NAG Library Routine Document

F04AXF

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

F04AXF calculates the approximate solution of a set of real sparse linear equations with a single right-hand side, $Ax = b$ or $A^{\mathrm{T}}x = b$, where A has been factorized by F01BRF or F01BSF.

2 Specification

```
SUBROUTINE F04AXF (N, A, LICN, ICN, IKEEP, RHS, W, MTYPE, IDISP, RESID)

INTEGER             N, LICN, ICN(LICN), IKEEP(5*N), MTYPE, IDISP(2)
REAL (KIND=nag_wp) A(LICN), RHS(N), W(N), RESID
```

3 Description

To solve a system of real linear equations $Ax = b$ or $A^{\mathrm{T}}x = b$, where A is a general sparse matrix, A must first be factorized by F01BRF or F01BSF. F04AXF then computes x by block forward or backward substitution using simple forward and backward substitution within each diagonal block.

The method is fully described in Duff (1977).

A more recent method is available through solver routine F11MFF and factorization routine F11MEF.

4 References

Duff I S (1977) MA28 – a set of Fortran subroutines for sparse unsymmetric linear equations *AERE Report R8730* HMSO

5 Parameters

1: N – INTEGER *Input*

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

Constraint: $\mathrm{N} \geq 0$.

2: A(LICN) – REAL (KIND=nag_wp) array *Input*

On entry: the nonzero elements in the factorization of the matrix A, as returned by F01BRF or F01BSF.

3: LICN – INTEGER *Input*

On entry: the dimension of the arrays A and ICN as declared in the (sub)program from which F04AXF is called.

4: ICN(LICN) – INTEGER array *Communication Array*

On entry: the column indices of the nonzero elements of the factorization, as returned by F01BRF or F01BSF.

5: IKEEP($5 \times$ N) – INTEGER array *Input*

IKEEP provides, on entry, indexing information about the factorization, as returned by F01BRF or F01BSF. Used as internal workspace prior to being restored and hence is unchanged.

6: RHS(N) – REAL (KIND=nag_wp) array *Input/Output*

On entry: the right-hand side vector b.

On exit: RHS is overwritten by the solution vector x.

7: W(N) – REAL (KIND=nag_wp) array *Workspace*

8: MTYPE – INTEGER *Input*

On entry: MTYPE specifies the task to be performed.

MTYPE $= 1$
Solve $Ax = b$.

MTYPE $\neq 1$
Solve $A^{\mathrm{T}}x = b$.

9: IDISP(2) – INTEGER array *Communication Array*

On entry: the values returned in IDISP by F01BRF.

10: RESID – REAL (KIND=nag_wp) *Output*

On exit: the value of the maximum residual, $\max\left(\left|b_i - \sum_j a_{ij}x_j\right|\right)$, over all the unsatisfied equations, in case F01BRF or F01BSF has been used to factorize a singular or rectangular matrix.

6 Error Indicators and Warnings

If an error is detected in an input parameter F04AXF will act as if a soft noisy exit has been requested (see Section 3.3.4 in the Essential Introduction).

7 Accuracy

The accuracy of the computed solution depends on the conditioning of the original matrix. Since F04AXF is always used with either F01BRF or F01BSF, you are recommended to set GROW = .TRUE. on entry to these routines and to examine the value of W(1) on exit (see F01BRF and F01BSF). For a detailed error analysis see page 17 of Duff (1977).

If storage for the original matrix is available then the error can be estimated by calculating the residual

$$r = b - Ax \qquad \left(\text{or } b - A^{\mathrm{T}}x\right)$$

and calling F04AXF again to find a correction δ for x by solving

$$A\delta = r \qquad \left(\text{or } A^{\mathrm{T}}\delta = r\right).$$

8 Further Comments

If the factorized form contains τ nonzeros (IDISP$(2) = \tau$) then the time taken is very approximately 2τ times longer than the inner loop of full matrix code. Some advantage is taken of zeros in the right-hand side when solving $A^{\mathrm{T}}x = b$ (MTYPE $\neq 1$).

9 Example

This example solves the set of linear equations $Ax = b$ where

$$A = \begin{pmatrix} 5 & 0 & 0 & 0 & 0 & 0 \\ 0 & 2 & -1 & 2 & 0 & 0 \\ 0 & 0 & 3 & 0 & 0 & 0 \\ -2 & 0 & 0 & 1 & 1 & 0 \\ -1 & 0 & 0 & -1 & 2 & -3 \\ -1 & -1 & 0 & 0 & 0 & 6 \end{pmatrix} \quad \text{and} \quad b = \begin{pmatrix} 15 \\ 12 \\ 18 \\ 3 \\ -6 \\ 0 \end{pmatrix}.$$

The nonzero elements of A and indexing information are read in by the program, as described in the document for F01BRF.

9.1 Program Text

```
    Program f04axfe

!     F04AXF Example Program Text

!     Mark 24 Release. NAG Copyright 2012.

!     .. Use Statements ..
      Use nag_library, Only: f01brf, f04axf, nag_wp
!     .. Implicit None Statement ..
      Implicit None
!     .. Parameters ..
      Integer, Parameter                 :: nin = 5, nout = 6
!     .. Local Scalars ..
      Real (Kind=nag_wp)                 :: resid, u
      Integer                            :: i, ifail, licn, lirn, mtype, n, nz
      Logical                            :: grow, lblock
!     .. Local Arrays ..
      Real (Kind=nag_wp), Allocatable    :: a(:), rhs(:), w(:)
      Integer, Allocatable               :: icn(:), ikeep(:,:), irn(:), iw(:,:)
      Integer                            :: idisp(10)
      Logical                            :: abort(4)
!     .. Executable Statements ..
      Write (nout,*) 'F04AXF Example Program Results'
      Write (nout,*)
!     Skip heading in data file
      Read (nin,*)
      Read (nin,*) n, nz
      licn = 3*nz
      lirn = 3*nz/2
      Allocate (a(licn),rhs(n),w(n),icn(licn),ikeep(n,5),irn(lirn),iw(n,8))
      Read (nin,*)(a(i),irn(i),icn(i),i=1,nz)
      u = 0.1E0_nag_wp
      lblock = .True.
      grow = .True.
      abort(1) = .True.
      abort(2) = .True.
      abort(3) = .False.
      abort(4) = .True.

!     ifail: behaviour on error exit
!             =0 for hard exit, =1 for quiet-soft, =-1 for noisy-soft
      ifail = 0
!     Decomposition of sparse matrix
      Call f01brf(n,nz,a,licn,irn,lirn,icn,u,ikeep,iw,w,lblock,grow,abort, &
        idisp,ifail)

      If (grow) Then
        Write (nout,*) 'On exit from F01BRF'
        Write (nout,99999) 'Value of W(1) = ', w(1)
      End If
      Read (nin,*) rhs(1:n)
      mtype = 1
```

```
!     Approximate solution of sparse linear equations
      Call f04axf(n,a,licn,icn,ikeep,rhs,w,mtype,idisp,resid)

      Write (nout,*)
      Write (nout,*) 'On exit from F04AXF'
      Write (nout,*) ' Solution'
      Write (nout,99998) rhs(1:n)

99999 Format (1X,A,F9.4)
99998 Format (1X,F9.4)
    End Program f04axfe
```

9.2 Program Data

```
F04AXF Example Program Data
  6 15                                                                : n, nz
   5.0  1  1   2.0  2  2  -1.0  2  3   2.0  2  4   3.0  3  3
  -2.0  4  1   1.0  4  4   1.0  4  5  -1.0  5  1  -1.0  5  4
   2.0  5  5  -3.0  5  6  -1.0  6  1  -1.0  6  2   6.0  6  6    : a
  15.0  12.0  18.0   3.0  -6.0   0.0                              : rhs
```

9.3 Program Results

```
 F04AXF Example Program Results

 On exit from F01BRF
 Value of W(1) =   18.0000

 On exit from F04AXF
  Solution
    3.0000
    3.0000
    6.0000
    6.0000
    3.0000
    1.0000
```