

## NAG Library Function Document

### nag\_bessel\_k1\_vector (s18arc)

#### 1 Purpose

nag\_bessel\_k1\_vector (s18arc) returns an array of values of the modified Bessel function  $K_1(x)$ .

#### 2 Specification

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

void nag_bessel_k1_vector (Integer n, const double x[], double f[],
                          Integer ivalid[], NagError *fail)
```

#### 3 Description

nag\_bessel\_k1\_vector (s18arc) evaluates an approximation to the modified Bessel function of the second kind  $K_1(x_i)$  for an array of arguments  $x_i$ , for  $i = 1, 2, \dots, n$ .

**Note:**  $K_1(x)$  is undefined for  $x \leq 0$  and the function will fail for such arguments.

The function is based on five Chebyshev expansions:

For  $0 < x \leq 1$ ,

$$K_1(x) = \frac{1}{x} + x \ln x \sum_{r=0} a_r T_r(t) - x \sum_{r=0} b_r T_r(t), \quad \text{where } t = 2x^2 - 1.$$

For  $1 < x \leq 2$ ,

$$K_1(x) = e^{-x} \sum_{r=0} c_r T_r(t), \quad \text{where } t = 2x - 3.$$

For  $2 < x \leq 4$ ,

$$K_1(x) = e^{-x} \sum_{r=0} d_r T_r(t), \quad \text{where } t = x - 3.$$

For  $x > 4$ ,

$$K_1(x) = \frac{e^{-x}}{\sqrt{x}} \sum_{r=0} e_r T_r(t), \quad \text{where } t = \frac{9 - x}{1 + x}.$$

For  $x$  near zero,  $K_1(x) \simeq \frac{1}{x}$ . This approximation is used when  $x$  is sufficiently small for the result to be correct to *machine precision*. For very small  $x$  it is impossible to calculate  $\frac{1}{x}$  without overflow and the function must fail.

For large  $x$ , where there is a danger of underflow due to the smallness of  $K_1$ , the result is set exactly to zero.

#### 4 References

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

## 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:*  $K_1(x_i)$ , 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  
 $x_i \leq 0.0$ ,  $K_1(x_i)$  is undefined. **f**[ $i - 1$ ] contains 0.0.  
**ivalid**[ $i - 1$ ] = 2  
 $x_i$  is too small, there is a danger of overflow. **f**[ $i - 1$ ] contains zero. The threshold value is the same as for **fail.code** = NE\_REAL\_ARG\_TOO\_SMALL in nag\_bessel\_k1 (s18adc), as defined in the Users' Note for your implementation.
- 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  $\mathbf{x}$  was invalid.  
Check **ivalid** for more information.

**7 Accuracy**

Let  $\delta$  and  $\epsilon$  be the relative errors in the argument and result respectively.

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

$$\epsilon \simeq \left| \frac{xK_0(x) - K_1(x)}{K_1(x)} \right| \delta.$$

Figure 1 shows the behaviour of the error amplification factor

$$\left| \frac{xK_0(x) - K_1(x)}{K_1(x)} \right|.$$

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

For small  $x$ ,  $\epsilon \simeq \delta$  and there is no amplification of errors.

For large  $x$ ,  $\epsilon \simeq x\delta$  and we have strong amplification of the relative error. Eventually  $K_1$ , which is asymptotically given by  $\frac{e^{-x}}{\sqrt{x}}$ , becomes so small that it cannot be calculated without underflow and hence the function will return zero. Note that for large  $x$  the errors will be dominated by those of the standard function  $\exp$ .

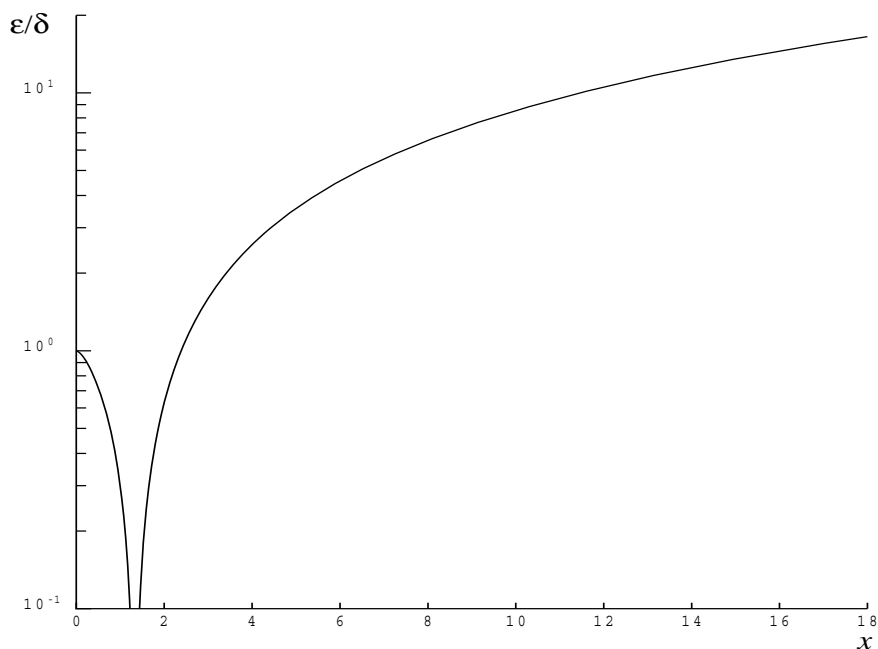


Figure 1

**8 Parallelism and Performance**

nag\_bessel\_k1\_vector (s18arc) 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_k1_vector (s18arc) 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_k1_vector (s18arc) 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_k1_vector (s18arc).
 * modified Bessel Function K1(x)
 */
nag_bessel_k1_vector(n, x, f, ivalid, &fail);
if (fail.code != NE_NOERROR && fail.code != NW_INVALID) {
    printf("Error from nag_bessel_k1_vector (s18arc).\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\_k1\_vector (s18arc) Example Program Data

10

0.4 0.6 1.4 1.6 2.5 3.5 6.0 8.0 10.0 1000.0

## 10.3 Program Results

nag\_bessel\_k1\_vector (s18arc) Example Program Results

x	f	ivalid
4.000e-01	2.184e+00	0
6.000e-01	1.303e+00	0
1.400e+00	3.208e-01	0
1.600e+00	2.406e-01	0
2.500e+00	7.389e-02	0
3.500e+00	2.224e-02	0
6.000e+00	1.344e-03	0
8.000e+00	1.554e-04	0
1.000e+01	1.865e-05	0
1.000e+03	0.000e+00	0

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