

NAG Fortran Library Routine Document

F08QUF (CTRSEN/ZTRSEN)

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

F08QUF (CTRSEN/ZTRSEN) reorders the Schur factorization of a complex general matrix so that a selected cluster of eigenvalues appears in the leading elements on the diagonal of the Schur form. The routine also optionally computes the reciprocal condition numbers of the cluster of eigenvalues and/or the invariant subspace.

2 Specification

```

SUBROUTINE F08QUF (JOB, COMPQ, SELECT, N, T, LDT, Q, LDQ, W, M, S, SEP,
1              WORK, LWORK, INFO)
ENTRY          ctrsen (JOB, COMPQ, SELECT, N, T, LDT, Q, LDQ, W, M, S, SEP,
1              WORK, LWORK, INFO)
INTEGER       N, LDT, LDQ, M, LWORK, INFO
real        S, SEP
complex    T(LDT,*), Q(LDQ,*), W(*), WORK(*)
LOGICAL       SELECT(*)
CHARACTER*1   JOB, COMPQ

```

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

3 Description

This routine reorders the Schur factorization of a complex general matrix $A = QTQ^H$, so that a selected cluster of eigenvalues appears in the leading diagonal elements of the Schur form.

The reordered Schur form \tilde{T} is computed by a unitary similarity transformation: $\tilde{T} = Z^H T Z$. Optionally the updated matrix \tilde{Q} of Schur vectors is computed as $\tilde{Q} = QZ$, giving $A = \tilde{Q}\tilde{T}\tilde{Q}^H$.

Let $\tilde{T} = \begin{pmatrix} T_{11} & T_{12} \\ 0 & T_{22} \end{pmatrix}$, where the selected eigenvalues are precisely the eigenvalues of the leading m by m submatrix T_{11} . Let \tilde{Q} be correspondingly partitioned as $(Q_1 \ Q_2)$ where Q_1 consists of the first m columns of Q . Then $AQ_1 = Q_1T_{11}$, and so the m columns of Q_1 form an orthonormal basis for the invariant subspace corresponding to the selected cluster of eigenvalues.

Optionally the routine also computes estimates of the reciprocal condition numbers of the average of the cluster of eigenvalues and of the invariant subspace.

4 References

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

5 Parameters

1: JOB – CHARACTER*1 *Input*

On entry: indicates whether condition numbers are required for the cluster of eigenvalues and/or the invariant subspace, as follows:

if JOB = 'N', no condition numbers are required;

if JOB = 'E', only the condition number for the cluster of eigenvalues is computed;

if JOB = 'V', only the condition number for the invariant subspace is computed;
 if JOB = 'B', condition numbers for both the cluster of eigenvalues and the invariant subspace are computed.

Constraint: JOB = 'N', 'E', 'V' or 'B'.

2: COMPQ – CHARACTER*1 *Input*

On entry: indicates whether the matrix Q of Schur vectors is to be updated, as follows:

if COMPQ = 'V', the matrix Q of Schur vectors is updated;

if COMPQ = 'N', no Schur vectors are updated.

Constraint: COMPQ = 'V' or 'N'.

3: SELECT(*) – LOGICAL array *Input*

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

On entry: specifies the eigenvalues in the selected cluster. To select a complex eigenvalue λ_j , SELECT(j) must be set .TRUE..

4: N – INTEGER *Input*

On entry: n , the order of the matrix T .

Constraint: $N \geq 0$.

5: T(LDT,*) – **complex** array *Input/Output*

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

On entry: the n by n upper triangular matrix T , as returned by F08PSF (CHSEQR/ZHSEQR).

On exit: T is overwritten by the updated matrix \tilde{T} .

6: LDT – INTEGER *Input*

On entry: the first dimension of the array T as declared in the (sub)program from which F08QUF (CTRSEN/ZTRSEN) is called.

Constraint: $LDT \geq \max(1, N)$.

7: Q(LDQ,*) – **complex** array *Input/Output*

Note: the second dimension of the array Q must be at least $\max(1, N)$ if COMPQ = 'V' and at least 1 if COMPQ = 'N' .

On entry: if COMPQ = 'V', Q must contain the n by n unitary matrix Q of Schur vectors, as returned by F08PSF (CHSEQR/ZHSEQR).

On exit: if COMPQ = 'V', Q contains the updated matrix of Schur vectors; the first m columns of Q form an orthonormal basis for the specified invariant subspace.

Q is not referenced if COMPQ = 'N'.

8: LDQ – INTEGER *Input*

On entry: the first dimension of the array Q as declared in the (sub)program from which F08QUF (CTRSEN/ZTRSEN) is called.

Constraints:

$LDQ \geq \max(1, N)$ if COMPQ = 'V',

$LDQ \geq 1$ if COMPQ = 'N'.

- 9: $W(*)$ – **complex** array *Output*
Note: the dimension of the array W must be at least $\max(1, N)$.
On exit: the reordered eigenvalues of \tilde{T} . The eigenvalues are stored in the same order as on the diagonal of \tilde{T} .
- 10: M – INTEGER *Output*
On exit: m , the dimension of the specified invariant subspace, which is the same as the number of selected eigenvalues (see SELECT); $0 \leq m \leq n$.
- 11: S – **real** *Output*
On exit: if JOB = 'E' or 'B', S is a lower bound on the reciprocal condition number of the average of the selected cluster of eigenvalues. If $M = 0$ or N , $S = 1$.
 S is not referenced if JOB = 'N' or 'V'.
- 12: SEP – **real** *Output*
On exit: if JOB = 'V' or 'B', SEP is the estimated reciprocal condition number of the specified invariant subspace. If $M = 0$ or N , $SEP = \|T\|$.
 SEP is not referenced if JOB = 'N' or 'E'.
- 13: $WORK(*)$ – **complex** array *Workspace*
Note: the dimension of the array $WORK$ must be at least $\max(1, LWORK)$.
On exit: if INFO = 0, the real part of $WORK(1)$ contains the minimum value of $LWORK$ required for optimum performance.
- 14: $LWORK$ – INTEGER *Input*
On entry: the dimension of the array $WORK$ as declared in the (sub)program from which F08QUF (CTRSEN/ZTRSEN) is called, unless $LWORK = -1$, in which case a workspace query is assumed and the routine only calculates the minimum dimension of $WORK$.
Constraints:
if JOB = 'N', then $LWORK \geq 1$ or $LWORK = -1$,
if JOB = 'E', then $LWORK \geq \max(1, m \times (N - m))$ or $LWORK = -1$,
if JOB = 'V' or 'B', then $LWORK \geq \max(1, 2m \times (N - m))$ or $LWORK = -1$
The actual amount of workspace required cannot exceed $N^2/4$ if JOB = 'E' or $N^2/2$ if JOB = 'V' or 'B'.
- 15: $INFO$ – INTEGER *Output*
On exit: $INFO = 0$ unless the routine detects an error (see Section 6).

6 Error Indicators and Warnings

Errors or warnings detected by the routine:

$INFO < 0$

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

7 Accuracy

The computed matrix \tilde{T} is similar to a matrix $T + E$, where

$$\|E\|_2 = O(\epsilon)\|T\|_2,$$

and ϵ is the *machine precision*.

S cannot underestimate the true reciprocal condition number by more than a factor of $\sqrt{\min(m, n - m)}$. SEP may differ from the true value by $\sqrt{m(n - m)}$. The angle between the computed invariant subspace and the true subspace is $\frac{O(\epsilon)\|A\|_2}{sep}$.

The values of the eigenvalues are never changed by the re-ordering.

8 Further Comments

The real analogue of this routine is F08QGF (STRSEN/DTRSEN).

9 Example

To reorder the Schur factorization of the matrix $A = QTQ^H$ such that the eigenvalues stored in elements t_{11} and t_{44} appear as the leading elements on the diagonal of the reordered matrix \tilde{T} , where

$$T = \begin{pmatrix} -6.0004 - 6.9999i & 0.3637 - 0.3656i & -0.1880 + 0.4787i & 0.8785 - 0.2539i \\ 0.0000 + 0.0000i & -5.0000 + 2.0060i & -0.0307 - 0.7217i & -0.2290 + 0.1313i \\ 0.0000 + 0.0000i & 0.0000 + 0.0000i & 7.9982 - 0.9964i & 0.9357 + 0.5359i \\ 0.0000 + 0.0000i & 0.0000 + 0.0000i & 0.0000 + 0.0000i & 3.0023 - 3.9998i \end{pmatrix}$$

and

$$Q = \begin{pmatrix} -0.8347 - 0.1364i & -0.0628 + 0.3806i & 0.2765 - 0.0846i & 0.0633 - 0.2199i \\ 0.0664 - 0.2968i & 0.2365 + 0.5240i & -0.5877 - 0.4208i & 0.0835 + 0.2183i \\ -0.0362 - 0.3215i & 0.3143 - 0.5473i & 0.0576 - 0.5736i & 0.0057 - 0.4058i \\ 0.0086 + 0.2958i & -0.3416 - 0.0757i & -0.1900 - 0.1600i & 0.8327 - 0.1868i \end{pmatrix}.$$

The original matrix A is given in F08NTF (CUNGHR/ZUNGHR).

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.

```
*      F08QUF Example Program Text
*      Mark 16 Release. NAG Copyright 1992.
*      .. Parameters ..
INTEGER          NIN, NOUT
PARAMETER       (NIN=5,NOUT=6)
INTEGER          NMAX, LDT, LDQ, LWORK
PARAMETER       (NMAX=8,LDT=NMAX,LDQ=NMAX,LWORK=NMAX*NMAX/2)
*      .. Local Scalars ..
real           S, SEP
INTEGER          I, IFAIL, INFO, J, M, N
*      .. Local Arrays ..
complex       Q(LDQ,NMAX), T(LDT,NMAX), W(NMAX), WORK(LWORK)
LOGICAL         SELECT(NMAX)
CHARACTER       CLABS(1), RLABS(1)
*      .. External Subroutines ..
EXTERNAL        X04DBF, ctrsen
*      .. Executable Statements ..
WRITE (NOUT,*) 'F08QUF Example Program Results'
*      Skip heading in data file
READ (NIN,*)
READ (NIN,*) N
IF (N.LE.NMAX) THEN
```

```

*
*   Read T and Q from data file
*
*   READ (NIN,*) ((T(I,J),J=1,N),I=1,N)
*   READ (NIN,*)
*   READ (NIN,*) ((Q(I,J),J=1,N),I=1,N)
*   READ (NIN,*)
*
*   READ (NIN,*) (SELECT(I),I=1,N)
*
*   Reorder the Schur factorization
*
*   CALL ctrsen('Both','Vectors',SELECT,N,T,LDT,Q,LDQ,W,M,S,SEP,
+             WORK,LWORK,INFO)
*
*   WRITE (NOUT,*)
*   IFAIL = 0
*
*   CALL X04DBF('General',' ',N,N,T,LDT,'Bracketed','F7.4',
+             'Reordered Schur form','Integer',RLABS,'Integer',
+             CLABS,80,0,IFAIL)
*
*   WRITE (NOUT,*)
*   IFAIL = 0
*
*   CALL X04DBF('General',' ',N,M,Q,LDQ,'Bracketed','F7.4',
+             'Basis of invariant subspace','Integer',RLABS,
+             'Integer',CLABS,80,0,IFAIL)
*
*   WRITE (NOUT,*)
*   WRITE (NOUT,99999) 'Condition number estimate',
+   ' of the selected cluster of eigenvalues = ', 1.0e0/S
*   WRITE (NOUT,*)
*   WRITE (NOUT,99999) 'Condition number estimate of the spec',
+   ' ified invariant subspace = ', 1.0e0/SEP
*   END IF
*   STOP
*
99999 FORMAT (1X,A,A,e10.2)
END

```

9.2 Program Data

F08QUF Example Program Data

```

4                                     :Value of N
(-6.0004,-6.9999) ( 0.3637,-0.3656) (-0.1880, 0.4787) ( 0.8785,-0.2539)
( 0.0000, 0.0000) (-5.0000, 2.0060) (-0.0307,-0.7217) (-0.2290, 0.1313)
( 0.0000, 0.0000) ( 0.0000, 0.0000) ( 7.9982,-0.9964) ( 0.9357, 0.5359)
( 0.0000, 0.0000) ( 0.0000, 0.0000) ( 0.0000, 0.0000) ( 3.0023,-3.9998)
                                     :End of matrix T
(-0.8347,-0.1364) (-0.0628, 0.3806) ( 0.2765,-0.0846) ( 0.0633,-0.2199)
( 0.0664,-0.2968) ( 0.2365, 0.5240) (-0.5877,-0.4208) ( 0.0835, 0.2183)
(-0.0362,-0.3215) ( 0.3143,-0.5473) ( 0.0576,-0.5736) ( 0.0057,-0.4058)
( 0.0086, 0.2958) (-0.3416,-0.0757) (-0.1900,-0.1600) ( 0.8327,-0.1868)
                                     :End of matrix Q
T   F   F   T                                     :End of SELECT

```

9.3 Program Results

F08QUF Example Program Results

Reordered Schur form

	1	2	3	4
1	(-6.0004, -6.9999)	(-0.9433, 0.0086)	(-0.4839, -0.2426)	(0.1539, 0.4000)
2	(0.0000, 0.0000)	(3.0023, -3.9998)	(0.3028, 0.1519)	(1.0421, -0.2338)
3	(0.0000, 0.0000)	(0.0000, 0.0000)	(-5.0000, 2.0060)	(0.6891, -0.1546)
4	(0.0000, 0.0000)	(0.0000, 0.0000)	(0.0000, 0.0000)	(7.9982, -0.9964)

Basis of invariant subspace

	1	2
1	(0.8458, 0.0000)	(0.0488, -0.2073)
2	(-0.0177, 0.3036)	(0.1275, 0.3006)
3	(0.0876, 0.3115)	(0.0398, -0.2711)
4	(-0.0562, -0.2905)	(0.8792, 0.0000)

Condition number estimate of the selected cluster of eigenvalues = 0.10E+01

Condition number estimate of the specified invariant subspace = 0.18E+00
