

## F07QRF (CSPTRF/ZSPTRF) – NAG Fortran Library Routine Document

**Note.** Before using this routine, please read the Users' Note for your implementation to check the interpretation of bold italicised terms and other implementation-dependent details.

### 1 Purpose

F07QRF (CSPTRF/ZSPTRF) computes the Bunch–Kaufman factorization of a complex symmetric matrix, using packed storage.

### 2 Specification

```

SUBROUTINE F07QRF(UPLO, N, AP, IPIV, INFO)
ENTRY      csptf(UPL0, N, AP, IPIV, INFO)
INTEGER    N, IPIV(*), INFO
complex  AP(*)
CHARACTER*1 UPL0

```

The ENTRY statement enables the routine to be called by its LAPACK name.

### 3 Description

This routine factorizes a complex symmetric matrix  $A$ , using the Bunch–Kaufman diagonal pivoting method and packed storage.  $A$  is factorized as either  $A = PUDU^T P^T$  if  $UPLO = 'U'$ , or  $A = PLDL^T P^T$  if  $UPLO = 'L'$ , where  $P$  is a permutation matrix,  $U$  (or  $L$ ) is a unit upper (or lower) triangular matrix and  $D$  is a symmetric block diagonal matrix with 1 by 1 and 2 by 2 diagonal blocks;  $U$  (or  $L$ ) has 2 by 2 unit diagonal blocks corresponding to the 2 by 2 blocks of  $D$ . Row and column interchanges are performed to ensure numerical stability while preserving symmetry.

### 4 References

- [1] Golub G H and van Loan C F (1996) *Matrix Computations* Johns Hopkins University Press (3rd Edition), Baltimore

### 5 Parameters

- 1: UPLO — CHARACTER\*1 *Input*  
*On entry:* indicates whether the upper or lower triangular part of  $A$  is stored and how  $A$  is factorized, as follows:
- if  $UPLO = 'U'$ , then the upper triangular part of  $A$  is stored and  $A$  is factorized as  $PUDU^T P^T$ , where  $U$  is upper triangular;
  - if  $UPLO = 'L'$ , then 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: N — INTEGER *Input*  
*On entry:*  $n$ , the order of the matrix  $A$ .  
*Constraint:*  $N \geq 0$ .

**3:** AP(\*) — *complex* array *Input/Output*

**Note:** the dimension of the array AP must be at least  $\max(1, N*(N+1)/2)$ .

*On entry:* the  $n$  by  $n$  symmetric matrix  $A$ , packed by columns. More precisely, if UPLO = 'U', the upper triangle of  $A$  must be stored with element  $a_{ij}$  in  $\text{AP}(i + j(j-1)/2)$  for  $i \leq j$ ; if UPLO = 'L', the lower triangle of  $A$  must be stored with element  $a_{ij}$  in  $\text{AP}(i + (2n-j)(j-1)/2)$  for  $i \geq j$ .

*On exit:*  $A$  is overwritten by details of the block diagonal matrix  $D$  and the multipliers used to obtain the factor  $U$  or  $L$  as specified by UPLO.

**4:** IPIV(\*) — INTEGER array *Output*

**Note:** the dimension of the array IPIV must be at least  $\max(1, N)$ .

*On exit:* details of the interchanges and the block structure of  $D$ . More precisely, if  $\text{IPIV}(i) = k > 0$ , then  $d_{ii}$  is a 1 by 1 pivot block and the  $i$ th row and column of  $A$  was interchanged with the  $k$ th row and column. If UPLO = 'U' and  $\text{IPIV}(i-1) = \text{IPIV}(i) = -l < 0$ , then  $\begin{pmatrix} d_{i-1, i-1} & d_{i, i-1} \\ d_{i, i-1} & d_{ii} \end{pmatrix}$  is a 2 by 2 pivot block and the  $(i-1)$ th row and column of  $A$  was interchanged with the  $l$ th row and column; if UPLO = 'L' and  $\text{IPIV}(i) = \text{IPIV}(i+1) = -m < 0$ , then  $\begin{pmatrix} d_{ii} & d_{i+1, i} \\ d_{i+1, i} & d_{i+1, i+1} \end{pmatrix}$  is a 2 by 2 pivot block and the  $(i+1)$ th row and column of  $A$  was interchanged with the  $m$ th row and column.

**5:** INFO — INTEGER *Output*

*On exit:* INFO = 0 unless the routine detects an error (see Section 6).

## 6 Error Indicators and Warnings

INFO < 0

If INFO =  $-i$ , the  $i$ th parameter had an illegal value. An explanatory message is output, and execution of the program is terminated.

INFO > 0

If INFO =  $i$ ,  $d_{ii}$  is exactly zero. The factorization has been completed but the block diagonal matrix  $D$  is exactly singular, and division by zero will occur if it is subsequently used to solve a system of linear equations or to compute  $A^{-1}$ .

## 7 Accuracy

If UPLO = 'U', the computed factors  $U$  and  $D$  are the exact factors of a perturbed matrix  $A + E$ , where

$$|E| \leq c(n)\epsilon P|U||D||U^T|P^T,$$

$c(n)$  is a modest linear function of  $n$ , and  $\epsilon$  is the *machine precision*. If UPLO = 'L', a similar statement holds for the computed factors  $L$  and  $D$ .

## 8 Further Comments

The elements of  $D$  overwrite the corresponding elements of  $A$ ; if  $D$  has 2 by 2 blocks, only the upper or lower triangle is stored, as specified by UPLO.

The unit diagonal elements of  $U$  or  $L$  and the 2 by 2 unit diagonal blocks are not stored. The remaining elements of  $U$  or  $L$  overwrite elements in the corresponding columns of  $A$ , but additional row interchanges must be applied to recover  $U$  or  $L$  explicitly (this is seldom necessary). If  $\text{IPIV}(i) = i$ , for  $i = 1, 2, \dots, n$ , then  $U$  or  $L$  are stored explicitly in packed form (except for their unit diagonal elements which are equal to 1).

The total number of real floating-point operations is approximately  $\frac{4}{3}n^3$ .

A call to this routine may be followed by calls to the routines:

F07QSF (CSPTRS/ZSPTRS) to solve  $AX = B$ ;

F07QUF (CSPCON/ZSPCON) to estimate the condition number of  $A$ ;

F07QWF (CSPTRI/ZSPTRI) to compute the inverse of  $A$ .

The real analogue of this routine is F07PDF (SSPTRF/DSPTRF).

## 9 Example

To compute the Bunch–Kaufman factorization of the matrix  $A$ , where

$$A = \begin{pmatrix} -0.39 - 0.71i & 5.14 - 0.64i & -7.86 - 2.96i & 3.80 + 0.92i \\ 5.14 - 0.64i & 8.86 + 1.81i & -3.52 + 0.58i & 5.32 - 1.59i \\ -7.86 - 2.96i & -3.52 + 0.58i & -2.83 - 0.03i & -1.54 - 2.86i \\ 3.80 + 0.92i & 5.32 - 1.59i & -1.54 - 2.86i & -0.56 + 0.12i \end{pmatrix},$$

using packed storage.

### 9.1 Program Text

**Note.** The listing of the example program presented below uses bold italicised terms to denote precision-dependent details. Please read the Users' Note for your implementation to check the interpretation of these terms. As explained in the Essential Introduction to this manual, the results produced may not be identical for all implementations.

```
*      F07QRF Example Program Text
*      Mark 15 Release. NAG Copyright 1991.
*      .. Parameters ..
      INTEGER          NIN, NOUT
      PARAMETER        (NIN=5,NOUT=6)
      INTEGER          NMAX
      PARAMETER        (NMAX=8)
*      .. Local Scalars ..
      INTEGER          I, IFAIL, INFO, J, N
      CHARACTER        UPLO
*      .. Local Arrays ..
      complex         AP(NMAX*(NMAX+1)/2)
      INTEGER          IPIV(NMAX)
      CHARACTER        CLABS(1), RLABS(1)
*      .. External Subroutines ..
      EXTERNAL         csptrf, X04DDF
*      .. Executable Statements ..
      WRITE (NOUT,*) 'F07QRF Example Program Results'
*      Skip heading in data file
      READ (NIN,*)
      READ (NIN,*) N
      IF (N.LE.NMAX) THEN
*
*      Read A from data file
*
      READ (NIN,*) UPLO
      IF (UPLO.EQ.'U') THEN
          READ (NIN,*) ((AP(I+J*(J-1)/2),J=I,N),I=1,N)
      ELSE IF (UPLO.EQ.'L') THEN
          READ (NIN,*) ((AP(I+(2*N-J)*(J-1)/2),J=1,I),I=1,N)
      END IF
*

```

```

*      Factorize A
*
*      CALL csptrf(UPL0,N,AP,IPIV,INFO)
*
*      WRITE (NOUT,*)
*
*      Print details of factorization
*
*      IFAIL = 0
*      CALL X04DDF(UPL0,'Nonunit',N,AP,'Bracketed','F7.4',
+                'Details of factorization','Integer',RLABS,
+                'Integer',CLABS,80,0,IFAIL)
*
*      Print pivot indices
*
*      WRITE (NOUT,*)
*      WRITE (NOUT,*) 'IPIV'
*      WRITE (NOUT,99999) (IPIV(I),I=1,N)
*
*      IF (INFO.NE.0) WRITE (NOUT,*) 'The factor D is singular'
*
*      END IF
*      STOP
*
*      99999 FORMAT ((1X,I12,3I18))
*      END

```

## 9.2 Program Data

F07QRF Example Program Data

```

4                                     :Value of N
'L'                                   :Value of UPL0
(-0.39,-0.71)
( 5.14,-0.64) ( 8.86, 1.81)
(-7.86,-2.96) (-3.52, 0.58) (-2.83,-0.03)
( 3.80, 0.92) ( 5.32,-1.59) (-1.54,-2.86) (-0.56, 0.12) :End of matrix A

```

## 9.3 Program Results

F07QRF Example Program Results

Details of factorization

	1	2	3	4
1	(-0.3900,-0.7100)			
2	(-7.8600,-2.9600)	(-2.8300,-0.0300)		
3	( 0.5279,-0.3715)	(-0.6078, 0.2811)	( 4.4079, 5.3991)	
4	( 0.4426, 0.1936)	(-0.4823, 0.0150)	(-0.1071,-0.3157)	(-2.0954,-2.2011)

IPIV

-3	-3	3	4
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