

NAG Toolbox for MATLAB

f07ph

1 Purpose

f07ph returns error bounds for the solution of a real symmetric indefinite system of linear equations with multiple right-hand sides, $AX = B$, using packed storage. It improves the solution by iterative refinement, in order to reduce the backward error as much as possible.

2 Syntax

```
[x, ferr, berr, info] = f07ph(uplo, ap, afp, ipiv, b, x, 'n', n,
    'nrhs_p', nrhs_p)
```

3 Description

f07ph returns the backward errors and estimated bounds on the forward errors for the solution of a real symmetric indefinite system of linear equations with multiple right-hand sides $AX = B$, using packed storage. The function handles each right-hand side vector (stored as a column of the matrix B) independently, so we describe the function of f07ph in terms of a single right-hand side b and solution x .

Given a computed solution x , the function computes the *component-wise backward error* β . This is the size of the smallest relative perturbation in each element of A and b such that x is the exact solution of a perturbed system

$$(A + \delta A)x = b + \delta b$$

$$|\delta a_{ij}| \leq \beta |a_{ij}| \quad \text{and} \quad |\delta b_i| \leq \beta |b_i|.$$

Then the function estimates a bound for the *component-wise forward error* in the computed solution, defined by:

$$\max_i |x_i - \hat{x}_i| / \max_i |x_i|$$

where $\hat{x}$ is the true solution.

For details of the method, see the F07 Chapter Introduction.

4 References

Golub G H and Van Loan C F 1996 *Matrix Computations* (3rd Edition) Johns Hopkins University Press, Baltimore

5 Parameters

5.1 Compulsory Input Parameters

1: **uplo** – string

Indicates whether the upper or lower triangular part of A is stored and how A is to be factorized.

uplo = 'U'

The upper triangular part of A is stored and A is factorized as $PUDU^T P^T$, where U is upper triangular.

uplo = 'L'

The lower triangular part of A is stored and A is factorized as $PLDL^T P^T$, where L is lower triangular.

Constraint: **uplo** = 'U' or 'L'.

2: **ap(*) – double array**

Note: the dimension of the array **ap** must be at least $\max(1, \mathbf{n} \times (\mathbf{n} + 1)/2)$.

The n by n original symmetric matrix A as supplied to f07pd.

3: **afp(*) – double array**

Note: the dimension of the array **afp** must be at least $\max(1, \mathbf{n} \times (\mathbf{n} + 1)/2)$.

The factorization of A stored in packed form, as returned by f07pd.

4: **ipiv(*) – int32 array**

Note: the dimension of the array **ipiv** must be at least $\max(1, \mathbf{n})$.

Details of the interchanges and the block structure of D , as returned by f07pd.

5: **b(ldb,*) – double array**

The first dimension of the array **b** must be at least $\max(1, \mathbf{n})$

The second dimension of the array must be at least $\max(1, \mathbf{nrhs_p})$

The n by r right-hand side matrix B .

6: **x(ldx,*) – double array**

The first dimension of the array **x** must be at least $\max(1, \mathbf{n})$

The second dimension of the array must be at least $\max(1, \mathbf{nrhs_p})$

The n by r solution matrix X , as returned by f07pe.

5.2 Optional Input Parameters1: **n – int32 scalar**

Default: The first dimension of the array **ap** and the second dimension of the array **ap**. (An error is raised if these dimensions are not equal.)

n , the order of the matrix A .

Constraint: $\mathbf{n} \geq 0$.

2: **nrhs_p – int32 scalar**

Default: The second dimension of the arrays **b**, **x**. (An error is raised if these dimensions are not equal.)

r , the number of right-hand sides.

Constraint: $\mathbf{nrhs_p} \geq 0$.

5.3 Input Parameters Omitted from the MATLAB Interface

ldb, ldx, work, iwork

5.4 Output Parameters1: **x(ldx,*) – double array**

The first dimension of the array **x** must be at least $\max(1, \mathbf{n})$

The second dimension of the array must be at least $\max(1, \mathbf{nrhs_p})$

The improved solution matrix X .

2: **ferr**(*) – double array

Note: the dimension of the array **ferr** must be at least $\max(1, \text{nrhs_p})$.

ferr(j) contains an estimated error bound for the j th solution vector, that is, the j th column of X , for $j = 1, 2, \dots, r$.

3: **berr**(*) – double array

Note: the dimension of the array **berr** must be at least $\max(1, \text{nrhs_p})$.

berr(j) contains the component-wise backward error bound β for the j th solution vector, that is, the j th column of X , for $j = 1, 2, \dots, r$.

4: **info** – int32 scalar

info = 0 unless the function detects an error (see Section 6).

6 Error Indicators and Warnings

Errors or warnings detected by the function:

info = $-i$

If **info** = $-i$, parameter i had an illegal value on entry. The parameters are numbered as follows:

1: **uplo**, 2: **n**, 3: **nrhs_p**, 4: **ap**, 5: **afp**, 6: **ipiv**, 7: **b**, 8: **ldb**, 9: **x**, 10: **ldx**, 11: **ferr**, 12: **berr**, 13: **work**, 14: **iwork**, 15: **info**.

It is possible that **info** refers to a parameter that is omitted from the MATLAB interface. This usually indicates that an error in one of the other input parameters has caused an incorrect value to be inferred.

7 Accuracy

The bounds returned in **ferr** are not rigorous, because they are estimated, not computed exactly; but in practice they almost always overestimate the actual error.

8 Further Comments

For each right-hand side, computation of the backward error involves a minimum of $4n^2$ floating-point operations. Each step of iterative refinement involves an additional $6n^2$ operations. At most five steps of iterative refinement are performed, but usually only 1 or 2 steps are required.

Estimating the forward error involves solving a number of systems of linear equations of the form $Ax = b$; the number is usually 4 or 5 and never more than 11. Each solution involves approximately $2n^2$ operations.

The complex analogues of this function are f07pv for Hermitian matrices and f07qv for symmetric matrices.

9 Example

```
uplo = 'L';
ap = [2.07;
      3.87;
      4.2;
      -1.15;
      -0.21;
      1.87;
      0.63;
```

```
1.15;  
2.06;  
-1.81];  
afp = [2.07;  
4.2;  
0.2230413840558341;  
0.6536583767489105;  
1.15;  
0.8115010321439103;  
-0.5959697237786296;  
-2.59067708640519;  
0.3030846795506181;  
0.4073851981348882];  
ipiv = [int32(-3);  
int32(-3);  
int32(3);  
int32(4)];  
b = [-9.5, 27.85;  
-8.3800000000000001, 9.9;  
-6.07, 19.25;  
-0.96, 3.93];  
x = [-4.0000000000000004, 1.0000000000000004;  
-1.0000000000000002, 4.0000000000000003;  
2.0000000000000004, 2.9999999999999993;  
5.0000000000000006, 1.9999999999999992];  
[xOut, ferr, berr, info] = f07ph(uplo, ap, afp, ipiv, b, x)
```

```
xOut =  
-4.0000    1.0000  
-1.0000    4.0000  
2.0000    3.0000  
5.0000    2.0000  
ferr =  
1.0e-13 *  
0.2255  
0.3168  
berr =  
1.0e-16 *  
0.4588  
0.2307  
info =  
0
```