

# NAG Library Function Document

## nag\_4d\_shep\_eval (e01tlc)

### 1 Purpose

nag\_4d\_shep\_eval (e01tlc) evaluates the four-dimensional interpolating function generated by nag\_4d\_shep\_interp (e01tkc) and its first partial derivatives.

### 2 Specification

```
#include <nag.h>
#include <nage01.h>

void nag_4d_shep_eval (Integer m, const double x[], const double f[],
    const Integer iq[], const double rq[], Integer n, const double xe[],
    double q[], double qx[], NagError *fail)
```

### 3 Description

nag\_4d\_shep\_eval (e01tlc) takes as input the interpolant  $Q(\mathbf{x})$ ,  $x \in \mathbb{R}^4$  of a set of scattered data points  $(\mathbf{x}_r, f_r)$ , for  $r = 1, 2, \dots, m$ , as computed by nag\_4d\_shep\_interp (e01tkc), and evaluates the interpolant and its first partial derivatives at the set of points  $\mathbf{x}_i$ , for  $i = 1, 2, \dots, n$ .

nag\_4d\_shep\_eval (e01tlc) must only be called after a call to nag\_4d\_shep\_interp (e01tkc).

nag\_4d\_shep\_eval (e01tlc) is derived from the new implementation of QS3GRD described by Renka (1988). It uses the modification for high-dimensional interpolation described by Berry and Minser (1999).

### 4 References

Berry M W, Minser K S (1999) Algorithm 798: high-dimensional interpolation using the modified Shepard method *ACM Trans. Math. Software* **25** 353–366

Renka R J (1988) Algorithm 661: QSHEP3D: Quadratic Shepard method for trivariate interpolation of scattered data *ACM Trans. Math. Software* **14** 151–152

### 5 Arguments

- 1: **m** – Integer *Input*  
*On entry:* **must** be the same value supplied for argument **m** in the preceding call to nag\_4d\_shep\_interp (e01tkc).  
*Constraint:*  $\mathbf{m} \geq 16$ .
- 2: **x**[4 × **m**] – const double *Input*  
**Note:** the coordinates of  $x_r$  are stored in  $\mathbf{x}[(r - 1) \times 4] \dots \mathbf{x}[(r - 1) \times 4 + 3]$ .  
*On entry:* **must** be the same array supplied as argument **x** in the preceding call to nag\_4d\_shep\_interp (e01tkc). It **must** remain unchanged between calls.
- 3: **f**[**m**] – const double *Input*  
*On entry:* **must** be the same array supplied as argument **f** in the preceding call to nag\_4d\_shep\_interp (e01tkc). It **must** remain unchanged between calls.

- 4: **iq**[ $2 \times m + 1$ ] – const Integer *Input*  
*On entry:* **must** be the same array returned as argument **iq** in the preceding call to nag\_4d\_shep\_interp (e01tkc). It **must** remain unchanged between calls.
- 5: **rq**[ $15 \times m + 9$ ] – const double *Input*  
*On entry:* **must** be the same array returned as argument **rq** in the preceding call to nag\_4d\_shep\_interp (e01tkc). It **must** remain unchanged between calls.
- 6: **n** – Integer *Input*  
*On entry:* *n*, the number of evaluation points.  
*Constraint:*  $n \geq 1$ .
- 7: **xe**[ $4 \times n$ ] – const double *Input*  
**Note:** the (*i*, *j*)th element of the matrix is stored in **xe**[(*j* – 1) × 4 + *i* – 1].  
*On entry:* **xe**[(*r* – 1) × 4], ..., **xe**[(*r* – 1) × 4 + 3] must be set to the evaluation point  $\mathbf{x}_i$ , for  $i = 1, 2, \dots, n$ .
- 8: **q**[*n*] – double *Output*  
*On exit:* **q**[*i* – 1] contains the value of the interpolant, at  $\mathbf{x}_i$ , for  $i = 1, 2, \dots, n$ . If any of these evaluation points lie outside the region of definition of the interpolant the corresponding entries in **q** are set to the largest machine representable number (see nag\_real\_largest\_number (X02ALC)), and nag\_4d\_shep\_eval (e01tlc) returns with **fail.code** = NE\_BAD\_POINT.
- 9: **qx**[ $4 \times n$ ] – double *Output*  
**Note:** the (*i*, *j*)th element of the matrix is stored in **qx**[(*j* – 1) × 4 + *i* – 1].  
*On exit:* **qx**[(*i* – 1) × 4 + *j* – 1] contains the value of the partial derivatives with respect to  $\mathbf{x}_j$  of the interpolant  $Q(\mathbf{x})$  at  $\mathbf{x}_i$ , for  $i = 1, 2, \dots, n$ , and for each of the four partial derivatives  $j = 1, 2, 3, 4$ . If any of these evaluation points lie outside the region of definition of the interpolant, the corresponding entries in **qx** are set to the largest machine representable number (see nag\_real\_largest\_number (X02ALC)), and nag\_4d\_shep\_eval (e01tlc) returns with **fail.code** = NE\_BAD\_POINT.
- 10: **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 *value* had an illegal value.

### NE\_BAD\_POINT

On entry, at least one evaluation point lies outside the region of definition of the interpolant. At all such points the corresponding values in **q** and **qx** have been set to nag\_real\_largest\_number: nag\_real\_largest\_number = *value*.

**NE\_INT**

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

Constraint: **m**  $\geq$  16.

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

Constraint: **n**  $\geq$  1.

**NE\_INT\_ARRAY**

On entry, values in **iq** appear to be invalid. Check that **iq** has not been corrupted between calls to nag\_4d\_shep\_interp (e01tkc) and nag\_4d\_shep\_eval (e01tlc).

**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.

**NE\_REAL\_ARRAY**

On entry, values in **rq** appear to be invalid. Check that **rq** has not been corrupted between calls to nag\_4d\_shep\_interp (e01tkc) and nag\_4d\_shep\_eval (e01tlc).

**7 Accuracy**

Computational errors should be negligible in most practical situations.

**8 Parallelism and Performance**

nag\_4d\_shep\_eval (e01tlc) is threaded by NAG for parallel execution in multithreaded implementations of the NAG Library.

Please consult the x06 Chapter Introduction for information on how to control and interrogate the OpenMP environment used within this function. Please also consult the Users' Note for your implementation for any additional implementation-specific information.

**9 Further Comments**

The time taken for a call to nag\_4d\_shep\_eval (e01tlc) will depend in general on the distribution of the data points. If the data points are approximately uniformly distributed, then the time taken should be only  $O(n)$ . At worst  $O(mn)$  time will be required.

**10 Example**

This program evaluates the function

$$f(x) = \frac{(1.25 + \cos(5.4x_4)) \cos(6x_1) \cos(6x_2)}{6 + 6(3x_3 - 1)^2}$$

at a set of 30 randomly generated data points and calls nag\_4d\_shep\_interp (e01tkc) to construct an interpolating function  $Q(x)$ . It then calls nag\_4d\_shep\_eval (e01tlc) to evaluate the interpolant at a set of random points.

To reduce the time taken by this example, the number of data points is limited to 30. Increasing this value improves the interpolation accuracy at the expense of more time.

See also Section 10 in nag\_4d\_shep\_interp (e01tkc).

## 10.1 Program Text

```

/* nag_4d_shep_eval (e01tlc) Example Program.
 *
 * NAGPRODCODE Version.
 *
 * Copyright 2016 Numerical Algorithms Group.
 *
 * Mark 26, 2016.
 */

#include <stdio.h>
#include <nag.h>
#include <nag_stdlib.h>
#include <nage01.h>
#include <nagg05.h>
#include <math.h>

#ifdef __cplusplus
extern "C"
{
#endif
    static double NAG_CALL funct(double x[]);
#ifdef __cplusplus
}
#endif

#define X(I, J) x[I *4 + J]
#define XE(I, J) xe[I *4 + J]

int main(void)
{
    /* Scalars */
    Integer exit_status, i, m, n, nq, nw, liq, lrq, lstate, subid;
    Integer lseed = 1;
    double fun;
    Nag_BaseRNG genid;
    NagError fail;
    /* Arrays */
    double *f = 0, *q = 0, *qx = 0, *rq = 0, *xe = 0, *x = 0;
    Integer *iq = 0, *state = 0;
    Integer seed[1], seed2[1];

    exit_status = 0;

    INIT_FAIL(fail);

    printf("nag_4d_shep_eval (e01tlc) Example Program Results\n");

    /* Skip heading in data file */
#ifdef _WIN32
    scanf_s("%*[\n] ");
#else
    scanf("%*[\n] ");
#endif

    /* Input the seeds. */
#ifdef _WIN32
    scanf_s("%" NAG_IFMT "%" NAG_IFMT "%*[\n] ", &seed[0], &seed2[0]);
#else
    scanf("%" NAG_IFMT "%" NAG_IFMT "%*[\n] ", &seed[0], &seed2[0]);
#endif

    /* Choose the base generator */
    genid = Nag_Basic;
    subid = 0;

    /* Get the length of the state array */

```

```

lstate = -1;
nag_rand_init_repeatabe(genid, subid, seed, lseed, state, &lstate, &fail);
if (fail.code != NE_NOERROR) {
    printf("Error from nag_rand_init_repeatabe (g05kfc).\n%s\n",
        fail.message);
    exit_status = 1;
    goto END;
}

/* Input the number of nodes. */
#ifdef _WIN32
scanf_s("%" NAG_IFMT "%*[\n] ", &m);
#else
scanf("%" NAG_IFMT "%*[\n] ", &m);
#endif

/* Allocate memory */
lrq = 21 * m + 11;
liq = 2 * m + 1;
if (!(f = NAG_ALLOC(m, double)) ||
    !(x = NAG_ALLOC(m * 4, double)) ||
    !(rq = NAG_ALLOC(lrq, double)) ||
    !(iq = NAG_ALLOC(liq, Integer)) ||
    !(state = NAG_ALLOC(lstate, Integer)))
{
    printf("Allocation failure\n");
    exit_status = -1;
    goto END;
}

/* Initialize the generator to a repeatable sequence */
nag_rand_init_repeatabe(genid, subid, seed, lseed, state, &lstate, &fail);
if (fail.code != NE_NOERROR) {
    printf("Error from nag_rand_init_repeatabe (g05kfc).\n%s\n",
        fail.message);
    exit_status = 1;
    goto END;
}

/* Generate the data points X */
nag_rand_basic(m * 4, state, x, &fail);
if (fail.code != NE_NOERROR) {
    printf("Error from nag_rand_basic (g05sac).\n%s\n", fail.message);
    exit_status = 1;
    goto END;
}

/* Evaluate F */
for (i = 0; i < m; ++i) {
    f[i] = funct(&X(i, 0));
}

/* Generate the interpolant. */
nq = 0;
nw = 0;

/* nag_4d_shep_interp (e01tkc).
 * Interpolating functions, modified Shepard's method, four
 * variables
 */
nag_4d_shep_interp(m, x, f, nw, nq, iq, rq, &fail);
if (fail.code != NE_NOERROR) {
    printf("Error from nag_4d_shep_interp (e01tkc).\n%s\n", fail.message);
    exit_status = 1;
    goto END;
}

/* Input the number of evaluation points. */
#ifdef _WIN32
scanf_s("%" NAG_IFMT "%*[\n] ", &n);
#else

```

```

scanf("%" NAG_IFMT "%*[\n] ", &n);
#endif

/* Allocate memory for nag_4d_shep_eval (e01tlc) */
if (!(q = NAG_ALLOC(n, double)) ||
    !(qx = NAG_ALLOC(n * 4, double)) || !(xe = NAG_ALLOC(n * 4, double)))
{
    printf("Allocation failure\n");
    exit_status = -1;
    goto END;
}

/* Generate repeatable evaluation points. */
nag_rand_init_repeatable(genid, subid, seed2, lseed, state, &lstate, &fail);
if (fail.code != NE_NOERROR) {
    printf("Error from nag_rand_init_repeatable (g05kfc).\n%s\n",
        fail.message);
    exit_status = 1;
    goto END;
}
nag_rand_basic(n * 4, state, xe, &fail);
if (fail.code != NE_NOERROR) {
    printf("Error from nag_rand_basic (g05sac).\n%s\n", fail.message);
    exit_status = 1;
    goto END;
}

/* nag_4d_shep_eval (e01tlc).
 * Interpolated values, evaluate interpolant and first derivatives
 * computed by nag_4d_shep_interp (e01tkc).
 */
fail.print = Nag_TRUE;
nag_4d_shep_eval(m, x, f, iq, rq, n, xe, q, qx, &fail);
if (fail.code != NE_NOERROR) {
    printf("Error from nag_4d_shep_eval (e01tlc).\n%s\n", fail.message);
    exit_status = 1;
    goto END;
}

printf("\n      i      f(x)      q(x)      |f(x)-q(x)|\n");
for (i = 0; i < n; ++i) {
    fun = funct(&XE(i, 0));
    printf("%6" NAG_IFMT "%10.4f%10.4f%10.4f\n", i, fun, q[i],
        fabs(fun - q[i]));
}

END:
NAG_FREE(f);
NAG_FREE(q);
NAG_FREE(qx);
NAG_FREE(rq);
NAG_FREE(xe);
NAG_FREE(x);
NAG_FREE(iq);
NAG_FREE(state);

return exit_status;
}

static double NAG_CALL funct(double x[])
{
    /* Scalars */
    double ret_val;

    ret_val = ((1.25 + cos(5.4 * x[3])) * cos(6.0 * x[0]) * cos(6.0 * x[1])) /
        (6.0 * (1.0 + pow((3.0 * x[2] - 1.0), 2.0)));
    return ret_val;
}

```

## 10.2 Program Data

```
nag_4d_shep_eval (e01tlc) Example Program Data
1762543 43331      : random seeds
30              : m the number of data points
8               : n the number of evaluation points
```

## 10.3 Program Results

```
nag_4d_shep_eval (e01tlc) Example Program Results
```

i	f(x)	q(x)	f(x)-q(x)
0	-0.0189	-0.0385	0.0196
1	-0.0186	0.0965	0.1151
2	0.1147	0.0613	0.0535
3	0.0096	-0.1494	0.1591
4	-0.1354	-0.1916	0.0562
5	0.0022	-0.1787	0.1809
6	-0.0095	-0.1220	0.1125
7	0.0113	-0.4374	0.4486

---