

# NAG Library Function Document

## nag\_fft\_multiple\_hermitian (c06fqc)

### 1 Purpose

nag\_fft\_multiple\_hermitian (c06fqc) computes the discrete Fourier transforms of  $m$  Hermitian sequences, each containing  $n$  complex data values.

### 2 Specification

```
#include <nag.h>
#include <nagc06.h>

void nag_fft_multiple_hermitian (Integer m, Integer n, double x[],
    const double trig[], NagError *fail)
```

### 3 Description

Given  $m$  Hermitian sequences of  $n$  complex data values  $z_j^p$ , for  $j = 0, 1, \dots, n - 1$  and  $p = 1, 2, \dots, m$ , this function simultaneously calculates the Fourier transforms of all the sequences defined by

$$\hat{x}_k^p = \frac{1}{\sqrt{n}} \sum_{j=0}^{n-1} z_j^p \exp(-2\pi i j k / n), \quad \text{for } k = 0, 1, \dots, n - 1; p = 1, 2, \dots, m.$$

(Note the scale factor  $1/\sqrt{n}$  in this definition.)

The transformed values are purely real.

The first call of nag\_fft\_multiple\_hermitian (c06fqc) must be preceded by a call to nag\_fft\_init\_trig (c06gzc) to initialize the array **trig** with trigonometric coefficients according to the value of **n**.

The discrete Fourier transform is sometimes defined using a positive sign in the exponential term

$$\hat{x}_k^p = \frac{1}{\sqrt{n}} \sum_{j=0}^{n-1} z_j^p \exp(+2\pi i j k / n).$$

For that form, this function should be preceded by a call to nag\_multiple\_conjugate\_hermitian (c06ggc) to form the complex conjugates of the  $\hat{z}_j^p$ .

The function uses a variant of the fast Fourier transform algorithm (Brigham (1974)) known as the Stockham self-sorting algorithm, which is described in Temperton (1983). Special code is included for the factors 2, 3, 4, 5 and 6.

### 4 References

Brigham E O (1974) *The Fast Fourier Transform* Prentice–Hall

Temperton C (1983) Fast mixed-radix real Fourier transforms *J. Comput. Phys.* **52** 340–350

### 5 Arguments

- 1: **m** – Integer *Input*  
*On entry:* the number of sequences to be transformed,  $m$ .  
*Constraint:* **m**  $\geq 1$ .

- 2: **n** – Integer *Input*  
*On entry:* the number of data values in each sequence,  $n$ .  
*Constraint:*  $n \geq 1$ .
- 3: **x**[ $m \times n$ ] – double *Input/Output*  
*On entry:* the  $m$  Hermitian sequences must be stored consecutively in **x** in Hermitian form. Sequence 1 should occupy the first  $n$  elements of **x**, sequence 2 the elements  $n$  to  $2n - 1$ , so that in general sequence  $p$  occupies the array elements  $(p - 1)n$  to  $pn - 1$ . If the  $n$  data values  $z_j^p$  are written as  $x_j^p + iy_j^p$ , then for  $0 \leq j \leq n/2$ ,  $x_j^p$  should be in array element **x**[( $p - 1$ )  $\times$   $n + j$ ] and for  $1 \leq j \leq (n - 1)/2$ ,  $y_j^p$  should be in array element **x**[( $p - 1$ )  $\times$   $n + n - j$ ].  
*On exit:* the components of the  $m$  discrete Fourier transforms, stored consecutively. Transform  $p$  occupies the elements  $(p - 1)n$  to  $pn - 1$  of **x** overwriting the corresponding original sequence; thus if the  $n$  components of the discrete Fourier transform are denoted by  $\hat{x}_k^p$ , for  $k = 0, 1, \dots, n - 1$ , then the  $mn$  elements of the array **x** contain the values
- $$\hat{x}_0^1, \hat{x}_1^1, \dots, \hat{x}_{n-1}^1, \hat{x}_0^2, \hat{x}_1^2, \dots, \hat{x}_{n-1}^2, \dots, \hat{x}_0^m, \hat{x}_1^m, \dots, \hat{x}_{n-1}^m.$$
- 4: **trig**[ $2 \times n$ ] – const double *Input*  
*On entry:* trigonometric coefficients as returned by a call of nag\_fft\_init\_trig (c06gzc). nag\_fft\_multiple\_hermitian (c06fqc) makes a simple check to ensure that **trig** has been initialized and that the initialization is compatible with the value of **n**
- 5: **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.

### NE\_C06\_NOT\_TRIG

Value of **n** and **trig** array are incompatible or **trig** array not initialized.

### NE\_INT\_ARG\_LT

On entry, **m** =  $\langle value \rangle$ .

Constraint:  $m \geq 1$ .

On entry, **n** =  $\langle value \rangle$ .

Constraint:  $n \geq 1$ .

## 7 Accuracy

Some indication of accuracy can be obtained by performing a subsequent inverse transform and comparing the results with the original sequence (in exact arithmetic they would be identical).

## 8 Parallelism and Performance

nag\_fft\_multiple\_hermitian (c06fqc) is not threaded in any implementation.

## 9 Further Comments

The time taken is approximately proportional to  $n \log(n)$ , but also depends on the factors of  $n$ . The function is fastest if the only prime factors of  $n$  are 2, 3 and 5, and is particularly slow if  $n$  is a large prime, or has large prime factors.

## 10 Example

This program reads in sequences of real data values which are assumed to be Hermitian sequences of complex data stored in Hermitian form. The sequences are expanded into full complex form using `nag_multiple_hermitian_to_complex` (c06gsc) and printed. The discrete Fourier transforms are then computed (using `nag_fft_multiple_hermitian` (c06fqc)) and printed out. Inverse transforms are then calculated by calling `nag_fft_multiple_real` (c06fpc) followed by `nag_multiple_conjugate_hermitian` (c06gqc) showing that the original sequences are restored.

### 10.1 Program Text

```

/* nag_fft_multiple_hermitian (c06fqc) Example Program.
 *
 * NAGPRODCODE Version.
 *
 * Copyright 2016 Numerical Algorithms Group.
 *
 * Mark 26, 2016.
 */

#include <nag.h>
#include <stdio.h>
#include <nag_stdlib.h>
#include <nagc06.h>

int main(void)
{
    Integer exit_status = 0, i, j, m, n;
    NagError fail;
    double *trig = 0, *u = 0, *v = 0, *x = 0;

    INIT_FAIL(fail);

    printf("nag_fft_multiple_hermitian (c06fqc) Example Program Results\n");
    /* Skip heading in data file */
#ifdef _WIN32
    scanf_s("%*[\n]");
#else
    scanf("%*[\n]");
#endif
#ifdef _WIN32
    while (scanf_s("%" NAG_IFMT "%" NAG_IFMT "", &m, &n) != EOF)
#else
    while (scanf("%" NAG_IFMT "%" NAG_IFMT "", &m, &n) != EOF)
#endif
    {
        if (m >= 1 && n >= 1) {
            printf("\n\nm = %2" NAG_IFMT " n = %2" NAG_IFMT "\n", m, n);
            if (!(trig = NAG_ALLOC(2 * n, double)) ||
                !(u = NAG_ALLOC(m * n, double)) ||
                !(v = NAG_ALLOC(m * n, double)) || !(x = NAG_ALLOC(m * n, double)))
            {
                printf("Allocation failure\n");
                exit_status = -1;
                goto END;
            }
        }
        else {
            printf("Invalid m or n.\n");
            exit_status = 1;
            return exit_status;
        }
    }
}

```

```

    }

    /* Read in data and print out. */
    for (j = 0; j < m; ++j)
        for (i = 0; i < n; ++i)
#ifdef _WIN32
            scanf_s("%lf", &x[j * n + i]);
#else
            scanf("%lf", &x[j * n + i]);
#endif
    printf("\nOriginal data values\n\n");
    for (j = 0; j < m; ++j) {
        printf("    ");
        for (i = 0; i < n; ++i)
            printf("%10.4f%s", x[j * n + i],
                (i % 6 == 5 && i != n - 1 ? "\n    " : ""));
        printf("\n");
    }
    /* Calculate full complex form of Hermitian data sequences */
    /* nag_multiple_hermitian_to_complex (c06gsc).
    * Convert Hermitian sequences to general complex sequences
    */
    nag_multiple_hermitian_to_complex(m, n, x, u, v, &fail);
    if (fail.code != NE_NOERROR) {
        exit_status = 1;
        goto END;
    }
    printf("\nOriginal data written in full complex form\n\n");
    for (j = 0; j < m; ++j) {
        printf("Real");
        for (i = 0; i < n; ++i)
            printf("%10.4f%s", u[j * n + i],
                (i % 6 == 5 && i != n - 1 ? "\n    " : ""));
        printf("\nImag");
        for (i = 0; i < n; ++i)
            printf("%10.4f%s", v[j * n + i],
                (i % 6 == 5 && i != n - 1 ? "\n    " : ""));
        printf("\n\n");
    }
    /* Initialize trig array */
    /* nag_fft_init_trig (c06gzc).
    * Initialization function for other c06 functions
    */
    nag_fft_init_trig(n, trig, &fail);
    if (fail.code != NE_NOERROR) {
        exit_status = 1;
        goto END;
    }
    /* Calculate transforms */
    /* nag_fft_multiple_hermitian (c06fqc).
    * Multiple one-dimensional Hermitian discrete Fourier
    * transforms
    */
    nag_fft_multiple_hermitian(m, n, x, trig, &fail);
    if (fail.code != NE_NOERROR) {
        exit_status = 1;
        goto END;
    }
    printf("\nDiscrete Fourier transforms (real values)\n\n");
    for (j = 0; j < m; ++j) {
        printf("    ");
        for (i = 0; i < n; ++i)
            printf("%10.4f%s", x[j * n + i],
                (i % 6 == 5 && i != n - 1 ? "\n    " : ""));
        printf("\n");
    }
    /* Calculate inverse transforms */
    /* nag_fft_multiple_real (c06fpc).
    * Multiple one-dimensional real discrete Fourier transforms
    */
    nag_fft_multiple_real(m, n, x, trig, &fail);

```

```

if (fail.code != NE_NOERROR) {
    exit_status = 1;
    goto END;
}
/* nag_multiple_conjugate_hermitian (c06gqc).
 * Complex conjugate of multiple Hermitian sequences
 */
nag_multiple_conjugate_hermitian(m, n, x, &fail);
if (fail.code != NE_NOERROR) {
    exit_status = 1;
    goto END;
}
printf("\nOriginal data as restored by inverse transform\n\n");
for (j = 0; j < m; ++j) {
    printf("  ");
    for (i = 0; i < n; ++i)
        printf("%10.4f%s", x[j * n + i],
            (i % 6 == 5 && i != n - 1 ? "\n      " : ""));
    printf("\n");
}
END:
    NAG_FREE(trig);
    NAG_FREE(u);
    NAG_FREE(v);
    NAG_FREE(x);
}
return exit_status;
}

```

## 10.2 Program Data

nag\_fft\_multiple\_hermitian (c06fqc) Example Program Data

3	6				
0.3854	0.6772	0.1138	0.6751	0.6362	0.1424
0.5417	0.2983	0.1181	0.7255	0.8638	0.8723
0.9172	0.0644	0.6037	0.6430	0.0428	0.4815

## 10.3 Program Results

nag\_fft\_multiple\_hermitian (c06fqc) Example Program Results

m = 3 n = 6

Original data values

0.3854	0.6772	0.1138	0.6751	0.6362	0.1424
0.5417	0.2983	0.1181	0.7255	0.8638	0.8723
0.9172	0.0644	0.6037	0.6430	0.0428	0.4815

Original data written in full complex form

Real	0.3854	0.6772	0.1138	0.6751	0.1138	0.6772
Imag	0.0000	0.1424	0.6362	0.0000	-0.6362	-0.1424
Real	0.5417	0.2983	0.1181	0.7255	0.1181	0.2983
Imag	0.0000	0.8723	0.8638	0.0000	-0.8638	-0.8723
Real	0.9172	0.0644	0.6037	0.6430	0.6037	0.0644
Imag	0.0000	0.4815	0.0428	0.0000	-0.0428	-0.4815

Discrete Fourier transforms (real values)

1.0788	0.6623	-0.2391	-0.5783	0.4592	-0.4388
0.8573	1.2261	0.3533	-0.2222	0.3413	-1.2291
1.1825	0.2625	0.6744	0.5523	0.0540	-0.4790

Original data as restored by inverse transform

0.3854	0.6772	0.1138	0.6751	0.6362	0.1424
0.5417	0.2983	0.1181	0.7255	0.8638	0.8723
0.9172	0.0644	0.6037	0.6430	0.0428	0.4815

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