NAG Library Function Document

nag_quad_md_gauss (d01fbc)

1 Purpose

nag_quad_md_gauss (d01fbc) computes an estimate of a multidimensional integral (from 1 to 20 dimensions), given the analytic form of the integrand and suitable Gaussian weights and abscissae.

2 Specification

```c
#include <nag.h>
#include <nagd01.h>

double nag_quad_md_gauss (Integer ndim, const Integer nptvec[], Integer lwa,
const double weight[], const double abscis[],
double (*fun)(Integer ndim, const double x[], Nag_Comm *comm),
Nag_Comm *comm, NagError *fail)
```

3 Description

nag_quad_md_gauss (d01fbc) approximates a multidimensional integral by evaluating the summation

\[
\sum_{i_1=1}^{l_1} w_{1;i_1} \sum_{i_2=1}^{l_2} w_{2;i_2} \cdots \sum_{i_n=1}^{l_n} w_{n;i_n} f(x_{1;i_1}, x_{2;i_2}, \ldots, x_{n;i_n})
\]

given the weights \(w_{j;i_j}\) and abscissae \(x_{j;i_j}\) for a multidimensional product integration rule (see Davis and Rabinowitz (1975)). The number of dimensions may be anything from 1 to 20.

The weights and abscissae for each dimension must have been placed in successive segments of the arrays weight and abscis; for example, by calling nag_quad_1d_gauss_wset (d01tbc) or nag_quad_1d_gauss_wgen (d01tcc) once for each dimension using a quadrature formula and number of abscissae appropriate to the range of each \(x_j\) and to the functional dependence of \(f\) on \(x_j\).

If normal weights are used, the summation will approximate the integral

\[
\int w_1(x_1) \int w_2(x_2) \cdots \int w_n(x_n) f(x_1, x_2, \ldots, x_n) \, dx_n \cdots dx_2 dx_1
\]

where \(w_j(x)\) is the weight function associated with the quadrature formula chosen for the \(j\)th dimension; while if adjusted weights are used, the summation will approximate the integral

\[
\int \int \cdots \int f(x_1, x_2, \ldots, x_n) \, dx_n \cdots dx_2 dx_1.
\]

You must supply a function to evaluate

\[
f(x_1, x_2, \ldots, x_n)
\]

at any values of \(x_1, x_2, \ldots, x_n\) within the range of integration.

4 References

5 Arguments

1: \texttt{ndim} – Integer \hspace{1cm} \textit{Input}

\textit{On entry:} $n$, the number of dimensions of the integral.
\textit{Constraint:} $1 \leq \texttt{ndim} \leq 20$.

2: \texttt{nptvec[ndim]} – const Integer \hspace{1cm} \textit{Input}

\textit{On entry:} \texttt{nptvec}[j-1] must specify the number of points in the $j$th dimension of the summation, for $j = 1, 2, \ldots, n$.

3: \texttt{lwa} – Integer \hspace{1cm} \textit{Input}

\textit{On entry:} the dimension of the arrays \texttt{weight} and \texttt{abscis}.
\textit{Constraint:} \texttt{lwa} $\geq$ \texttt{nptvec}[0] + \texttt{nptvec}[1] + \cdots + \texttt{nptvec}[\texttt{ndim}] - 1$.

4: \texttt{weight[lwa]} – const double \hspace{1cm} \textit{Input}

\textit{On entry:} must contain in succession the weights for the various dimensions, i.e., \texttt{weight}[k-1] contains the $i$th weight for the $j$th dimension, with
\[ k = \texttt{nptvec}[0] + \texttt{nptvec}[1] + \cdots + \texttt{nptvec}[j-2] + i. \]

5: \texttt{abscis[lwa]} – const double \hspace{1cm} \textit{Input}

\textit{On entry:} must contain in succession the abscissae for the various dimensions, i.e., \texttt{abscis}[k-1] contains the $i$th abscissa for the $j$th dimension, with
\[ k = \texttt{nptvec}[0] + \texttt{nptvec}[1] + \cdots + \texttt{nptvec}[j-2] + i. \]

6: \texttt{fun} – function, supplied by the user \hspace{1cm} \textit{External Function}

\texttt{fun} must return the value of the integrand $f$ at a specified point.

The specification of \texttt{fun} is:
\begin{verbatim}
double fun (Integer ndim, const double x[], Nag_Comm *comm)
\end{verbatim}

1: \texttt{ndim} – Integer \hspace{1cm} \textit{Input}

\textit{On entry:} $n$, the number of dimensions of the integral.

2: \texttt{x[ndim]} – const double \hspace{1cm} \textit{Input}

\textit{On entry:} the coordinates of the point at which the integrand $f$ must be evaluated.

3: \texttt{comm} – Nag_Comm *

Pointer to structure of type Nag_Comm; the following members are relevant to \texttt{fun}.
\begin{verbatim}
    user – double *
    iuser – Integer *
    p – Pointer
\end{verbatim}

The type \texttt{Pointer} will be \texttt{void *}.
Before calling \texttt{nag_quad_md_gauss (d01fbc)} you may allocate memory and initialize these pointers with various quantities for use by \texttt{fun} when called from \texttt{nag_quad_md_gauss (d01fbc)} (see Section 3.2.1.1 in the Essential Introduction).

7: \texttt{comm} – Nag_Comm *

The NAG communication argument (see Section 3.2.1.1 in the Essential Introduction).
6 Error Indicators and Warnings

NE_ALLOC_FAIL
Dynamic memory allocation failed.
See Section 3.2.1.2 in the Essential Introduction for further information.

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

NE_INT
On entry, $\text{ndim} = \langle$value$\rangle$.
Constraint: $\text{ndim} \leq 20$.
On entry, $\text{ndim} = \langle$value$\rangle$.
Constraint: $\text{ndim} \geq 1$.

NE_INT_2
On entry, $\text{lwa}$ is too small. $\text{lwa} = \langle$value$\rangle$. Minimum possible dimension: $\langle$value$\rangle$.

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 3.6.6 in the Essential Introduction for further information.

NE_NO_LICENCE
Your licence key may have expired or may not have been installed correctly.
See Section 3.6.5 in the Essential Introduction for further information.

7 Accuracy
The accuracy of the computed multidimensional sum depends on the weights and the integrand values at the abscissae. If these numbers vary significantly in size and sign then considerable accuracy could be lost. If these numbers are all positive, then little accuracy will be lost in computing the sum.

8 Parallelism and Performance
Not applicable.

9 Further Comments
The total time taken by nag_quad_md_gauss (d01fbc) will be proportional to

$$T \times \text{nptvec}[0] \times \text{nptvec}[1] \times \cdots \times \text{nptvec}[\text{ndim} - 1],$$

where $T$ is the time taken for one evaluation of $\text{fun}$. 
10 Example

This example evaluates the integral
\[
\int_{-\infty}^{\infty} \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} \int_{1}^{2} \frac{(x_1 x_2 x_3)^6}{(x_4 + 2)^8} e^{-2x_1} e^{-0.5x_1^2} dx_4 dx_3 dx_2 dx_1
\]
using adjusted weights. The quadrature formulae chosen are:

- \(x_1\): Gauss–Legendre, \(a = 1.0, b = 2.0\),
- \(x_2\): Gauss–Laguerre, \(a = 0.0, b = 2.0\),
- \(x_3\): Gauss–Hermite, \(a = 0.0, b = 0.5\),
- \(x_4\): rational Gauss, \(a = 1.0, b = 2.0\).

Four points are sufficient in each dimension, as this integral is in fact a product of four one-dimensional integrals, for each of which the chosen four-point formula is exact.

10.1 Program Text

/* nag_quad_md_gauss (d01fbc) Example Program. */
* Copyright 2014 Numerical Algorithms Group.
* Mark 23, 2011.
*/
#include <stdio.h>
#include <math.h>
#include <nag.h>
#include <nag_stdlib.h>
#include <nagd01.h>
#include <nagx04.h>

#ifdef __cplusplus
extern "C" {
#endif
static double NAG_CALL fun(Integer ndim, const double x[], Nag_Comm *comm);
#ifdef __cplusplus
}
#endif
int main(void)
{
    static double ruser[1] = {-1.0};
    Integer exit_status = 0;
    Integer ndim;
    double a, ans, b;
    Integer i, j, lwa;
    double *abscis = 0, *weight = 0;
    Integer *nptvec = 0;
    char nag_enum_arg[40];
    Nag_Comm comm;
    Nag_QuadType quadtype;
    NagError fail;
    INIT_FAIL(fail);

    printf("nag_quad_md_gauss (d01fbc) Example Program Results
");

    /* For communication with user-supplied functions: */
    comm.user = ruser;

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

    return exit_status;
}
/* Input parameters */
#ifdef _WIN32
    scanf_s("%"NAG_IFMT"%[\n ]", &ndim);
#else
    scanf("%"NAG_IFMT"%[\n ]", &ndim);
#endif
if (!(nptvec = NAG_ALLOC(ndim, Integer)))
{
    printf("Allocation failure\n");
    exit_status = -1;
    goto END;
}
lwa = 0.0;
for (i = 0; i < ndim; i++)
{
#ifdef _WIN32
    scanf_s("%"NAG_IFMT" ", &nptvec[i]);
#else
    scanf("%"NAG_IFMT" ", &nptvec[i]);
#endif
    lwa = lwa + nptvec[i];
}
#ifdef _WIN32
    scanf_s("%[\n ] ");
#else
    scanf("%[\n ] ");
#endif
if (! (abscis = NAG_ALLOC(lwa, double)) ||
    ! (weight = NAG_ALLOC(lwa, double)))
{
    printf("Allocation failure\n");
    exit_status = -1;
    goto END;
}
j = 0;
for (i = 0; i < ndim; i++)
{
#ifdef _WIN32
    scanf_s("%39s%[\n ]", nag_enum_arg, _countof(nag_enum_arg));
#else
    scanf("%39s%[\n ]", nag_enum_arg);
#endif
    quadtype = (Nag_QuadType) nag_enum_name_to_value (nag_enum_arg);
#ifdef _WIN32
    scanf_s("%lf %lf%[\n ]", &a, &b);
#else
    scanf("%lf %lf%[\n ]", &a, &b);
#endif
    /* nag_quad_1d_gauss_wset (d01tbc).
    * Pre-computed weights and abscissae for
    * Gaussian quadrature rules, restricted choice of rule.
    */
    nag_quad_1d_gauss_wset(quadtype, a, b, nptvec[i], &weight[j], &abscis[j], &fail);
    if (fail.code != NE_NOERROR)
    {
        printf("Error from nag_quad_1d_gauss_wset (d01tbc).
fail.message\n");
        exit_status = 1;
        goto END;
    }
    j = j + nptvec[i];
}

/* nag_quad_md_gauss (d01fbc).
* Multidimensional Gaussian quadrature over hyper-rectangle.
/* 
ans = nag_quad_md_gauss(ndim, nptvec, lwa, weight, abscis, fun, &comm, 
   &fail);
if (fail.code != NE_NOERROR)
{
   printf("Error from nag_quad_md_gauss (d01fbc).
   
   nAnswer = %10.5f
   
   END:
   NAG_FREE(nptvec);
   NAG_FREE(abscis);
   NAG_FREE(weight);
   return exit_status;
}
static double NAG_CALL fun(Integer ndim, const double x[], Nag_Comm *comm)
{
   if (comm->user[0] == -1.0)
   {
      printf("(User-supplied callback fun, first invocation.)\n"");
      comm->user[0] = 0.0;
   }
   return pow((x[0] * x[1] * x[2]), 6)/pow((x[3] + 2.0), 8)
      * exp(-2.0 * x[1] - 0.5 * x[2] * x[2]);

10.2 Program Data
None.

10.3 Program Results
nag_quad_md_gauss (d01fbc) Example Program Results
(User-supplied callback fun, first invocation.)
Answer = 0.25065

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