

# NAG Library Function Document

## nag\_wav\_3d\_coeff\_ins (c09fzc)

### 1 Purpose

nag\_wav\_3d\_coeff\_ins (c09fzc) inserts a selected set of three-dimensional discrete wavelet transform (DWT) coefficients into the full set of coefficients stored in compact form, which may be later used as input to the reconstruction functions nag\_idwt\_3d (c09fbc) or nag\_imldwt\_3d (c09fdc).

### 2 Specification

```
#include <nag.h>
#include <nagc09.h>

void nag_wav_3d_coeff_ins (Integer ilev, Integer cindex, Integer lenc,
    double c[], const double d[], Integer ldd, Integer sdd, Integer icomm[],
    NagError *fail)
```

### 3 Description

nag\_wav\_3d\_coeff\_ins (c09fzc) inserts a selected set of three-dimensional DWT coefficients into the full set of coefficients stored in compact form in a one-dimensional array **c**. It is required that nag\_wav\_3d\_coeff\_ins (c09fzc) is preceded by a call to the initialization function nag\_wfilt\_3d (c09acc) and either the forwards transform function nag\_dwt\_3d (c09fac) or multi-level forwards transform function nag\_mldwt\_3d (c09fcc).

Given an initial three-dimensional data set  $A$ , a prior call to nag\_dwt\_3d (c09fac) or nag\_mldwt\_3d (c09fcc) computes the approximation coefficients (at the highest requested level in the case of nag\_mldwt\_3d (c09fcc)) and, seven sets of detail coefficients (at all levels in the case of nag\_mldwt\_3d (c09fcc)) and stores these in compact form in a one-dimensional array **c**. nag\_wav\_3d\_coeff\_ext (c09fyc) can then extract either the approximation coefficients or one of the sets of detail coefficients (at one of the levels following nag\_mldwt\_3d (c09fcc)) as three-dimensional data into the array, **d**. Following some calculation on this set of coefficients (for example, denoising), the updated coefficients in **d** are inserted back into the full set **c** using nag\_wav\_3d\_coeff\_ins (c09fzc). Several extractions and insertions may be performed. nag\_idwt\_3d (c09fbc) or nag\_imldwt\_3d (c09fdc) can then be used to reconstruct a manipulated data set  $\hat{A}$ . The dimensions of the three-dimensional data stored in **d** depend on the level extracted and are available from either: the arrays **dwtlvm**, **dwtlvn** and **dwtlvfr** as returned by nag\_mldwt\_3d (c09fcc) if this was called first; or, otherwise from **nwct**, **nwcn** and **nwcfrr** as returned by nag\_wfilt\_3d (c09acc). See Section 2.1 in the c09 Chapter Introduction for a discussion of the three-dimensional DWT.

### 4 References

None.

### 5 Arguments

**Note:** the following notation is used in this section:

$n_{cm}$  is the number of wavelet coefficients in the first dimension. Following a call to nag\_dwt\_3d (c09fac) (i.e., when **ilev** = 0) this is equal to **nwct**/(8 × **nwcn** × **nwcfrr**) as returned by nag\_wfilt\_3d (c09acc). Following a call to nag\_mldwt\_3d (c09fcc) transforming **nwl** levels, and when inserting at level **ilev** > 0, this is equal to **dwtlvm**[**nwl** – **ilev**].

$n_{cn}$  is the number of wavelet coefficients in the second dimension. Following a call to nag\_dwt\_3d (c09fac) (i.e., when **ilev** = 0) this is equal to **nwcn** as returned by nag\_wfilt\_3d

(c09acc). Following a call to nag\_mldwt\_3d (c09fcc) transforming **nwl** levels, and when inserting at level **ilev** > 0, this is equal to **dwtlvn[nwl - ilev]**.

$n_{\text{cfr}}$  is the number of wavelet coefficients in the third dimension. Following a call to nag\_dwt\_3d (c09fac) (i.e., when **ilev** = 0) this is equal to **nwcfr** as returned by nag\_wfilt\_3d (c09acc). Following a call to nag\_mldwt\_3d (c09fcc) transforming **nwl** levels, and when inserting at level **ilev** > 0, this is equal to **dwtlvfr[nwl - ilev]**.

1: **ilev** – Integer *Input*

*On entry:* the level at which coefficients are to be inserted.

If **ilev** = 0, it is assumed that the coefficient array **c** was produced by a preceding call to the single level function nag\_dwt\_3d (c09fac).

If **ilev** > 0, it is assumed that the coefficient array **c** was produced by a preceding call to the multi-level function nag\_mldwt\_3d (c09fcc).

*Constraints:*

- ilev** = 0 (following a call to nag\_dwt\_3d (c09fac));
- $0 \leq \mathbf{ilev} \leq \mathbf{nwl}$ , where **nwl** is as used in a preceding call to nag\_mldwt\_3d (c09fcc);
- if **cindex** = 0, **ilev** = **nwl** (following a call to nag\_mldwt\_3d (c09fcc)).

2: **cindex** – Integer *Input*

*On entry:* identifies which coefficients to insert. The coefficients are identified as follows:

**cindex** = 0

The approximation coefficients, produced by application of the low pass filter over columns, rows and frames of *A* (LLL). After a call to the multi-level transform function nag\_mldwt\_3d (c09fcc) (which implies that **ilev** > 0) the approximation coefficients are present only for **ilev** = **nwl**, where **nwl** is the value used in a preceding call to nag\_mldwt\_3d (c09fcc).

**cindex** = 1

The detail coefficients produced by applying the low pass filter over columns and rows of *A* and the high pass filter over frames (LLH).

**cindex** = 2

The detail coefficients produced by applying the low pass filter over columns, high pass filter over rows and low pass filter over frames of *A* (LHL).

**cindex** = 3

The detail coefficients produced by applying the low pass filter over columns of *A* and high pass filter over rows and frames (LHH).

**cindex** = 4

The detail coefficients produced by applying the high pass filter over columns of *A* and low pass filter over rows and frames (HLL).

**cindex** = 5

The detail coefficients produced by applying the high pass filter over columns, low pass filter over rows and high pass filter over frames of *A* (HLH).

**cindex** = 6

The detail coefficients produced by applying the high pass filter over columns and rows of *A* and the low pass filter over frames (HHL).

**cindex** = 7

The detail coefficients produced by applying the high pass filter over columns, rows and frames of *A* (HHH).

*Constraints:*

if **ilev** = 0,  $0 \leq \mathbf{cindex} \leq 7$ ;  
 if **ilev** = **nwl**, following a call to nag\_mldwt\_3d (c09fcc) transforming **nwl** levels,  
 $0 \leq \mathbf{cindex} \leq 7$ ;  
 otherwise  $1 \leq \mathbf{cindex} \leq 7$ .

3: **lenc** – Integer *Input*

*On entry:* the dimension of the array **c**.

*Constraint:* **lenc** must be unchanged from the value used in the preceding call to either nag\_dwt\_3d (c09fac) or nag\_mldwt\_3d (c09fcc)..

4: **c[lenc]** – double *Input/Output*

*On entry:* contains the DWT coefficients inserted by previous calls to nag\_wav\_3d\_coeff\_ins (c09fzc), or computed by a previous call to either nag\_dwt\_3d (c09fac) or nag\_mldwt\_3d (c09fcc).

*On exit:* contains the same DWT coefficients provided on entry except for those identified by **ilev** and **cindex**, which are updated with the values supplied in **d**, inserted into the correct locations as expected by one of the reconstruction functions nag\_idwt\_3d (c09fbc) (if nag\_dwt\_3d (c09fac) was called previously) or nag\_imldwt\_3d (c09fdc) (if nag\_mldwt\_3d (c09fcc) was called previously).

5: **d[dim]** – const double *Input*

**Note:** the dimension, *dim*, of the array **d** must be at least  $\mathbf{ldd} \times \mathbf{sdd} \times n_{\text{cfr}}$ .

*On entry:* the coefficients to be inserted.

If the DWT coefficients were computed by nag\_dwt\_3d (c09fac) then

if **cindex** = 0, the approximation coefficients must be stored in  $\mathbf{d}[(k-1) \times \mathbf{ldd} \times \mathbf{sdd} + (j-1) \times \mathbf{ldd} + i - 1]$ , for  $i = 1, 2, \dots, n_{\text{cm}}$ ,  $j = 1, 2, \dots, n_{\text{cn}}$  and  $k = 1, 2, \dots, n_{\text{cfr}}$ ;

if  $1 \leq \mathbf{cindex} \leq 7$ , the detail coefficients, as indicated by **cindex**, must be stored in  $\mathbf{d}[(k-1) \times \mathbf{ldd} \times \mathbf{sdd} + (j-1) \times \mathbf{ldd} + i - 1]$ , for  $i = 1, 2, \dots, n_{\text{cm}}$ ,  $j = 1, 2, \dots, n_{\text{cn}}$  and  $k = 1, 2, \dots, n_{\text{cfr}}$ .

If the DWT coefficients were computed by nag\_mldwt\_3d (c09fcc) then

if **cindex** = 0 and **ilev** = **nwl**, the approximation coefficients must be stored in  $\mathbf{d}[(k-1) \times \mathbf{ldd} \times \mathbf{sdd} + (j-1) \times \mathbf{ldd} + i - 1]$ , for  $i = 1, 2, \dots, n_{\text{cm}}$ ,  $j = 1, 2, \dots, n_{\text{cn}}$  and  $k = 1, 2, \dots, n_{\text{cfr}}$ ;

if  $1 \leq \mathbf{cindex} \leq 7$ , the detail coefficients, as indicated by **cindex**, for level **ilev** must be stored in  $\mathbf{d}[(k-1) \times \mathbf{ldd} \times \mathbf{sdd} + (j-1) \times \mathbf{ldd} + i - 1]$ , for  $i = 1, 2, \dots, n_{\text{cm}}$ ,  $j = 1, 2, \dots, n_{\text{cn}}$  and  $k = 1, 2, \dots, n_{\text{cfr}}$ .

6: **ldd** – Integer *Input*

*On entry:* the stride separating row elements of each of the sets of frame coefficients in the three-dimensional data stored in **d**.

*Constraint:*  $\mathbf{ldd} > n_{\text{cm}}$ .

7: **sdd** – Integer *Input*

*On entry:* the stride separating corresponding coefficients of consecutive frames in the three-dimensional data stored in **d**.

*Constraint:*  $\mathbf{sdd} > n_{\text{cn}}$ .

- 8: **icomm**[260] – Integer *Communication Array*  
*On entry:* contains details of the discrete wavelet transform and the problem dimension as setup in the call to the initialization function nag\_wfilt\_3d (c09acc).
- 9: **fail** – NagError \* *Input/Output*  
 The NAG error argument (see Section 2.7 in How to Use the NAG Library and its Documentation).

## 6 Error Indicators and Warnings

### NE\_ALLOC\_FAIL

Dynamic memory allocation failed.  
 See Section 2.3.1.2 in How to Use the NAG Library and its Documentation for further information.

### NE\_BAD\_PARAM

On entry, argument  $\langle value \rangle$  had an illegal value.

### NE\_INITIALIZATION

Either the initialization function has not been called first or **icomm** has been corrupted.

### NE\_INT

On entry, **cindex** =  $\langle value \rangle$ .  
 Constraint: **cindex**  $\leq 7$ .

On entry, **cindex** =  $\langle value \rangle$ .  
 Constraint: **cindex**  $\geq 0$ .

On entry, **ilev** =  $\langle value \rangle$ .  
 Constraint: **ilev** = 0 following a call to the single level function nag\_dwt\_3d (c09fac).

On entry, **ilev** =  $\langle value \rangle$ .  
 Constraint: **ilev**  $> 0$  following a call to the multi-level function nag\_mldwt\_3d (c09fcc).

### NE\_INT\_2

On entry, **ilev** =  $\langle value \rangle$  and **nwl** =  $\langle value \rangle$ .  
 Constraint: **ilev**  $\leq$  **nwl**, where **nwl** is the number of levels used in the call to nag\_mldwt\_3d (c09fcc).

On entry, **idd** =  $\langle value \rangle$  and  $n_{cm}$  =  $\langle value \rangle$ .  
 Constraint: **idd**  $\geq n_{cm}$ , where  $n_{cm}$  is the number of DWT coefficients in the first dimension following the single level transform.

On entry, **lenc** =  $\langle value \rangle$  and  $n_{ct}$  =  $\langle value \rangle$ .  
 Constraint: **lenc**  $\geq n_{ct}$ , where  $n_{ct}$  is the number of DWT coefficients computed in a previous call to nag\_dwt\_3d (c09fac).

On entry, **lenc** =  $\langle value \rangle$  and  $n_{ct}$  =  $\langle value \rangle$ .  
 Constraint: **lenc**  $\geq n_{ct}$ , where  $n_{ct}$  is the number of DWT coefficients computed in a previous call to nag\_mldwt\_3d (c09fcc).

On entry, **sdd** =  $\langle value \rangle$  and  $n_{cn}$  =  $\langle value \rangle$ .  
 Constraint: **sdd**  $\geq n_{cn}$ , where  $n_{cn}$  is the number of DWT coefficients in the second dimension following the single level transform.

**NE\_INT\_3**

On entry, **ilev** =  $\langle value \rangle$  and **nwl** =  $\langle value \rangle$ , but **cindex** = 0.

Constraint: **cindex** > 0 when **ilev** < **nwl** in the preceding call to `nag_mldwt_3d` (c09fcc).

On entry, **idd** =  $\langle value \rangle$  and  $n_{cm}$  =  $\langle value \rangle$ .

Constraint: **idd**  $\geq n_{cm}$ , where  $n_{cm}$  is the number of DWT coefficients in the first dimension at the selected level **ilev**.

On entry, **sdd** =  $\langle value \rangle$  and  $n_{cn}$  =  $\langle value \rangle$ .

Constraint: **sdd**  $\geq n_{cn}$ , where  $n_{cn}$  is the number of DWT coefficients in the second dimension at the selected level **ilev**.

**NE\_INTERNAL\_ERROR**

An internal error has occurred in this function. Check the function call and any array sizes. If the call is correct then please contact NAG for assistance.

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

See Section 2.7.6 in *How to Use the NAG Library and its Documentation* for further information.

**NE\_NO\_LICENCE**

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

See Section 2.7.5 in *How to Use the NAG Library and its Documentation* for further information.

**7 Accuracy**

Not applicable.

**8 Parallelism and Performance**

`nag_wav_3d_coeff_ins` (c09fzc) is not threaded in any implementation.

**9 Further Comments**

None.

**10 Example**

The following example demonstrates using the coefficient extraction and insertion functions in order to apply denoising using a thresholding operation. The original input data has artificial noise introduced to it, taken from a normal random number distribution. Reconstruction then takes place on both the noisy data and denoised data. The Mean Square Errors (MSE) of the two reconstructions are printed along with the reconstruction of the denoised data. The MSE of the denoised reconstruction is less than that of the noisy reconstruction.

**10.1 Program Text**

```
/* nag_wav_3d_coeff_ins (c09fzc) Example Program.
 *
 * NAGPRODCODE Version.
 *
 * Copyright 2016 Numerical Algorithms Group.
 *
 * Mark 26, 2016.
 */
#include <stdio.h>
#include <math.h>
#include <nag.h>
#include <nag_stdlib.h>
#include <nagc09.h>
#include <nagg05.h>
```

```

#define A(I,J,K) a[(K-1)*lda*sda + (J-1)*lda + I-1]
#define AN(I,J,K) an[(K-1)*lda*sda + (J-1)*lda + I-1]
#define B(I,J,K) b[(K-1)*ldb*sdb + (J-1)*ldb + I-1]
#define D(I,J,K) d[(K-1)*ldd*sdd + (J-1)*ldd + I-1]

int main(void)
{
    /* Scalars */
    Integer exit_status = 0;
    Integer lstate = 1, lseed = 1;
    Integer i, j, k, lda, ldb, ldd, lenc, m, n, fr, mnfr, nf;
    Integer nwc, nwct, nwcfr;
    Integer nwl, subid, denoised, cindex, ilev, sda, sdb, sdd, kk;
    Nag_BaseRNG genid;
    double mse, thresh, var, xmu;
    /* Arrays */
    char mode[25], wavnam[25];
    double *a = 0, *an = 0, *b = 0, *c = 0, *d = 0, *x = 0;
    Integer *dwtlvm = 0, *dwtlvn = 0, *dwtlvfr = 0, *state = 0;
    Integer icomm[260], seed[1];
    /* Nag Types */
    Nag_Wavelet wavnamenum;
    Nag_WaveletMode modenum;
    Nag_MatrixType matrix = Nag_GeneralMatrix;
    Nag_OrderType order = Nag_ColMajor;
    Nag_DiagType diag = Nag_NonUnitDiag;
    NagError fail;

    INIT_FAIL(fail);

    printf("nag_wav_3d_coeff_ins (c09fzc) Example Program Results\n\n");
    /* Skip heading in data file and read problem parameters. */
#ifdef _WIN32
    scanf_s("%*[\n] %" NAG_IFMT "%" NAG_IFMT "%" NAG_IFMT "%*[\n] ", &m, &n,
            &fr);
#else
    scanf("%*[\n] %" NAG_IFMT "%" NAG_IFMT "%" NAG_IFMT "%*[\n] ", &m, &n,
            &fr);
#endif
#ifdef _WIN32
    scanf_s("%24s%24s%*[\n] ", wavnam, (unsigned)_countof(wavnam), mode,
            (unsigned)_countof(mode));
#else
    scanf("%24s%24s%*[\n] ", wavnam, mode);
#endif

    printf("MLDWT :: Wavelet : %s\n", wavnam);
    printf("          End mode : %s\n", mode);
    printf("          m : %4" NAG_IFMT "\n", m);
    printf("          n : %4" NAG_IFMT "\n", n);
    printf("          fr : %4" NAG_IFMT "\n\n", fr);

    /* Allocate arrays to hold the original data, A, original data plus noise,
     * AN, reconstruction using denoised coefficients, B, and randomly generated
     * noise, X.
     */
    lda = m;
    ldb = m;
    sda = n;
    sdb = n;
    if (!(a = NAG_ALLOC((sda) * (lda) * (fr), double)) ||
        !(an = NAG_ALLOC((sda) * (lda) * (fr), double)) ||
        !(b = NAG_ALLOC((sdb) * (ldb) * (fr), double)) ||
        !(x = NAG_ALLOC((m * n * fr), double)))
    {
        printf("Allocation failure\n");
        exit_status = 1;
        goto END;
    }
}

```

```

/* nag_enum_name_to_value (x04nac).
 * Converts NAG enum member name to value.
 */
wavnamenum = (Nag_Wavelet) nag_enum_name_to_value(wavnam);
modenum = (Nag_WaveletMode) nag_enum_name_to_value(mode);

/* Read in the original data. */
for (k = 1; k <= fr; k++) {
    for (i = 1; i <= m; i++) {
#ifdef _WIN32
        for (j = 1; j <= n; j++)
            scanf_s("%lf", &A(i, j, k));
#else
        for (j = 1; j <= n; j++)
            scanf("%lf", &A(i, j, k));
#endif
#ifdef _WIN32
            scanf_s("%*[\n]");
#else
            scanf("%*[\n]");
#endif
    }
#ifdef _WIN32
    scanf_s("%*[\n]");
#else
    scanf("%*[\n]");
#endif
}

/* Output the original data. */
printf("Input data :\n");
fflush(stdout);
for (k = 1; k <= fr; k++) {
    nag_gen_real_mat_print_comp(order, matrix, diag, m, n, &A(1, 1, k), lda,
                                "%11.4e", " ", Nag_NoLabels, 0,
                                Nag_NoLabels, 0, 80, 0, 0, &fail);
    if (fail.code != NE_NOERROR) {
        printf("Error from nag_gen_real_mat_print_comp (x04cbc).\n%s\n",
                fail.message);
        exit_status = 2;
        goto END;
    }
    printf("\n");
    fflush(stdout);
}

/* Set up call to nag_rand_normal (g05skc) in order to create some random
 * noise from a normal distribution to add to the original data.
 * Initial call to RNG initializer to get size of STATE array.
 */
seed[0] = 642521;
genid = Nag_MersenneTwister;
subid = 0;
if (!(state = NAG_ALLOC((lstate), Integer)))
{
    printf("Allocation failure\n");
    exit_status = -1;
    goto END;
}

/* nag_rand_init_repeatable (g05kfc).
 * Query the size of state.
 */
lstate = 0;
nag_rand_init_repeatable(genid, subid, seed, lseed, state, &lstate, &fail);
if (fail.code != NE_NOERROR) {
    printf("Error from nag_rand_init_repeatable (g05kfc).\n%s\n",
            fail.message);
    exit_status = 3;
    goto END;
}

```

```

/* Reallocate STATE. */
NAG_FREE(state);
if (!(state = NAG_ALLOC((lstate), Integer)))
{
    printf("Allocation failure\n");
    exit_status = 4;
    goto END;
}

/* nag_rand_init_repeatable (g05kfc).
 * Initialize the generator to a repeatable sequence.
 */
nag_rand_init_repeatable(genid, subid, seed, lseed, state, &lstate, &fail);
if (fail.code != NE_NOERROR) {
    printf("Error from nag_rand_init_repeatable (g05kfc).\n%s\n",
        fail.message);
    exit_status = 5;
    goto END;
}

/* Set the distribution parameters for the random noise. */
xmu = 0.0;
var = 0.1E-3;

/* Generate the noise variates. */

/* nag_rand_normal (g05skc).
 * Generates a vector of pseudorandom numbers from a Normal distribution.
 */
mnfr = n * m * fr;
nag_rand_normal(mnfr, xmu, var, state, x, &fail);
if (fail.code != NE_NOERROR) {
    printf("Error from nag_rand_normal (g05skc).\n%s\n", fail.message);
    exit_status = 6;
    goto END;
}

/* Add the noise to the original input and save in AN */
kk = 0;
for (k = 1; k <= n; k++) {
    for (j = 1; j <= n; j++) {
        for (i = 1; i <= m; i++) {
            AN(i, j, k) = A(i, j, k) + x[kk];
            kk = kk + 1;
        }
    }
}

/* Output the noisy data */
printf("Input data plus noise :\n");
fflush(stdout);
for (k = 1; k <= fr; k++) {
    nag_gen_real_mat_print_comp(order, matrix, diag, m, n, &AN(1, 1, k), lda,
        "%11.4e", " ",
        Nag_NoLabels, 0, Nag_NoLabels, 0, 80, 0, 0,
        &fail);
    if (fail.code != NE_NOERROR) {
        printf("Error from nag_gen_real_mat_print_comp (x04cbc).\n%s\n",
            fail.message);
        exit_status = 7;
        goto END;
    }
    printf("\n");
    fflush(stdout);
}

/* nag_wfilt_3d (c09acc).
 * Three-dimensional wavelet filter initialization.
 */
nag_wfilt_3d(wavnamenum, Nag_MultiLevel, modenum, m, n, fr, &nwl, &nf,

```



```

        &nwct, &nwcn, &nwcf, icomm, &fail);
if (fail.code != NE_NOERROR) {
    printf("Error from nag_wfilt_3d (c09acc).\n%s\n", fail.message);
    exit_status = 8;
    goto END;
}

/* Allocate arrays to hold the coefficients, c, and the dimensions
 * of the coefficients at each level, dwtlvm, dwtlvn.
 */
lenc = nwct;
if (!(c = NAG_ALLOC((lenc), double)) ||
    !(dwtlvm = NAG_ALLOC((nwl), Integer)) ||
    !(dwtlvn = NAG_ALLOC((nwl), Integer)) ||
    !(dwtlvfr = NAG_ALLOC((nwl), Integer)))
{
    printf("Allocation failure\n");
    exit_status = 9;
    goto END;
}

/* Perform a forwards multi-level transform on the noisy data. */

/* nag_mldwt_3d (c09fcc).
 * Two-dimensional multi-level discrete wavelet transform.
 */
nag_mldwt_3d(m, n, fr, an, lda, sda, lenc, c, nwl, dwtlvm, dwtlvn,
            dwtlvfr, icomm, &fail);
if (fail.code != NE_NOERROR) {
    printf("Error from nag_mldwt_3d (c09fcc).\n%s\n", fail.message);
    exit_status = 10;
    goto END;
}

/* Reconstruct without thresholding of detail coefficients. */

/* nag_imldwt_3d (c09fdc).
 * Two-dimensional inverse multi-level discrete wavelet transform.
 */
nag_imldwt_3d(nwl, lenc, c, m, n, fr, b, ldb, sdb, icomm, &fail);
if (fail.code != NE_NOERROR) {
    printf("Error from nag_imldwt_3d (c09fdc).\n%s\n", fail.message);
    exit_status = 11;
    goto END;
}

/* Calculate the Mean Square Error of the noisy reconstruction. */
mse = 0.0;
for (k = 1; k <= fr; k++)
    for (j = 1; j <= n; j++)
        for (i = 1; i <= m; i++)
            mse = mse + pow((A(i, j, k) - B(i, j, k)), 2);
mse = mse / (double) (m * n * fr);
printf("Without denoising Mean Square Error is %11.4e\n\n", mse);

/* Now perform the denoising by extracting each of the detail
 * coefficients at each level and applying hard thresholding
 * Allocate a 2D array to hold the detail coefficients
 */
ldd = dwtlvm[nwl - 1];
sdd = dwtlvn[nwl - 1];
if (!(d = NAG_ALLOC((ldd) * (sdd) * (dwtlvfr[nwl - 1]), double)))
{
    printf("Allocation failure\n");
    exit_status = 12;
    goto END;
}

/* Calculate the threshold based on VisuShrink denoising. */
thresh = sqrt(var) * sqrt(2. * log((double) (m * n * fr)));
denoised = 0;

```

```

/* For each level */
for (ilev = nwl; ilev >= 1; ilev -= 1) {
  /* Select detail coefficients */
  for (cindex = 1; cindex <= 7; cindex++) {
    /* Extract coefficients into the 2D array d */

    /* nag_wav_3d_coeff_ext (c09fyc).
     * Three-dimensional discrete wavelet transform coefficient extraction.
     */
    nag_wav_3d_coeff_ext(ilev, cindex, lenc, c, d, ldd, sdd, icomm, &fail);
    if (fail.code != NE_NOERROR) {
      printf("Error from nag_wav_3d_coeff_ext (c09fyc).\n%s\n",
             fail.message);
      exit_status = 13;
      goto END;
    }

    /* Perform the hard thresholding operation */
    for (k = 1; k <= dwtlvfr[nwl - ilev]; k++)
      for (j = 1; j <= dwtlvn[nwl - ilev]; j++)
        for (i = 1; i <= dwtlvm[nwl - ilev]; i++)
          if (fabs(D(i, j, k)) < thresh) {
            D(i, j, k) = 0.0;
            denoised = denoised + 1;
          }

    /* Insert the denoised coefficients back into c. */

    /* nag_wav_3d_coeff_ins (c09fzc).
     * Three-dimensional discrete wavelet transform coefficient insertion.
     */
    nag_wav_3d_coeff_ins(ilev, cindex, lenc, c, d, ldd, sdd, icomm, &fail);
    if (fail.code != NE_NOERROR) {
      printf("Error from nag_wav_3d_coeff_ins (c09fzc).\n%s\n",
             fail.message);
      exit_status = 14;
      goto END;
    }
  }
}

/* Output the number of coefficients that were set to zero */
printf("Number of coefficients denoised is %4" NAG_IFMT " out of %4"
       NAG_IFMT "\n\n", denoised,
       nwct - dwtlvm[0] * dwtlvn[0] * dwtlvfr[0]);
fflush(stdout);

/* Reconstruct original data following thresholding of detail coefficients */

/* nag_imldwt_3d (c09fdc).
 * Three-dimensional inverse multi-level discrete wavelet transform.
 */
nag_imldwt_3d(nwl, lenc, c, m, n, fr, b, ldb, sdb, icomm, &fail);
if (fail.code != NE_NOERROR) {
  printf("Error from nag_imldwt_3d (c09fdc).\n%s\n", fail.message);
  exit_status = 15;
  goto END;
}

/* Calculate the Mean Square Error of the denoised reconstruction. */
mse = 0.0;
for (k = 1; k <= n; k++)
  for (j = 1; j <= n; j++)
    for (i = 1; i <= m; i++)
      mse = mse + pow((A(i, j, k) - B(i, j, k)), 2);
mse = mse / (double) (m * n * fr);
printf("With denoising Mean Square Error is %11.4e \n\n", mse);

/* Output the denoised reconstruction. */
printf("Reconstruction of denoised input :\n");

```

```

fflush(stdout);
for (k = 1; k <= fr; k++) {
    nag_gen_real_mat_print_comp(order, matrix, diag, m, n, &B(1, 1, k), ldb,
                                "%11.4e", " ",
                                Nag_NoLabels, 0, Nag_NoLabels, 0, 80, 0, 0,
                                &fail);
    if (fail.code != NE_NOERROR) {
        printf("Error from nag_gen_real_mat_print_comp (x04cbc).\n%s\n",
              fail.message);
        exit_status = 16;
        goto END;
    }
    if (k < fr)
        printf("\n");
    fflush(stdout);
}

END:
NAG_FREE(a);
NAG_FREE(an);
NAG_FREE(b);
NAG_FREE(c);
NAG_FREE(d);
NAG_FREE(x);
NAG_FREE(dwtlvm);
NAG_FREE(dwtlvn);
NAG_FREE(dwtlvfr);
NAG_FREE(state);
return exit_status;
}

```

## 10.2 Program Data

nag\_wav\_3d\_coeff\_ins (c09fzc) Example Program Data

```

4 4 4 : m, n, fr
Nag_Haar Nag_Periodic : wavnam, mode
0.1000E-01 0.1000E-01 0.1000E-01 0.1000E-01
0.1000E+01 0.1000E+01 0.1000E+01 0.1000E+01
0.1000E-01 0.1000E-01 0.1000E-01 0.1000E-01
0.1000E+01 0.1000E+01 0.1000E+01 0.1000E+01

0.1000E+01 0.1000E+01 0.1000E+01 0.1000E+01
0.1000E-01 0.1000E-01 0.1000E-01 0.1000E-01
0.1000E+01 0.1000E+01 0.1000E+01 0.1000E+01
0.1000E-01 0.1000E-01 0.1000E-01 0.1000E-01

0.1000E-01 0.1000E-01 0.1000E-01 0.1000E-01
0.1000E+01 0.1000E+01 0.1000E+01 0.1000E+01
0.1000E-01 0.1000E-01 0.1000E-01 0.1000E-01
0.1000E+01 0.1000E+01 0.1000E+01 0.1000E+01

0.1000E+01 0.1000E+01 0.1000E+01 0.1000E+01
0.1000E-01 0.1000E-01 0.1000E-01 0.1000E-01
0.1000E+01 0.1000E+01 0.1000E+01 0.1000E+01
0.1000E-01 0.1000E-01 0.1000E-01 0.1000E-01

```

## 10.3 Program Results

nag\_wav\_3d\_coeff\_ins (c09fzc) Example Program Results

```

MLDWT :: Wavelet : Nag_Haar
        End mode : Nag_Periodic
        m :      4
        n :      4
        fr :     4

Input data :
1.0000e-02 1.0000e-02 1.0000e-02 1.0000e-02
1.0000e+00 1.0000e+00 1.0000e+00 1.0000e+00
1.0000e-02 1.0000e-02 1.0000e-02 1.0000e-02

```

1.0000e+00	1.0000e+00	1.0000e+00	1.0000e+00
1.0000e+00	1.0000e+00	1.0000e+00	1.0000e+00
1.0000e-02	1.0000e-02	1.0000e-02	1.0000e-02
1.0000e+00	1.0000e+00	1.0000e+00	1.0000e+00
1.0000e-02	1.0000e-02	1.0000e-02	1.0000e-02
1.0000e-02	1.0000e-02	1.0000e-02	1.0000e-02
1.0000e+00	1.0000e+00	1.0000e+00	1.0000e+00
1.0000e-02	1.0000e-02	1.0000e-02	1.0000e-02
1.0000e+00	1.0000e+00	1.0000e+00	1.0000e+00
1.0000e-02	1.0000e-02	1.0000e-02	1.0000e-02
1.0000e+00	1.0000e+00	1.0000e+00	1.0000e+00
1.0000e-02	1.0000e-02	1.0000e-02	1.0000e-02
1.0000e+00	1.0000e+00	1.0000e+00	1.0000e+00
1.0000e-02	1.0000e-02	1.0000e-02	1.0000e-02

Input data plus noise :

1.3549e-02	-9.3452e-03	-3.7110e-04	3.7765e-02
1.0015e+00	9.8416e-01	1.0007e+00	9.8894e-01
-1.7004e-03	1.3876e-02	1.3834e-02	-4.9390e-03
9.8993e-01	1.0070e+00	1.0049e+00	9.9833e-01
1.0094e+00	1.0080e+00	9.9208e-01	9.9019e-01
1.0467e-02	-8.5383e-04	1.5987e-02	1.9701e-02
9.9938e-01	1.0044e+00	9.9562e-01	1.0014e+00
9.0719e-03	-8.3748e-03	1.8721e-02	2.3127e-03
5.8176e-03	-5.3098e-03	1.1169e-03	1.5873e-02
1.0113e+00	9.8944e-01	1.0018e+00	9.9924e-01
1.0583e-02	8.2037e-03	9.2665e-03	1.5297e-02
1.0023e+00	1.0157e+00	1.0084e+00	9.8344e-01
9.9692e-01	1.0010e+00	9.9042e-01	9.9677e-01
2.2743e-02	2.1923e-03	6.2213e-03	2.1367e-02
9.9480e-01	9.9810e-01	9.9514e-01	9.9681e-01
1.2116e-02	1.0294e-02	1.1353e-02	2.0623e-02

Without denoising Mean Square Error is 8.0946e-05

Number of coefficients denoised is 55 out of 63

With denoising Mean Square Error is 1.4878e-05

Reconstruction of denoised input :

5.3377e-03	5.3377e-03	1.6635e-02	1.6635e-02
1.0026e+00	1.0026e+00	9.9133e-01	9.9133e-01
5.5007e-03	5.5007e-03	7.6994e-03	7.6994e-03
1.0025e+00	1.0025e+00	1.0003e+00	1.0003e+00
1.0026e+00	1.0026e+00	9.9133e-01	9.9133e-01
5.3377e-03	5.3377e-03	1.6635e-02	1.6635e-02
1.0025e+00	1.0025e+00	1.0003e+00	1.0003e+00
5.5007e-03	5.5007e-03	7.6994e-03	7.6994e-03
7.3252e-03	7.3252e-03	1.1020e-02	1.1020e-02
1.0006e+00	1.0006e+00	9.9694e-01	9.9694e-01
7.7713e-03	7.7713e-03	1.3076e-02	1.3076e-02
1.0002e+00	1.0002e+00	9.9489e-01	9.9489e-01
1.0006e+00	1.0006e+00	9.9694e-01	9.9694e-01
7.3252e-03	7.3252e-03	1.1020e-02	1.1020e-02
1.0002e+00	1.0002e+00	9.9489e-01	9.9489e-01
7.7713e-03	7.7713e-03	1.3076e-02	1.3076e-02

---