NAG C Library Function Document

nag_2d_cheb_eval (e02cbc)

1 Purpose

nag_2d_cheb_eval (e02cbc) evaluates a bivariate polynomial from the rectangular array of coefficients in its double Chebyshev-series representation.

2 Specification

```
void nag_2d_cheb_eval (Integer mfirst, Integer mlast, Integer k, Integer l,
      const double x[], double xmin, double xmax, double y, double ymin,
      double ymax, double ff[], const double a[], NagError *fail)
```

3 Description

This function evaluates a bivariate polynomial (represented in double Chebyshev form) of degree k in one variable, $\bar{x}$, and degree l in the other, $\bar{y}$. The range of both variables is -1 to $+1$. However, these normalised variables will usually have been derived (as when the polynomial has been computed by nag_2d_cheb_fit_lines (e02cac), for example) from the user's original variables x and y by the transformations

$$\bar{x} = \frac{2x - (x_{\max} + x_{\min})}{(x_{\max} - x_{\min})} \quad \text{and} \quad \bar{y} = \frac{2y - (y_{\max} + y_{\min})}{(y_{\max} - y_{\min})}.$$

(Here $x_{\min}$ and $x_{\max}$ are the ends of the range of x which has been transformed to the range -1 to $+1$ of $\bar{x}$. $y_{\min}$ and $y_{\max}$ are correspondingly for y. See Section 8). For this reason, the function has been designed to accept values of x and y rather than $\bar{x}$ and $\bar{y}$, and so requires values of $x_{\min}$, etc. to be supplied by the user. In fact, for the sake of efficiency in appropriate cases, the function evaluates the polynomial for a sequence of values of x, all associated with the same value of y.

The double Chebyshev-series can be written as

$$\sum_{i=0}^{k} \sum_{j=0}^{l} a_{ij} T_i(\bar{x}) T_j(\bar{y}),$$

where $T_i(\bar{x})$ is the Chebyshev polynomial of the first kind of degree i and argument $\bar{x}$, and $T_j(\bar{y})$ is similarly defined. However the standard convention, followed in this function, is that coefficients in the above expression which have either i or j zero are written $\frac{1}{2}a_{ij}$, instead of simply a_{ij}, and the coefficient with both i and j zero is written $\frac{1}{4}a_{0,0}$.

The function first forms $c_i = \sum_{j=0}^{l} a_{ij} T_j(\bar{y})$, with $a_{i,0}$ replaced by $\frac{1}{2}a_{i,0}$, for each of $i = 0, 1, \ldots, k$. The value of the double series is then obtained for each value of x, by summing $c_i \times T_i(\bar{x})$, with c_0 replaced by $\frac{1}{2}c_0$, over $i = 0, 1, \ldots, k$. The Clenshaw three term recurrence (Clenshaw (1955)) with modifications due to Reinsch and Gentleman (1969) is used to form the sums.

4 References

Clenshaw C W (1955) A note on the summation of Chebyshev series *Math. Tables Aids Comput.* **9** 118–120

Gentleman W M (1969) An error analysis of Goertzel's (Watt's) method for computing Fourier coefficients *Comput. J.* **12** 160–165

5 Parameters

1: **mfirst** – Integer *Input*
2: **mlast** – Integer *Input*

On entry: the index of the first and last x value in the array x at which the evaluation is required respectively (see Section 8).

Constraint: **mlast** $\geq$ **mfirst**.

3: **k** – Integer *Input*
4: **l** – Integer *Input*

On entry: the degree k of x and l of y, respectively, in the polynomial.

Constraint: **k** ≥ 0 and **l** ≥ 0.

5: **x**[**mlast**] – const double *Input*

On entry: **x**$[i-1]$, for $i =$ **mfirst**, **mfirst** $+ 1, \ldots,$ **mlast**, must contain the x values at which the evaluation is required.

Constraint: **xmin** $\leq$ **x**$[i-1] \leq$ **xmax**, for all i.

6: **xmin** – double *Input*
7: **xmax** – double *Input*

On entry: the lower and upper ends, x_{min} and x_{max}, of the range of the variable x (see Section 3).

The values of **xmin** and **xmax** may depend on the value of y (e.g., when the polynomial has been derived using nag_2d_cheb_fit_lines (e02cac)).

Constraint: **xmax** $>$ **xmin**.

8: **y** – double *Input*

On entry: the value of the y co-ordinate of all the points at which the evaluation is required.

Constraint: **ymin** $\leq$ **y** $\leq$ **ymax**.

9: **ymin** – double *Input*
10: **ymax** – double *Input*

On entry: the lower and upper ends, y_{min} and y_{max}, of the range of the variable y (see Section 3).

Constraint: **ymax** $>$ **ymin**.

11: **ff**[**mlast**] – double *Output*

On exit: **ff**$[i-1]$ gives the value of the polynomial at the point (x_i, y), for $i =$ **mfirst**, **mfirst** $+ 1, \ldots,$ **mlast**.

12: **a**[dim] – const double *Input*

Note: the dimension, dim, of the array **a** must be at least $($**k** $+ 1) \times ($**l** $+ 1)$.

On entry: the Chebyshev coefficients of the polynomial. The coefficient a_{ij} defined according to the standard convention (see Section 3) must be in **a**$[i \times (l+1) + j]$.

13: **fail** – NagError * *Input/Output*

The NAG error parameter (see the Essential Introduction).

6 Error Indicators and Warnings

NE_INT_2

On entry, **k** = ⟨*value*⟩, **l** = ⟨*value*⟩.
Constraint: **k** ≥ 0 and **l** ≥ 0.

On entry, **mfirst** > **mlast**: **mfirst** = ⟨*value*⟩, **mlast** = ⟨*value*⟩.

NE_INTERNAL_ERROR

Unexpected failure in internal call to nag_1d_cheb_eval (e02aec).

NE_REAL_2

On entry, **xmin** ≥ **xmax**: **xmin** = ⟨*value*⟩, **xmax** = ⟨*value*⟩.

On entry, **y** > **ymax**: **y** = ⟨*value*⟩, **ymax** = ⟨*value*⟩.

On entry, **y** < **ymin**: **y** = ⟨*value*⟩, **ymin** = ⟨*value*⟩.

On entry, **ymin** ≥ **ymax**: **ymin** = ⟨*value*⟩, **ymax** = ⟨*value*⟩.

NE_REAL_ARRAY

On entry, **x**$[i-1]$ < **xmin**: i = ⟨*value*⟩, **x**$[i-1]$ = ⟨*value*⟩, **xmin** = ⟨*value*⟩.

On entry, **x**$[i-1]$ > **xmax**: i = ⟨*value*⟩, **x**$[i-1]$ = ⟨*value*⟩, **xmax** = ⟨*value*⟩.

NE_ALLOC_FAIL

Memory allocation failed.

NE_BAD_PARAM

On entry, parameter ⟨*value*⟩ had an illegal value.

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 consult NAG for assistance.

7 Accuracy

The method is numerically stable in the sense that the computed values of the polynomial are exact for a set of coefficients which differ from those supplied by only a modest multiple of ***machine precision***.

8 Further Comments

The time taken is approximately proportional to $(k+1) \times (m+l+1)$, where $m =$ **mlast** $-$ **mfirst** $+ 1$, the number of points at which the evaluation is required.

This function is suitable for evaluating the polynomial surface fits produced by the function nag_2d_cheb_fit_lines (e02cac), which provides the array **a** in the required form. For this use, the values of $y_{\min}$ and $y_{\max}$ supplied to the present function must be the same as those supplied to nag_2d_cheb_fit_lines (e02cac). The same applies to $x_{\min}$ and $x_{\max}$ if they are independent of y. If they vary with y, their values must be consistent with those supplied to nag_2d_cheb_fit_lines (e02cac) (see Section 8 of the document for nag_2d_cheb_fit_lines (e02cac)).

The parameters **mfirst** and **mlast** are intended to permit the selection of a segment of the array **x** which is to be associated with a particular value of y, when, for example, other segments of **x** are associated with other values of y. Such a case arises when, after using nag_2d_cheb_fit_lines (e02cac) to fit a set of data, the user wishes to evaluate the resulting polynomial at all the data values. In this case, if the parameters **x**, **y**, **mfirst** and **mlast** of the present routine are set respectively (in terms of parameters of nag_2d_cheb_fit_lines (e02cac)) to **x**, $\mathbf{y}(s)$, $1 + \sum_{i=1}^{s-1} \mathbf{m}(i)$ and $\sum_{i=1}^{s} \mathbf{m}(i)$, the function will compute values of the polynomial surface at all data points which have $y[s-1]$ as their y co-ordinate (from which values the residuals of the fit may be derived).

9 Example

The example program reads data in the following order, using the notation of the parameter list above:

n **k** **l**
$\mathbf{a}[i-1]$, for $i = 1, 2, \ldots, (\mathbf{k}+1) \times (\mathbf{l}+1)$
ymin **ymax**
$\mathbf{y}[i-1]$ $m(i-1)$ $\mathbf{xmin}[i-1]$ $\mathbf{xmax}[i-1]$ $x1(i)$ $xm(i)$, for $i = 1, 2, \ldots, n$.

For each line $\mathbf{y} = \mathbf{y}[i-1]$ the polynomial is evaluated at $m(i)$ equispaced points between $x1(i)$ and $xm(i)$ inclusive.

9.1 Program Text

```
/* nag_2d_cheb_eval (e02cbc) Example Program.
 *
 * Copyright 2001 Numerical Algorithms Group.
 *
 * Mark 7, 2001.
 */

#include <stdio.h>
#include <nag.h>
#include <nag_stdlib.h>
#include <nage02.h>

int main(void)
{
  /* Scalars */
  double x1, xm, xmax, xmin, y, ymax, ymin;
  Integer exit_status, i, ifail, j, k, l, m, n, ncoef, one;
  NagError fail;

  /* Arrays */
  double *a = 0, *ff = 0, *x = 0;

  INIT_FAIL(fail);
  exit_status = 0;
  Vprintf("e02cbc Example Program Results\n");

  /* Skip heading in data file */
  Vscanf("%*[^\n] ");
  while (scanf("%ld%ld%ld%*[^\n] ", &n, &k, &l) != EOF)
    {
      /* Allocate array a */
      ncoef = (k + 1) * (l + 1);
      if ( !(a = NAG_ALLOC(ncoef, double)))
        {
          Vprintf("Allocation failure\n");
          exit_status = -1;
          goto END;
        }

      for (i = 0; i < ncoef; ++i)
        Vscanf("%lf", &a[i]);
      Vscanf("%*[^\n] ");

      Vscanf("%lf%lf%*[^\n] ", &ymin, &ymax);

      for (i = 0; i < n; ++i)
        {
          Vscanf("%lf%ld%lf%lf%lf%lf%*[^\n] ",
```

```
                &y, &m, &xmin, &xmax, &x1, &xm);

          /* Allocate arrays x and ff */
          if ( !(x = NAG_ALLOC(m, double)) ||
               !(ff = NAG_ALLOC(m, double)) )
            {
              Vprintf("Allocation failure\n");
              exit_status = -1;
              goto END;
            }

          for (j = 0; j < m; ++j)
            x[j] = x1 + (xm - x1) * (double)j / (double)(m - 1);

          one = 1;
          ifail = 0;
          e02cbc(one, m, k, l, x, xmin, xmax, y, ymin, ymax,
                 ff, a, &fail);
          if (fail.code != NE_NOERROR)
            {
              Vprintf("Error from e02cbc.\n%s\n", fail.message);
              exit_status = 1;
              goto END;
            }

          Vprintf("\n");
          Vprintf("y = %13.4e\n", y);
          Vprintf("\n");
          Vprintf("  i     x(i)      Poly(x(i),y)\n");
          for (j = 0; j < m; ++j)
            Vprintf("%3ld%13.4e%13.4e\n", j, x[j], ff[j]);

          if (ff) NAG_FREE(ff);
          if (x) NAG_FREE(x);
        }

      if (a) NAG_FREE(a);
    }

 END:
  if (a) NAG_FREE(a);
  if (ff) NAG_FREE(ff);
  if (x) NAG_FREE(x);

  return exit_status;
}
```

9.2 Program Data

```
e02cbc Example Program Data
   3   3   2
15.34820
 5.15073
 0.10140
 1.14719
 0.14419
-0.10464
 0.04901
-0.00314
-0.00699
 0.00153
-0.00033
-0.00022
   0.0          4.0
   1.0          9   0.1          4.5          0.5          4.5
   1.5          8   0.225        4.25         0.5          4.0
   2.0          8   0.4          4.0          0.5          4.0
```

9.3 Program Results

```
e02cbc Example Program Results

y =    1.0000e+00

  i      x(i)      Poly(x(i),y)
  0   5.0000e-01   2.0812e+00
  1   1.0000e+00   2.1888e+00
  2   1.5000e+00   2.3018e+00
  3   2.0000e+00   2.4204e+00
  4   2.5000e+00   2.5450e+00
  5   3.0000e+00   2.6758e+00
  6   3.5000e+00   2.8131e+00
  7   4.0000e+00   2.9572e+00
  8   4.5000e+00   3.1084e+00

y =    1.5000e+00

  i      x(i)      Poly(x(i),y)
  0   5.0000e-01   2.6211e+00
  1   1.0000e+00   2.7553e+00
  2   1.5000e+00   2.8963e+00
  3   2.0000e+00   3.0444e+00
  4   2.5000e+00   3.2002e+00
  5   3.0000e+00   3.3639e+00
  6   3.5000e+00   3.5359e+00
  7   4.0000e+00   3.7166e+00

y =    2.0000e+00

  i      x(i)      Poly(x(i),y)
  0   5.0000e-01   3.1700e+00
  1   1.0000e+00   3.3315e+00
  2   1.5000e+00   3.5015e+00
  3   2.0000e+00   3.6806e+00
  4   2.5000e+00   3.8692e+00
  5   3.0000e+00   4.0678e+00
  6   3.5000e+00   4.2769e+00
  7   4.0000e+00   4.4971e+00
```