">fdc_inform_type</a>	fdc_inform	inform parameters for FDC
struct <a href="#">sbls_inform_type</a>	sbls_inform	inform parameters for SBLS
struct <a href="#">gltr_inform_type</a>	gltr_inform	return information from GLTR

## 3.1.2 Function Documentation

## 3.1.2.1 eqp\_initialize()

```
void eqp_initialize (
    void ** data,
    struct eqp\_control\_type * control,
    int * status )
```

Set default control values and initialize private data

## Parameters

in, out	<i>data</i>	holds private internal data
out	<i>control</i>	is a struct containing control information (see <a href="#">eqp_control_type</a> )
out	<i>status</i>	is a scalar variable of type int, that gives the exit status from the package. Possible values are (currently): <ul style="list-style-type: none"> <li>• 0. The import was succesful.</li> </ul>

### 3.1.2.2 eqp\_read\_specfile()

```
void eqp_read_specfile (
    struct eqp\_control\_type * control,
    const char specfile[] )
```

Read the content of a specification file, and assign values associated with given keywords to the corresponding control parameters

#### Parameters

in, out	<i>control</i>	is a struct containing control information (see <a href="#">eqp_control_type</a> )
in	<i>specfile</i>	is a character string containing the name of the specification file

### 3.1.2.3 eqp\_import()

```
void eqp_import (
    struct eqp\_control\_type * control,
    void ** data,
    int * status,
    int n,
    int m,
    const char H_type[],
    int H_ne,
    const int H_row[],
    const int H_col[],
    const int H_ptr[],
    const char A_type[],
    int A_ne,
    const int A_row[],
    const int A_col[],
    const int A_ptr[] )
```

Import problem data into internal storage prior to solution.

#### Parameters

in	<i>control</i>	is a struct whose members provide control parameters for the remaining procedures (see <a href="#">eqp_control_type</a> )
in, out	<i>data</i>	holds private internal data

## Parameters

in, out	status	<p>is a scalar variable of type int, that gives the exit status from the package. Possible values are:</p> <ul style="list-style-type: none"> <li>• 0. The import was succesful</li> <li>• -1. An allocation error occurred. A message indicating the offending array is written on unit control.error, and the returned allocation status and a string containing the name of the offending array are held in inform.alloc_status and inform.bad_alloc respectively.</li> <li>• -2. A deallocation error occurred. A message indicating the offending array is written on unit control.error and the returned allocation status and a string containing the name of the offending array are held in inform.alloc_status and inform.bad_alloc respectively.</li> <li>• -3. The restrictions <math>n &gt; 0</math> or <math>m &gt; 0</math> or requirement that a type contains its relevant string 'dense', 'coordinate', 'sparse_by_rows', 'diagonal', 'scaled_identity', 'identity', 'zero' or 'none' has been violated.</li> <li>• -23. An entry from the strict upper triangle of <math>H</math> has been specified.</li> </ul>
in	n	is a scalar variable of type int, that holds the number of variables.
in	m	is a scalar variable of type int, that holds the number of general linear constraints.
in	H_type	is a one-dimensional array of type char that specifies the <a href="#">symmetric storage scheme</a> used for the Hessian, $H$ . It should be one of 'coordinate', 'sparse_by_rows', 'dense', 'diagonal', 'scaled_identity', 'identity', 'zero' or 'none', the latter pair if $H = 0$ ; lower or upper case variants are allowed.
in	H_ne	is a scalar variable of type int, that holds the number of entries in the lower triangular part of $H$ in the sparse co-ordinate storage scheme. It need not be set for any of the other schemes.
in	H_row	is a one-dimensional array of size H_ne and type int, that holds the row indices of the lower triangular part of $H$ in the sparse co-ordinate storage scheme. It need not be set for any of the other three schemes, and in this case can be NULL.
in	H_col	is a one-dimensional array of size H_ne and type int, that holds the column indices of the lower triangular part of $H$ in either the sparse co-ordinate, or the sparse row-wise storage scheme. It need not be set when the dense, diagonal or (scaled) identity storage schemes are used, and in this case can be NULL.
in	H_ptr	is a one-dimensional array of size n+1 and type int, 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. It need not be set when the other schemes are used, and in this case can be NULL.
in	A_type	is a one-dimensional array of type char that specifies the <a href="#">unsymmetric storage scheme</a> used for the constraint Jacobian, $A$ . It should be one of 'coordinate', 'sparse_by_rows' or 'dense'; lower or upper case variants are allowed.
in	A_ne	is a scalar variable of type int, that holds the number of entries in $A$ in the sparse co-ordinate storage scheme. It need not be set for any of the other schemes.
in	A_row	is a one-dimensional array of size A_ne and type int, that holds the row indices of $A$ in the sparse co-ordinate storage scheme. It need not be set for any of the other schemes, and in this case can be NULL.
in	A_col	is a one-dimensional array of size A_ne and type int, that holds the column indices of $A$ in either the sparse co-ordinate, or the sparse row-wise storage scheme. It need not be set when the dense or diagonal storage schemes are used, and in this case can be NULL.



## Parameters

in	<i>A_ptr</i>	is a one-dimensional array of size $n+1$ and type <code>int</code> , that holds the starting position of each row of $A$ , as well as the total number of entries plus one, in the sparse row-wise storage scheme. It need not be set when the other schemes are used, and in this case can be <code>NULL</code> .
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## 3.1.2.4 eqp\_reset\_control()

```
void eqp_reset_control (
    struct eqp_control_type * control,
    void ** data,
    int * status )
```

Reset control parameters after import if required.

## Parameters

in	<i>control</i>	is a struct whose members provide control parameters for the remaining procedures (see <a href="#">eqp_control_type</a> )
in, out	<i>data</i>	holds private internal data
in, out	<i>status</i>	is a scalar variable of type <code>int</code> , that gives the exit status from the package. Possible values are: <ul style="list-style-type: none"> <li>• 0. The import was successful.</li> </ul>

## 3.1.2.5 eqp\_solve\_qp()

```
void eqp_solve_qp (
    void ** data,
    int * status,
    int n,
    int m,
    int h_ne,
    const real_wp_ H_val[],
    const real_wp_ g[],
    const real_wp_ f,
    int a_ne,
    const real_wp_ A_val[],
    real_wp_ c[],
    real_wp_ x[],
    real_wp_ y[] )
```

Solve the quadratic program when the Hessian  $H$  is available.

## Parameters

in, out	<i>data</i>	holds private internal data
---------	-------------	-----------------------------

## Parameters

<i>in, out</i>	<i>status</i>	<p>is a scalar variable of type int, that gives the entry and exit status from the package. Possible exit are:</p> <ul style="list-style-type: none"> <li>• 0. The run was succesful.</li> <li>• -1. An allocation error occurred. A message indicating the offending array is written on unit control.error, and the returned allocation status and a string containing the name of the offending array are held in inform.alloc_status and inform.bad_alloc respectively.</li> <li>• -2. A deallocation error occurred. A message indicating the offending array is written on unit control.error and the returned allocation status and a string containing the name of the offending array are held in inform.alloc_status and inform.bad_alloc respectively.</li> <li>• -3. The restrictions <math>n &gt; 0</math> and <math>m &gt; 0</math> or requirement that a type contains its relevant string 'dense', 'coordinate', 'sparse_by_rows', 'diagonal', 'scaled_identity', 'identity', 'zero' or 'none' has been violated.</li> <li>• -7. The constraints appear to have no feasible point.</li> <li>• -9. The analysis phase of the factorization failed; the return status from the factorization package is given in the component inform.factor_status</li> <li>• -10. The factorization failed; the return status from the factorization package is given in the component inform.factor_status.</li> <li>• -11. The solution of a set of linear equations using factors from the factorization package failed; the return status from the factorization package is given in the component inform.factor_status.</li> <li>• -16. The problem is so ill-conditioned that further progress is impossible.</li> <li>• -17. The step is too small to make further impact.</li> <li>• -18. Too many iterations have been performed. This may happen if control.maxit is too small, but may also be symptomatic of a badly scaled problem.</li> <li>• -19. The CPU time limit has been reached. This may happen if control.cpu_time_limit is too small, but may also be symptomatic of a badly scaled problem.</li> <li>• -23. An entry from the strict upper triangle of <math>H</math> has been specified.</li> </ul>
<i>in</i>	<i>n</i>	is a scalar variable of type int, that holds the number of variables
<i>in</i>	<i>m</i>	is a scalar variable of type int, that holds the number of general linear constraints.
<i>in</i>	<i>h_ne</i>	is a scalar variable of type int, that holds the number of entries in the lower triangular part of the Hessian matrix $H$ .
<i>in</i>	<i>H_val</i>	is a one-dimensional array of size h_ne and type double, that holds the values of the entries of the lower triangular part of the Hessian matrix $H$ in any of the available storage schemes.
<i>in</i>	<i>g</i>	is a one-dimensional array of size n and type double, that holds the linear term $g$ of the objective function. The $j$ -th component of $g$ , $j = 0, \dots, n-1$ , contains $g_j$ .
<i>in</i>	<i>f</i>	is a scalar of type double, that holds the constant term $f$ of the objective function.
<i>in</i>	<i>a_ne</i>	is a scalar variable of type int, that holds the number of entries in the constraint Jacobian matrix $A$ .
<i>in</i>	<i>A_val</i>	is a one-dimensional array of size a_ne and type double, that holds the values of the entries of the constraint Jacobian matrix $A$ in any of the available storage schemes.

## Parameters

in	$c$	is a one-dimensional array of size $m$ and type double, that holds the linear term $c$ in the constraints. The $i$ -th component of $c$ , $i = 0, \dots, m-1$ , contains $c_i$ .
in, out	$x$	is a one-dimensional array of size $n$ and type double, that holds the values $x$ of the optimization variables. The $j$ -th component of $x$ , $j = 0, \dots, n-1$ , contains $x_j$ .
in, out	$y$	is a one-dimensional array of size $n$ and type double, that holds the values $y$ of the Lagrange multipliers for the linear constraints. The $j$ -th component of $y$ , $i = 0, \dots, m-1$ , contains $y_i$ .

## 3.1.2.6 eqp\_solve\_sldqp()

```

void eqp_solve_sldqp (
    void ** data,
    int * status,
    int n,
    int m,
    const real_wp_ w[],
    const real_wp_ x0[],
    const real_wp_ g[],
    const real_wp_ f,
    int a_ne,
    const real_wp_ A_val[],
    real_wp_ c[],
    real_wp_ x[],
    real_wp_ y[] )

```

Solve the shifted least-distance quadratic program

## Parameters

in, out	<i>data</i>	holds private internal data
---------	-------------	-----------------------------

## Parameters

<code>in, out</code>	<code>status</code>	<p>is a scalar variable of type int, that gives the entry and exit status from the package. Possible exit are:</p> <ul style="list-style-type: none"> <li>• 0. The run was succesful</li> <li>• -1. An allocation error occurred. A message indicating the offending array is written on unit control.error, and the returned allocation status and a string containing the name of the offending array are held in <code>inform.alloc_status</code> and <code>inform.bad_alloc</code> respectively.</li> <li>• -2. A deallocation error occurred. A message indicating the offending array is written on unit control.error and the returned allocation status and a string containing the name of the offending array are held in <code>inform.alloc_status</code> and <code>inform.bad_alloc</code> respectively.</li> <li>• -3. The restrictions <math>n &gt; 0</math> and <math>m &gt; 0</math> or requirement that a type contains its relevant string 'dense', 'coordinate', 'sparse_by_rows', 'diagonal', 'scaled_identity', 'identity', 'zero' or 'none' has been violated.</li> <li>• -7. The constraints appear to have no feasible point.</li> <li>• -9. The analysis phase of the factorization failed; the return status from the factorization package is given in the component <code>inform.factor_status</code></li> <li>• -10. The factorization failed; the return status from the factorization package is given in the component <code>inform.factor_status</code>.</li> <li>• -11. The solution of a set of linear equations using factors from the factorization package failed; the return status from the factorization package is given in the component <code>inform.factor_status</code>.</li> <li>• -16. The problem is so ill-conditioned that further progress is impossible.</li> <li>• -17. The step is too small to make further impact.</li> <li>• -18. Too many iterations have been performed. This may happen if <code>control.maxit</code> is too small, but may also be symptomatic of a badly scaled problem.</li> <li>• -19. The CPU time limit has been reached. This may happen if <code>control.cpu_time_limit</code> is too small, but may also be symptomatic of a badly scaled problem.</li> <li>• -23. An entry from the strict upper triangle of <math>H</math> has been specified.</li> </ul>
<code>in</code>	<code>n</code>	is a scalar variable of type int, that holds the number of variables
<code>in</code>	<code>m</code>	is a scalar variable of type int, that holds the number of general linear constraints.
<code>in</code>	<code>w</code>	is a one-dimensional array of size n and type double, that holds the values of the weights $w$ .
<code>in</code>	<code>x0</code>	is a one-dimensional array of size n and type double, that holds the values of the shifts $x^0$ .
<code>in</code>	<code>g</code>	is a one-dimensional array of size n and type double, that holds the linear term $g$ of the objective function. The j-th component of $g$ , $j = 0, \dots, n-1$ , contains $g_j$ .
<code>in</code>	<code>f</code>	is a scalar of type double, that holds the constant term $f$ of the objective function.
<code>in</code>	<code>a_ne</code>	is a scalar variable of type int, that holds the number of entries in the constraint Jacobian matrix $A$ .
<code>in</code>	<code>A_val</code>	is a one-dimensional array of size <code>a_ne</code> and type double, that holds the values of the entries of the constraint Jacobian matrix $A$ in any of the available storage schemes.
<code>in</code>	<code>c</code>	is a one-dimensional array of size m and type double, that holds the linear term $c$ in the constraints. The i-th component of $c$ , $i = 0, \dots, m-1$ , contains $c_i$ .

## Parameters

in, out	$x$	is a one-dimensional array of size $n$ and type double, that holds the values $x$ of the optimization variables. The $j$ -th component of $x$ , $j = 0, \dots, n-1$ , contains $x_j$ .
in, out	$y$	is a one-dimensional array of size $n$ and type double, that holds the values $y$ of the Lagrange multipliers for the linear constraints. The $j$ -th component of $y$ , $i = 0, \dots, m-1$ , contains $y_i$ .

## 3.1.2.7 eqp\_resolve\_qp()

```
void eqp_resolve_qp (
    void ** data,
    int * status,
    int n,
    int m,
    const real_wp_ g[],
    const real_wp_ f,
    real_wp_ c[],
    real_wp_ x[],
    real_wp_ y[] )
```

Resolve the quadratic program or shifted least-distance quadratic program when some or all of the data  $g$ ,  $f$  and  $c$  has changed

## Parameters

in, out	<i>data</i>	holds private internal data
---------	-------------	-----------------------------

## Parameters

<code>in, out</code>	<code>status</code>	<p>is a scalar variable of type int, that gives the entry and exit status from the package. Possible exit are:</p> <ul style="list-style-type: none"> <li>• 0. The run was succesful.</li> <li>• -1. An allocation error occurred. A message indicating the offending array is written on unit control.error, and the returned allocation status and a string containing the name of the offending array are held in <code>inform.alloc_status</code> and <code>inform.bad_alloc</code> respectively.</li> <li>• -2. A deallocation error occurred. A message indicating the offending array is written on unit control.error and the returned allocation status and a string containing the name of the offending array are held in <code>inform.alloc_status</code> and <code>inform.bad_alloc</code> respectively.</li> <li>• -3. The restrictions <math>n &gt; 0</math> and <math>m &gt; 0</math> or requirement that a type contains its relevant string 'dense', 'coordinate', 'sparse_by_rows', 'diagonal', 'scaled_identity', 'identity', 'zero' or 'none' has been violated.</li> <li>• -7. The constraints appear to have no feasible point.</li> <li>• -11. The solution of a set of linear equations using factors from the factorization package failed; the return status from the factorization package is given in the component <code>inform.factor_status</code>.</li> <li>• -16. The problem is so ill-conditioned that further progress is impossible.</li> <li>• -17. The step is too small to make further impact.</li> <li>• -18. Too many iterations have been performed. This may happen if <code>control.maxit</code> is too small, but may also be symptomatic of a badly scaled problem.</li> <li>• -19. The CPU time limit has been reached. This may happen if <code>control.cpu_time_limit</code> is too small, but may also be symptomatic of a badly scaled problem.</li> <li>• -23. An entry from the strict upper triangle of <math>H</math> has been specified.</li> </ul>
<code>in</code>	<code>n</code>	is a scalar variable of type int, that holds the number of variables
<code>in</code>	<code>m</code>	is a scalar variable of type int, that holds the number of general linear constraints.
<code>in</code>	<code>g</code>	is a one-dimensional array of size n and type double, that holds the linear term $g$ of the objective function. The j-th component of $g$ , $j = 0, \dots, n-1$ , contains $g_j$ .
<code>in</code>	<code>f</code>	is a scalar of type double, that holds the constant term $f$ of the objective function.
<code>in</code>	<code>c</code>	is a one-dimensional array of size m and type double, that holds the linear term $c$ in the constraints. The i-th component of $c$ , $i = 0, \dots, m-1$ , contains $c_i$ .
<code>in, out</code>	<code>x</code>	is a one-dimensional array of size n and type double, that holds the values $x$ of the optimization variables. The j-th component of $x$ , $j = 0, \dots, n-1$ , contains $x_j$ .
<code>in, out</code>	<code>y</code>	is a one-dimensional array of size n and type double, that holds the values $y$ of the Lagrange multipliers for the linear constraints. The j-th component of $y$ , $i = 0, \dots, m-1$ , contains $y_i$ .

3.1.2.8 `eqp_information()`

```
void eqp_information (
    void ** data,
```

```

    struct eqp_inform_type * inform,
    int * status )

```

Provides output information

#### Parameters

in, out	<i>data</i>	holds private internal data
out	<i>inform</i>	is a struct containing output information (see <a href="#">eqp_inform_type</a> )
out	<i>status</i>	is a scalar variable of type int, that gives the exit status from the package. Possible values are (currently): <ul style="list-style-type: none"> <li>• 0. The values were recorded succesfully</li> </ul>

### 3.1.2.9 eqp\_terminate()

```

void eqp_terminate (
    void ** data,
    struct eqp_control_type * control,
    struct eqp_inform_type * inform )

```

Deallocate all internal private storage

#### Parameters

in, out	<i>data</i>	holds private internal data
out	<i>control</i>	is a struct containing control information (see <a href="#">eqp_control_type</a> )
out	<i>inform</i>	is a struct containing output information (see <a href="#">eqp_inform_type</a> )





## Chapter 4

# Example Documentation

### 4.1 eqpt.c

This is an example of how to use the package to solve a quadratic program. A variety of supported Hessian and constraint matrix storage formats are shown.

Notice that C-style indexing is used, and that this is flagged by setting `control.f_indexing` to `false`.

### 4.2 eqptf.c

This is the same example, but now fortran-style indexing is used.



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