

## NAG Library Function Document

### nag\_bessel\_y1\_vector (s17arc)

#### 1 Purpose

nag\_bessel\_y1\_vector (s17arc) returns an array of values of the Bessel function  $Y_1(x)$ .

#### 2 Specification

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

void nag_bessel_y1_vector (Integer n, const double x[], double f[],
                          Integer ivalid[], NagError *fail)
```

#### 3 Description

nag\_bessel\_y1\_vector (s17arc) evaluates an approximation to the Bessel function of the second kind  $Y_1(x_i)$  for an array of arguments  $x_i$ , for  $i = 1, 2, \dots, n$ .

**Note:**  $Y_1(x)$  is undefined for  $x \leq 0$  and the function will fail for such arguments.

The function is based on four Chebyshev expansions:

For  $0 < x \leq 8$ ,

$$Y_1(x) = \frac{2}{\pi} \ln x \frac{x}{8} \sum_{r=0} a_r T_r(t) - \frac{2}{\pi x} + \frac{x}{8} \sum_{r=0} b_r T_r(t), \quad \text{with } t = 2\left(\frac{x}{8}\right)^2 - 1.$$

For  $x > 8$ ,

$$Y_1(x) = \sqrt{\frac{2}{\pi x}} \left\{ P_1(x) \sin\left(x - 3\frac{\pi}{4}\right) + Q_1(x) \cos\left(x - 3\frac{\pi}{4}\right) \right\}$$

where  $P_1(x) = \sum_{r=0} c_r T_r(t)$ ,

and  $Q_1(x) = \frac{8}{x} \sum_{r=0} d_r T_r(t)$ , with  $t = 2\left(\frac{8}{x}\right)^2 - 1$ .

For  $x$  near zero,  $Y_1(x) \simeq -\frac{2}{\pi x}$ . This approximation is used when  $x$  is sufficiently small for the result to be correct to **machine precision**. For extremely small  $x$ , there is a danger of overflow in calculating  $-\frac{2}{\pi x}$  and for such arguments the function will fail.

For very large  $x$ , it becomes impossible to provide results with any reasonable accuracy (see Section 7), hence the function fails. Such arguments contain insufficient information to determine the phase of oscillation of  $Y_1(x)$ ; only the amplitude,  $\sqrt{\frac{2}{\pi x}}$ , can be determined and this is returned on failure. The range for which this occurs is roughly related to **machine precision**; the function will fail if  $x \gtrsim 1/\text{machine precision}$  (see the Users' Note for your implementation for details).

#### 4 References

Abramowitz M and Stegun I A (1972) *Handbook of Mathematical Functions* (3rd Edition) Dover Publications

Clenshaw C W (1962) Chebyshev Series for Mathematical Functions *Mathematical tables* HMSO

## 5 Arguments

- 1: **n** – Integer *Input*  
*On entry:*  $n$ , the number of points.  
*Constraint:*  $n \geq 0$ .
- 2: **x[n]** – const double *Input*  
*On entry:* the argument  $x_i$  of the function, for  $i = 1, 2, \dots, n$ .  
*Constraint:*  $x[i - 1] > 0.0$ , for  $i = 1, 2, \dots, n$ .
- 3: **f[n]** – double *Output*  
*On exit:*  $Y_1(x_i)$ , the function values.
- 4: **ivalid[n]** – Integer *Output*  
*On exit:* **ivalid**[ $i - 1$ ] contains the error code for  $x_i$ , for  $i = 1, 2, \dots, n$ .  
**ivalid**[ $i - 1$ ] = 0  
 No error.  
**ivalid**[ $i - 1$ ] = 1  
 On entry,  $x_i$  is too large. **f**[ $i - 1$ ] contains the amplitude of the  $Y_1$  oscillation,  $\sqrt{\frac{2}{\pi x_i}}$ .  
**ivalid**[ $i - 1$ ] = 2  
 On entry,  $x_i \leq 0.0$ ,  $Y_1$  is undefined. **f**[ $i - 1$ ] contains 0.0.  
**ivalid**[ $i - 1$ ] = 3  
 $x_i$  is too close to zero, there is a danger of overflow. On failure, **f**[ $i - 1$ ] contains the value of  $Y_1(x)$  at the smallest valid argument.
- 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.

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  $\langle value \rangle$  had an illegal value.

### NE\_INT

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

Constraint:  $n \geq 0$ .

### 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.

### NW\_INVALID

On entry, at least one value of **x** was invalid.  
Check **ivalid** for more information.

## 7 Accuracy

Let  $\delta$  be the relative error in the argument and  $E$  be the absolute error in the result. (Since  $Y_1(x)$  oscillates about zero, absolute error and not relative error is significant, except for very small  $x$ .)

If  $\delta$  is somewhat larger than the *machine precision* (e.g., if  $\delta$  is due to data errors etc.), then  $E$  and  $\delta$  are approximately related by:

$$E \simeq |xY_0(x) - Y_1(x)|\delta$$

(provided  $E$  is also within machine bounds). Figure 1 displays the behaviour of the amplification factor  $|xY_0(x) - Y_1(x)|$ .

However, if  $\delta$  is of the same order as *machine precision*, then rounding errors could make  $E$  slightly larger than the above relation predicts.

For very small  $x$ , absolute error becomes large, but the relative error in the result is of the same order as  $\delta$ .

For very large  $x$ , the above relation ceases to apply. In this region,  $Y_1(x) \simeq \sqrt{\frac{2}{\pi x}} \sin\left(x - \frac{3\pi}{4}\right)$ . The amplitude  $\sqrt{\frac{2}{\pi x}}$  can be calculated with reasonable accuracy for all  $x$ , but  $\sin\left(x - \frac{3\pi}{4}\right)$  cannot. If  $x - \frac{3\pi}{4}$  is written as  $2N\pi + \theta$  where  $N$  is an integer and  $0 \leq \theta < 2\pi$ , then  $\sin\left(x - \frac{3\pi}{4}\right)$  is determined by  $\theta$  only. If  $x > \delta^{-1}$ ,  $\theta$  cannot be determined with any accuracy at all. Thus if  $x$  is greater than, or of the order of, the inverse of the *machine precision*, it is impossible to calculate the phase of  $Y_1(x)$  and the function must fail.

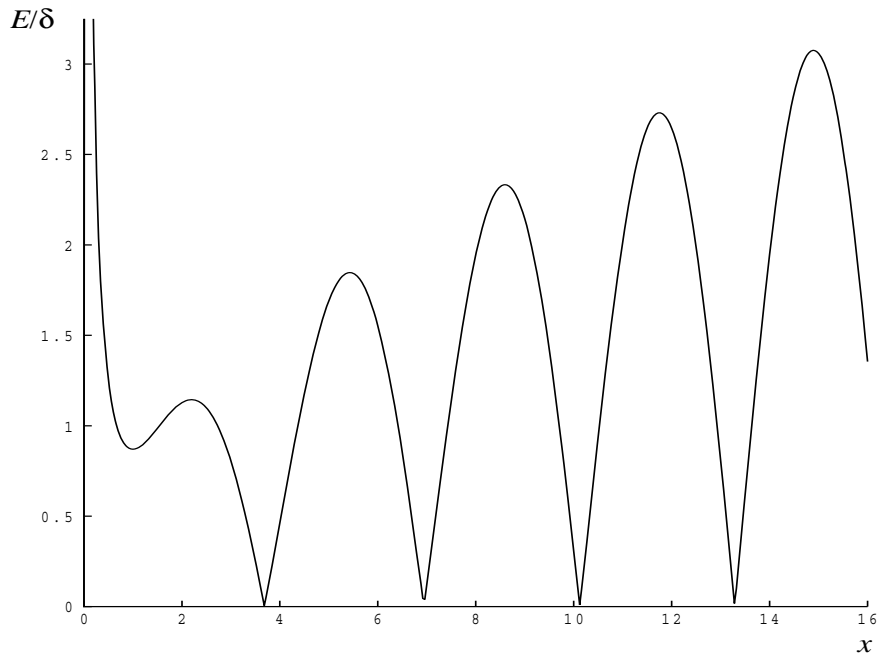


Figure 1

## 8 Parallelism and Performance

nag\_bessel\_y1\_vector (s17arc) is not threaded in any implementation.

## 9 Further Comments

None.

## 10 Example

This example reads values of  $x$  from a file, evaluates the function at each value of  $x_i$  and prints the results.

### 10.1 Program Text

```

/* nag_bessel_y1_vector (s17arc) Example Program.
 *
 * NAGPRODCODE Version.
 *
 * Copyright 2016 Numerical Algorithms Group.
 *
 * Mark 26, 2016.
 */
#include <nag.h>
#include <stdio.h>
#include <nag_stdlib.h>
#include <nags.h>

int main(void)
{
  Integer exit_status = 0;
  Integer i, n;
  double *f = 0, *x = 0;
  Integer *ivalid = 0;
  NagError fail;

  INIT_FAIL(fail);

```

```

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

    printf("nag_bessel_y1_vector (s17arc) Example Program Results\n");
    printf("\n");
    printf("      x      f      ivalid\n");
    printf("\n");
#ifdef _WIN32
    scanf_s("%" NAG_IFMT " ", &n);
#else
    scanf("%" NAG_IFMT " ", &n);
#endif
#ifdef _WIN32
    scanf_s("%*[\n]");
#else
    scanf("%*[\n]");
#endif

/* Allocate memory */
if (!(x = NAG_ALLOC(n, double)) ||
    !(f = NAG_ALLOC(n, double)) || !(ivalid = NAG_ALLOC(n, Integer)))
{
    printf("Allocation failure\n");
    exit_status = -1;
    goto END;
}

for (i = 0; i < n; i++)
#ifdef _WIN32
    scanf_s("%lf", &x[i]);
#else
    scanf("%lf", &x[i]);
#endif
#ifdef _WIN32
    scanf_s("%*[\n]");
#else
    scanf("%*[\n]");
#endif

/* nag_bessel_y1_vector (s17arc).
 * Bessel function Y_1(x)
 */
nag_bessel_y1_vector(n, x, f, ivalid, &fail);
if (fail.code != NE_NOERROR && fail.code != NW_INVALID) {
    printf("Error from nag_bessel_y1_vector (s17arc).\n%s\n", fail.message);
    exit_status = 1;
    goto END;
}

for (i = 0; i < n; i++)
    printf(" %11.3e %11.3e %4" NAG_IFMT "\n", x[i], f[i], ivalid[i]);

END:
NAG_FREE(f);
NAG_FREE(x);
NAG_FREE(ivalid);

return exit_status;
}

```

## 10.2 Program Data

nag\_bessel\_y1\_vector (s17arc) Example Program Data

7

0.5 1.0 3.0 6.0 8.0 10.0 1000.0

## 10.3 Program Results

nag\_bessel\_y1\_vector (s17arc) Example Program Results

x	f	ivalid
5.000e-01	-1.471e+00	0
1.000e+00	-7.812e-01	0
3.000e+00	3.247e-01	0
6.000e+00	-1.750e-01	0
8.000e+00	-1.581e-01	0
1.000e+01	2.490e-01	0
1.000e+03	-2.478e-02	0

---