NAG Library Routine Document

C09ABF

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

C09ABF returns the details of the chosen two-dimensional discrete wavelet filter. For a chosen mother wavelet, discrete wavelet transform type (single-level or multi-level DWT) and end extension method, this routine returns the maximum number of levels of resolution (appropriate to a multi-level transform), the filter length, the total number of approximation, horizontal, vertical and diagonal coefficients and the number of coefficients in the second dimension for the single-level case. This routine must be called before any of the two-dimensional transform routines in this chapter.

2 Specification

```
SUBROUTINE C09ABF (WAVNAM, WTRANS, MODE, M, N, NWLMAX, NF, NWCT, NWCN,     &
                   ICOMM, IFAIL)

INTEGER      M, N, NWLMAX, NF, NWCT, NWCN, ICOMM(180), IFAIL
CHARACTER(*) WAVNAM
CHARACTER(1) WTRANS, MODE
```

3 Description

Two-dimensional discrete wavelet transforms (DWT) are characterised by the mother wavelet, the end extension method and whether multiresolution analysis is to be performed. For the selected combination of choices for these three characteristics, and for given dimensions ($m \times n$) of data matrix A, C09ABF returns the dimension details for the transform determined by this combination. The dimension details are: $l_{\max}$, the maximum number of levels of resolution that would be computed were a multi-level DWT applied; n_f, the filter length; n_{ct} the total number of approximation, horizontal, vertical and diagonal coefficients (over all levels in the multi-level DWT case); and n_{cn}, the number of coefficients in the second dimension for a single-level DWT. These values are also stored in the communication array ICOMM, as are the input choices, so that they may be conveniently communicated to the two-dimensional transform routines in this chapter.

4 References

None.

5 Arguments

1: WAVNAM – CHARACTER(*) *Input*

On entry: the name of the mother wavelet. See the C09 Chapter Introduction for details.

WAVNAM = 'HAAR'
Haar wavelet.

WAVNAM = 'DB***n***', where ***n*** $= 2, 3, \ldots, 10$
Daubechies wavelet with ***n*** vanishing moments (2***n*** coefficients). For example, WAVNAM = 'DB4' is the name for the Daubechies wavelet with 4 vanishing moments (8 coefficients).

WAVNAM = 'BIOR***x.y***', where ***x.y*** can be one of 1.1, 1.3, 1.5, 2.2, 2.4, 2.6, 2.8, 3.1, 3.3, 3.5 or 3.7

Biorthogonal wavelet of order ***x.y***. For example WAVNAM = 'BIOR3.1' is the name for the biorthogonal wavelet of order 3.1.

Constraint: WAVNAM = 'HAAR', 'DB2', 'DB3', 'DB4', 'DB5', 'DB6', 'DB7', 'DB8', 'DB9', 'DB10', 'BIOR1.1', 'BIOR1.3', 'BIOR1.5', 'BIOR2.2', 'BIOR2.4', 'BIOR2.6', 'BIOR2.8', 'BIOR3.1', 'BIOR3.3', 'BIOR3.5' or 'BIOR3.7'.

2: WTRANS – CHARACTER(1) *Input*

On entry: the type of discrete wavelet transform that is to be applied.

WTRANS = 'S'
Single-level decomposition or reconstruction by discrete wavelet transform.

WTRANS = 'M'
Multiresolution, by a multi-level DWT or its inverse.

Constraint: WTRANS = 'S' or 'M'.

3: MODE – CHARACTER(1) *Input*

On entry: the end extension method.

MODE = 'P'
Periodic end extension.

MODE = 'H'
Half-point symmetric end extension.

MODE = 'W'
Whole-point symmetric end extension.

MODE = 'Z'
Zero end extension.

Constraint: MODE = 'P', 'H', 'W' or 'Z'.

4: M – INTEGER *Input*

On entry: the number of elements, m, in the first dimension (number of rows of data matrix A) of the input data.

Constraint: M ≥ 2.

5: N – INTEGER *Input*

On entry: the number of elements, n, in the second dimension (number of columns of data matrix A) of the input data.

Constraint: N ≥ 2.

6: NWLMAX – INTEGER *Output*

On exit: the maximum number of levels of resolution, $l_{\max}$, that can be computed if a multi-level discrete wavelet transform is applied (WTRANS = 'M'). It is such that $2^{l_{\max}} \leq \min(m,n) < 2^{l_{\max}+1}$, for $l_{\max}$ an integer.

If WTRANS = 'S', NWLMAX is not set.

7: NF – INTEGER *Output*

On exit: the filter length, n_f, for the supplied mother wavelet. This is used to determine the number of coefficients to be generated by the chosen transform.

8: NWCT – INTEGER *Output*

On exit: the total number of wavelet coefficients, n_{ct}, that will be generated. When WTRANS = 'S' the number of rows required in each of the output coefficient matrices can be calculated as $n_{\mathrm{cm}} = n_{\mathrm{ct}}/(4n_{\mathrm{cn}})$. When WTRANS = 'M' the length of the array used to store all of the coefficient matrices must be at least n_{ct}.

9: NWCN – INTEGER *Output*

On exit: for a single-level transform (WTRANS = 'S'), the number of coefficients that would be generated in the second dimension, n_{cn}, for each coefficient type. For a multi-level transform (WTRANS = 'M') this is set to 1.

10: ICOMM(180) – INTEGER array *Communication Array*

On exit: contains details of the wavelet transform and the problem dimension which is to be communicated to the two-dimensional discrete transform routines in this chapter.

11: IFAIL – INTEGER *Input/Output*

On entry: IFAIL must be set to 0, -1 or 1. If you are unfamiliar with this argument you should refer to Section 3.4 in How to Use the NAG Library and its Documentation for details.

For environments where it might be inappropriate to halt program execution when an error is detected, the value -1 or 1 is recommended. If the output of error messages is undesirable, then the value 1 is recommended. Otherwise, if you are not familiar with this argument, the recommended value is 0. **When the value -1 or 1 is used it is essential to test the value of IFAIL on exit.**

On exit: IFAIL = 0 unless the routine detects an error or a warning has been flagged (see Section 6).

6 Error Indicators and Warnings

If on entry IFAIL = 0 or -1, explanatory error messages are output on the current error message unit (as defined by X04AAF).

Errors or warnings detected by the routine:

IFAIL = 1

On entry, WAVNAM = ⟨*value*⟩ was an illegal value.

IFAIL = 2

On entry, WTRANS = ⟨*value*⟩ was an illegal value.

IFAIL = 3

On entry, MODE = ⟨*value*⟩ was an illegal value.

IFAIL = 4

On entry, M = ⟨*value*⟩.
Constraint: M $\geq$ 2.

On entry, N = ⟨*value*⟩.
Constraint: N $\geq$ 2.

IFAIL = -99

An unexpected error has been triggered by this routine. Please contact NAG.

See Section 3.9 in How to Use the NAG Library and its Documentation for further information.

IFAIL $= -399$

Your licence key may have expired or may not have been installed correctly.

See Section 3.8 in How to Use the NAG Library and its Documentation for further information.

IFAIL $= -999$

Dynamic memory allocation failed.

See Section 3.7 in How to Use the NAG Library and its Documentation for further information.

7 Accuracy

Not applicable.

8 Parallelism and Performance

C09ABF is not threaded in any implementation.

9 Further Comments

None.

10 Example

This example computes the two-dimensional multi-level resolution for a 6×6 matrix by a discrete wavelet transform using the Haar wavelet with whole-point symmetric end extensions. The number of levels of transformation actually performed is one less than the maximum possible. This number of levels, the length of the wavelet filter, the total number of coefficients and the number of coefficients in each dimension for each level are printed along with the vertical detail coefficients from the first level, before a reconstruction is performed.

10.1 Program Text

```
    Program c09abfe

!     C09ABF Example Program Text
!     Mark 26 Release. NAG Copyright 2016.

!     .. Use Statements ..
      Use nag_library, Only: c09abf, c09ecf, c09edf, c09eyf, nag_wp
!     .. Implicit None Statement ..
      Implicit None
!     .. Parameters ..
      Integer, Parameter               :: nin = 5, nout = 6
!     .. Local Scalars ..
      Integer                          :: i, ifail, lda, ldb, lenc, m, n, nf,  &
                                          nwcm, nwcn, nwct, nwl, nwlmax,       &
                                          want_coeffs, want_level
      Character (10)                   :: mode, wavnam, wtrans
!     .. Local Arrays ..
      Real (Kind=nag_wp), Allocatable  :: a(:,:), b(:,:), c(:), d(:,:)
      Integer, Allocatable             :: dwtlevm(:), dwtlevn(:)
      Integer                          :: icomm(180)
!     .. Intrinsic Procedures ..
      Intrinsic                        :: sum
!     .. Executable Statements ..
      Continue
      Write (nout,*) 'C09ABF Example Program Results'
      Write (nout,*)
!     Skip heading in data file
      Read (nin,*)
!     Read problem parameters
      Read (nin,*) m, n
```

```
      lda = m
      ldb = m
      Read (nin,*) wavnam, mode
      Allocate (a(lda,n),b(ldb,n))

      Write (nout,99999) wavnam, mode, m, n

!     Read data array and write it out
      Do i = 1, m
        Read (nin,*) a(i,1:n)
      End Do

      Write (nout,*) ' Input Data           A :'
      Do i = 1, m
        Write (nout,99998) a(i,1:n)
      End Do

!     Query wavelet filter dimensions
!     For Multi-Resolution Analysis, decomposition, wtrans = 'M'
      wtrans = 'Multilevel'

!     ifail: behaviour on error exit
!             =0 for hard exit, =1 for quiet-soft, =-1 for noisy-soft
      ifail = 0
      Call c09abf(wavnam,wtrans,mode,m,n,nwlmax,nf,nwct,nwcn,icomm,ifail)

      lenc = nwct
      Allocate (c(lenc),dwtlevm(nwlmax),dwtlevn(nwlmax))

!     Calculate one less than the max possible number of levels
      nwl = nwlmax - 1

!     Perform Discrete Wavelet transform
      ifail = 0
      Call c09ecf(m,n,a,lda,lenc,c,nwl,dwtlevm,dwtlevn,icomm,ifail)

!     c09abf returns nwct based on max levels, so recalculate.
      nwct = sum(3*dwtlevm(1:nwl)*dwtlevn(1:nwl))
      nwct = nwct + dwtlevm(1)*dwtlevn(1)

!     Print the details of the transform.
      Write (nout,*)
      Write (nout,99997) nf
      Write (nout,99996) nwl
      Write (nout,99995)
      Write (nout,99994) dwtlevm(1:nwl)
      Write (nout,99993)
      Write (nout,99994) dwtlevn(1:nwl)
      Write (nout,99992) nwct
      Write (nout,*)
      Write (nout,99991)
      Write (nout,99998) c(1:nwct)

!     Now select a nominated matrix of coefficients at a nominated level.
!     Remember that level 0 is input data, 1 first coeffs and so on up to nwl,
!     which is the deepest level and contains approx. coefficients.
      want_level = nwl - 1
!     Print only vertical detail coeffs at selected level.
      want_coeffs = 1
      nwcm = dwtlevm(nwl-want_level+1)
      nwcn = dwtlevn(nwl-want_level+1)
      Allocate (d(nwcm,nwcn))

!     Extract the selected set of coefficients.
      Call c09eyf(want_level,want_coeffs,lenc,c,d,nwcm,icomm,ifail)

!     Print out the selected coefficients
      Write (nout,*)
      Write (nout,99989) want_coeffs, want_level
      Do i = 1, nwcm
        Write (nout,99998) d(i,1:nwcn)
```

```
      End Do

!     Reconstruct original data
      ifail = 0
      Call c09edf(nwl,lenc,c,m,n,b,ldb,icomm,ifail)

      Write (nout,*)
      Write (nout,99990)
      Do i = 1, m
        Write (nout,99998) b(i,1:n)
      End Do

99999 Format (1X,' Parameters read from file :: ',/,'     Wavelet : ',A10,     &
        ' End mode : ',A10,' M = ',I10,' N = ',I10)
99998 Format (8(F8.4,1X),:)
99997 Format (1X,' Length of wavelet filter :            ',I10)
99996 Format (1X,' Number of Levels :                    ',I10)
99995 Format (1X,                                                             &
        ' Number of coefficients in first dimension for each level : ')
99994 Format (16X,8(I8,1X),:)
99993 Format (1X,                                                             &
        ' Number of coefficients in second dimension for each level : ')
99992 Format (1X,' Total number of wavelet coefficients : ',I10)
99991 Format (1X,' All Wavelet coefficients C : ')
99990 Format (1X,' Reconstruction       B : ')
99989 Format (1X,' Type ',I1,' coefficients at selected wavelet level, ',I4,  &
        ': ')
    End Program c09abfe
```

10.2 Program Data

```
C09ABF Example Program Data
 8, 8                              : m, n
 Haar Whole : wavnam, mode
  6.0000   7.0000   8.0000   0.0000   1.0000   9.0000   7.0000   8.0000
  9.0000   1.0000   9.0000   9.0000   2.0000   8.0000   1.0000   9.0000
  3.0000   0.0000   4.0000   1.0000   3.0000   1.0000   0.0000   4.0000
  2.0000   5.0000   9.0000   4.0000   4.0000   2.0000   5.0000   9.0000
  1.0000   8.0000   3.0000   3.0000   5.0000   3.0000   8.0000   3.0000
  8.0000   1.0000   6.0000   4.0000   6.0000   1.0000   1.0000   6.0000
  8.0000   1.0000   1.0000   1.0000   2.0000   3.0000   1.0000   6.0000
  9.0000   2.0000   2.0000   4.0000   6.0000   1.0000   2.0000   9.0000
```

10.3 Program Results

```
 C09ABF Example Program Results

  Parameters read from file ::
     Wavelet : Haar       End mode : Whole      M =          8 N =          8
  Input Data           A :
  6.0000   7.0000   8.0000   0.0000   1.0000   9.0000   7.0000   8.0000
  9.0000   1.0000   9.0000   9.0000   2.0000   8.0000   1.0000   9.0000
  3.0000   0.0000   4.0000   1.0000   3.0000   1.0000   0.0000   4.0000
  2.0000   5.0000   9.0000   4.0000   4.0000   2.0000   5.0000   9.0000
  1.0000   8.0000   3.0000   3.0000   5.0000   3.0000   8.0000   3.0000
  8.0000   1.0000   6.0000   4.0000   6.0000   1.0000   1.0000   6.0000
  8.0000   1.0000   1.0000   1.0000   2.0000   3.0000   1.0000   6.0000
  9.0000   2.0000   2.0000   4.0000   6.0000   1.0000   2.0000   9.0000

  Length of wavelet filter :                      2
  Number of Levels :                              2
  Number of coefficients in first dimension for each level :
                       2        4
  Number of coefficients in second dimension for each level :
                       2        4
  Total number of wavelet coefficients :         64

  All Wavelet coefficients C :
 19.2500  15.5000  18.2500  15.7500  -2.7500   3.5000  -3.2500  -2.2500
  5.2500   1.5000   4.2500   0.7500   1.2500  -2.5000   0.7500   0.7500
```

```
 3.5000   0.0000   0.0000   7.0000   4.0000   4.0000   1.0000  -1.0000
-7.0000   2.0000   3.5000   2.0000  -4.5000  -4.0000   0.0000  -6.0000
 1.5000  -2.0000   0.0000  -1.0000  -5.0000  -4.0000  -2.0000  -2.0000
 0.0000  -1.0000   0.5000  -1.0000   2.5000  -5.0000   2.0000  -2.0000
-4.5000   3.0000  -7.0000  -0.0000   4.0000  -1.0000  -1.0000   1.0000
-1.0000   0.0000  -1.5000  -3.0000   3.5000   0.0000   5.0000   1.0000

 Type 1 coefficients at selected wavelet level,    1:
 3.5000   4.0000  -7.0000  -4.5000
 0.0000   4.0000   2.0000  -4.0000
 0.0000   1.0000   3.5000   0.0000
 7.0000  -1.0000   2.0000  -6.0000

 Reconstruction       B :
 6.0000   7.0000   8.0000   0.0000   1.0000   9.0000   7.0000   8.0000
 9.0000   1.0000   9.0000   9.0000   2.0000   8.0000   1.0000   9.0000
 3.0000   0.0000   4.0000   1.0000   3.0000   1.0000   0.0000   4.0000
 2.0000   5.0000   9.0000   4.0000   4.0000   2.0000   5.0000   9.0000
 1.0000   8.0000   3.0000   3.0000   5.0000   3.0000   8.0000   3.0000
 8.0000   1.0000   6.0000   4.0000   6.0000   1.0000   1.0000   6.0000
 8.0000   1.0000   1.0000   1.0000   2.0000   3.0000   1.0000   6.0000
 9.0000   2.0000   2.0000   4.0000   6.0000   1.0000   2.0000   9.0000
```