

NAG C Library Function Document

nag_1d_quad_wt_trig (d01anc)

1 Purpose

nag_1d_quad_wt_trig (d01anc) calculates an approximation to the sine or the cosine transform of a function g over $[a, b]$:

$$I = \int_a^b g(x) \sin(\omega x) dx \quad \text{or} \quad I = \int_a^b g(x) \cos(\omega x) dx$$

(for a user-specified value of ω).

2 Specification

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

void nag_1d_quad_wt_trig (double (*g)(double x),
    double a, double b, double omega, Nag_TrigTransform wt_func,
    double epsabs, double epsrel, Integer max_num_subint,
    double *result, double *abserr, Nag_QuadProgress *qp, NagError *fail)
```

3 Description

This function is based upon the QUADPACK routine QFOUR (Piessens *et al.* (1983)). It is an adaptive routine, designed to integrate a function of the form $g(x)w(x)$, where $w(x)$ is either $\sin(\omega x)$ or $\cos(\omega x)$. If a sub-interval has length

$$L = |b - a|2^{-l}$$

then the integration over this sub-interval is performed by means of a modified Clenshaw-Curtis procedure (Piessens and Branders (1975)) if $L\omega > 4$ and $l \leq 20$. In this case a Chebyshev-series approximation of degree 24 is used to approximate $g(x)$, while an error estimate is computed from this approximation together with that obtained using Chebyshev-series of degree 12. If the above conditions do not hold then Gauss 7-point and Kronrod 15-point rules are used. The algorithm, described in Piessens *et al.* (1983), incorporates a global acceptance criterion (as defined in Malcolm and Simpson (1976)) together with the ϵ -algorithm (Wynn (1956)) to perform extrapolation. The local error estimation is described in Piessens *et al.* (1983).

4 Parameters

1: **g** – function supplied by user *Function*

The function **g**, supplied by the user, must return the value of the function g at a given point.

The specification of **g** is:

```
double g(double x)

1:   x – double Input
    On entry: the point at which the function  $g$  must be evaluated.
```

2: **a** – double *Input*

On entry: the lower limit of integration, a .

- 3: **b** – double *Input*
On entry: the upper limit of integration, b . It is not necessary that $a < b$.
- 4: **omega** – double *Input*
On entry: the parameter ω in the weight function of the transform.
- 5: **wt_func** – Nag_TrigTransform *Input*
On entry: indicates which integral is to be computed:
 if **wt_func** = **Nag_Cosine**, $w(x) = \cos(\omega x)$;
 if **wt_func** = **Nag_Sine**, $w(x) = \sin(\omega x)$.
Constraint: **wt_func** = **Nag_Cosine** or **Nag_Sine**.
- 6: **epsabs** – double *Input*
On entry: the absolute accuracy required. If **epsabs** is negative, the absolute value is used. See Section 6.1.
- 7: **epsrel** – double *Input*
On entry: the relative accuracy required. If **epsrel** is negative, the absolute value is used. See Section 6.1.
- 8: **max_num_subint** – Integer *Input*
On entry: the upper bound on the number of sub-intervals into which the interval of integration may be divided by the function. The more difficult the integrand, the larger **max_num_subint** should be.
Suggested values: a value in the range 200 to 500 is adequate for most problems.
Constraint: **max_num_subint** ≥ 1 .
- 9: **result** – double * *Output*
On exit: the approximation to the integral I .
- 10: **abserr** – double * *Output*
On exit: an estimate of the modulus of the absolute error, which should be an upper bound for $|I - \text{result}|$.
- 11: **qp** – Nag_QuadProgress *
 Pointer to structure of type **Nag_QuadProgress** with the following members:
- num_subint** – Integer *Output*
On exit: the actual number of sub-intervals used.
- fun_count** – Integer *Output*
On exit: the number of function evaluations performed by `nag_1d_quad_wt_trig`.
- sub_int_beg_pts** – double * *Output*
sub_int_end_pts – double * *Output*
sub_int_result – double * *Output*
sub_int_error – double * *Output*
- On exit:* these pointers are allocated memory internally with **max_num_subint** elements. If an error exit other than **NE_INT_ARG_LT**, **NE_BAD_PARAM** or **NE_ALLOC_FAIL** occurs, these arrays will contain information which may be useful. For details, see Section 6.

Before a subsequent call to `nag_1d_quad_wt_trig` is made, or when the information contained in these arrays is no longer useful, the user should free the storage allocated by these pointers using the NAG macro `NAG_FREE`.

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

The NAG error parameter (see the Essential Introduction).

Users are recommended to declare and initialise **fail** and set **fail.print** = **TRUE** for this function.

5 Error Indicators and Warnings

NE_INT_ARG_LT

On entry, **max_num_subint** must not be less than 1: **max_num_subint** = *<value>*.

NE_BAD_PARAM

On entry, parameter **wt_func** had an illegal value.

NE_ALLOC_FAIL

Memory allocation failed.

NE_QUAD_MAX_SUBDIV

The maximum number of subdivisions has been reached: **max_num_subint** = *<value>*.

The maximum number of subdivisions has been reached without the accuracy requirements being achieved. Look at the integrand in order to determine the integration difficulties. If the position of a local difficulty within the interval can be determined (e.g., a singularity of the integrand or its derivative, a peak, a discontinuity, etc.) you will probably gain from splitting up the interval at this point and calling the integrator on the sub-intervals. If necessary, another integrator, which is designed for handling the type of difficulty involved, must be used. Alternatively, consider relaxing the accuracy requirements specified by **epsabs** and **epsrel**, or increasing the value of **max_num_subint**.

NE_QUAD_ROUNDOff_TOL

Round-off error prevents the requested tolerance from being achieved: **epsabs** = *<value>*, **epsrel** = *<value>*.

The error may be underestimated. Consider relaxing the accuracy requirements specified by **epsabs** and **epsrel**.

NE_QUAD_BAD_SUBDIV

Extremely bad integrand behaviour occurs around the sub-interval (*<value>*, *<value>*).

The same advice applies as in the case of **NE_QUAD_MAX_SUBDIV**.

NE_QUAD_ROUNDOff_EXTRAPL

Round-off error is detected during extrapolation.

The requested tolerance cannot be achieved, because the extrapolation does not increase the accuracy satisfactorily; the returned result is the best that can be obtained.

The same advice applies as in the case of **NE_QUAD_MAX_SUBDIV**.

NE_QUAD_NO_CONV

The integral is probably divergent or slowly convergent.

Please note that divergence can also occur with any error exit other than **NE_INT_ARG_LT**, **NE_BAD_PARAM** or **NE_ALLOC_FAIL**.

6 Further Comments

The time taken by `nag_1d_quad_wt_trig` depends on the integrand and the accuracy required.

If the function fails with an error exit other than `NE_INT_ARG_LT`, `NE_BAD_PARAM` or `NE_ALLOC_FAIL`, then the user may wish to examine the contents of the structure `qp`. These contain the end-points of the sub-intervals used by `nag_1d_quad_wt_trig` along with the integral contributions and error estimates over the sub-intervals.

Specifically, for $i = 1, 2, \dots, n$, let r_i denote the approximation to the value of the integral over the sub-interval $[a_i, b_i]$ in the partition of $[a, b]$ and e_i be the corresponding absolute error estimate.

Then, $\int_{a_i}^{b_i} g(x)w(x) dx \simeq r_i$ and `result` = $\sum_{i=1}^n r_i$ unless the function terminates while testing for divergence of the integral (see Section 3.4.3 of Piessens *et al.* (1983)). In this case, `result` (and `abserr`) are taken to be the values returned from the extrapolation process. The value of n is returned in `num_subint`, and the values a_i , b_i , r_i and e_i are stored in the structure `qp` as

$$\begin{aligned} a_i &= \text{sub_int_beg_pts}[i - 1], \\ b_i &= \text{sub_int_end_pts}[i - 1], \\ r_i &= \text{sub_int_result}[i - 1] \text{ and} \\ e_i &= \text{sub_int_error}[i - 1]. \end{aligned}$$

6.1 Accuracy

The function cannot guarantee, but in practice usually achieves, the following accuracy:

$$|I - \text{result}| \leq \text{tol}$$

where

$$\text{tol} = \max\{|\text{epsabs}|, |\text{epsrel}| \times |I|\}$$

and `epsabs` and `epsrel` are user-specified absolute and relative error tolerances. Moreover it returns the quantity `abserr` which, in normal circumstances, satisfies

$$|I - \text{result}| \leq \text{abserr} \leq \text{tol}.$$

6.2 References

Malcolm M A and Simpson R B (1976) Local versus global strategies for adaptive quadrature *ACM Trans. Math. Software* **1** 129–146

Piessens R and Branders M (1975) Algorithm 002. Computation of oscillating integrals *J. Comput. Appl. Math.* **1** 153–164

Piessens R, De Doncker-Kapenga E, Überhuber C and Kahaner D (1983) *QUADPACK, A Subroutine Package for Automatic Integration* Springer-Verlag

Wynn P (1956) On a device for computing the $e_m(S_n)$ transformation *Math. Tables Aids Comput.* **10** 91–96

7 See Also

`nag_1d_quad_gen` (d01ajc)

8 Example

To compute

$$\int_0^1 \ln x \sin(10\pi x) dx.$$

8.1 Program Text

```

/* nag_ld_quad_wt_trig(d01anc) Example Program
 *
 * Copyright 1991 Numerical Algorithms Group.
 *
 * Mark 2, 1991.
 *
 * Mark 6 revised, 2000.
 */

#include <nag.h>
#include <stdio.h>
#include <nag_stdlib.h>
#include <math.h>
#include <nagd01.h>
#include <nagx01.h>

static double g(double x);

main()
{
    double a, b;
    double omega;
    double epsabs, abserr, epsrel, result;
    Nag_TrigTransform wt_func;
    Nag_QuadProgress qp;
    Integer max_num_subint;
    static NagError fail;

    Vprintf("d01anc Example Program Results\n");
    epsrel = 0.0001;
    epsabs = 0.0;
    a = 0.0;
    b = 1.0;
    omega = X01AAC * 10.0;
    wt_func = Nag_Sine;
    max_num_subint = 200;
    d01anc(g, a, b, omega, wt_func, epsabs, epsrel, max_num_subint, &result,
        &abserr, &qp, &fail);
    Vprintf("a      - lower limit of integration = %10.4f\n", a);
    Vprintf("b      - upper limit of integration = %10.4f\n", b);
    Vprintf("epsabs - absolute accuracy requested = %9.2e\n", epsabs);
    Vprintf("epsrel - relative accuracy requested = %9.2e\n\n", epsrel);
    if (fail.code != NE_NOERROR)
        Vprintf("%s\n", fail.message);
    if (fail.code != NE_INT_ARG_LT && fail.code != NE_BAD_PARAM &&
        fail.code != NE_ALLOC_FAIL)
    {
        Vprintf("result - approximation to the integral = %9.5f\n", result);
        Vprintf("abserr - estimate of the absolute error = %9.2e\n", abserr);
        Vprintf("qp.fun_count - number of function evaluations = %4ld\n",
            qp.fun_count);
        Vprintf("qp.num_subint - number of subintervals used = %4ld\n",
            qp.num_subint);
        /* Free memory used by qp */
        NAG_FREE(qp.sub_int_beg_pts);
        NAG_FREE(qp.sub_int_end_pts);
        NAG_FREE(qp.sub_int_result);
    }
}

```

```
        NAG_FREE(qp.sub_int_error);
        exit(EXIT_SUCCESS);
    }
    exit(EXIT_FAILURE);
}

static double g(double x)
{
    return (x>0.0) ? log(x) : 0.0;
}
```

8.2 Program Data

None.

8.3 Program Results

```
d01anc Example Program Results
a      - lower limit of integration =    0.0000
b      - upper limit of integration =    1.0000
epsabs - absolute accuracy requested =  0.00e+00
epsrel - relative accuracy requested =  1.00e-04

result - approximation to the integral = -0.12814
abserr - estimate of the absolute error =  3.58e-06
qp.fun_count - number of function evaluations = 275
qp.num_subint - number of subintervals used =    8
```
