NAG Library Function Document

nag_bessel_j1 (s17afc)

1 Purpose

nag_bessel_j1 (s17afc) returns the value of the Bessel function $J_1(x)$.

2 Specification

```
#include <nag.h>
#include <nags.h>
double nag_bessel_j1 (double x, NagError *fail)
```

3 Description

nag_bessel_j1 (s17afc) evaluates an approximation to the Bessel function of the first kind $J_1(x)$.

Note: $J_1(-x) = -J_1(x)$, so the approximation need only consider $x \geq 0$.

The function is based on three Chebyshev expansions:

For $0 < x \leq 8$,

$$J_1(x) = \frac{x}{8}\sum_{r=0} a_r T_r(t), \qquad \text{with } t = 2\left(\frac{x}{8}\right)^2 - 1.$$

For $x > 8$,

$$J_1(x) = \sqrt{\frac{2}{\pi x}}\left\{P_1(x)\cos\left(x - \frac{3\pi}{4}\right) - Q_1(x)\sin\left(x - \frac{3\pi}{4}\right)\right\}$$

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

and $Q_1(x) = \frac{8}{x}\sum_{r=0} c_r T_r(t)$,

with $t = 2\left(\frac{8}{x}\right)^2 - 1$.

For x near zero, $J_1(x) \simeq \frac{x}{2}$. This approximation is used when x is sufficiently small for the result to be correct to ***machine precision***.

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 $J_1(x)$; 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 $|x| \gtrsim 1/$***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: **x** – double *Input*

On entry: the argument x of the function.

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

The NAG error argument (see Section 3.6 in the Essential Introduction).

6 Error Indicators and Warnings

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.

NE_REAL_ARG_GT

On entry, $\mathbf{x} = \langle value \rangle$.
Constraint: $|\mathbf{x}| \leq \langle value \rangle$.
$|\mathbf{x}|$ is too large, the function returns the amplitude of the J_1 oscillation, $\sqrt{2/(\pi|x|)}$.

7 Accuracy

Let δ be the relative error in the argument and E be the absolute error in the result. (Since $J_1(x)$ oscillates about zero, absolute error and not relative error is significant.)

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

$$E \simeq |xJ_0(x) - J_1(x)|\delta$$

(provided E is also within machine bounds). Figure 1 displays the behaviour of the amplification factor $|xJ_0(x) - J_1(x)|$.

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

For very large x, the above relation ceases to apply. In this region, $J_1(x) \simeq \sqrt{\frac{2}{\pi|x|}}\cos\left(x - \frac{3\pi}{4}\right)$. The amplitude $\sqrt{\frac{2}{\pi|x|}}$ can be calculated with reasonable accuracy for all x, but $\cos\left(x - \frac{3\pi}{4}\right)$ 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 $\cos\left(x - \frac{3\pi}{4}\right)$ is determined by θ only. If $x \gtrsim \delta^{-1}$, θ cannot be determined with any accuracy at all. Thus if x is greater than, or of the order of, the reciprocal of ***machine precision***, it is impossible to calculate the phase of $J_1(x)$ and the function must fail.

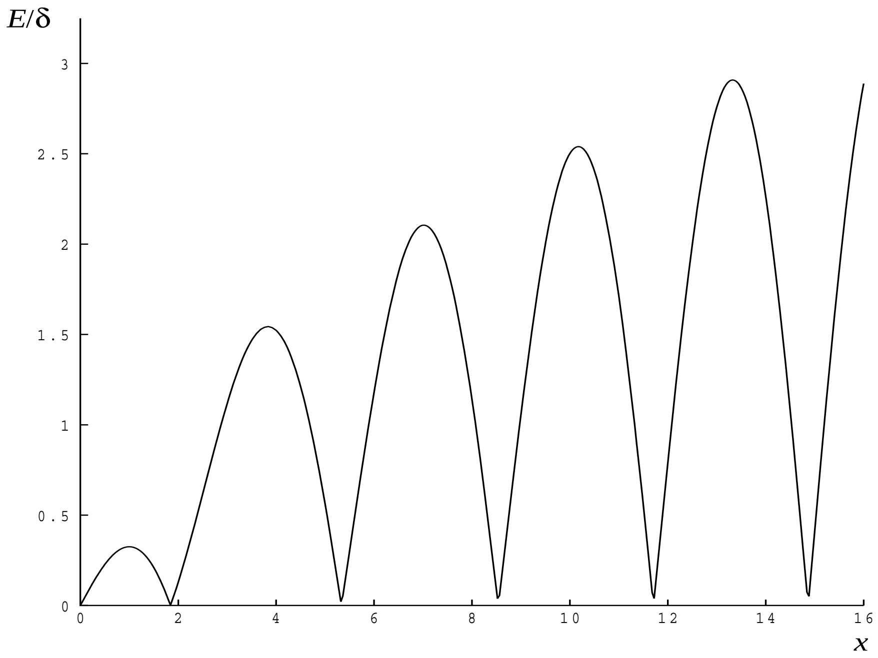


Figure 1

8 Parallelism and Performance

Not applicable.

9 Further Comments

None.

10 Example

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

10.1 Program Text

```
/* nag_bessel_j1 (s17afc) Example Program.
 *
 * Copyright 1990 Numerical Algorithms Group.
 *
 * Mark 2 revised, 1992.
 */

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

int main(void)
{
  Integer  exit_status = 0;
  double   x, y;
  NagError fail;

  INIT_FAIL(fail);

  /* Skip heading in data file */
  scanf("%*[^\n]");
  printf("nag_bessel_j1 (s17afc) Example Program Results\n");
```

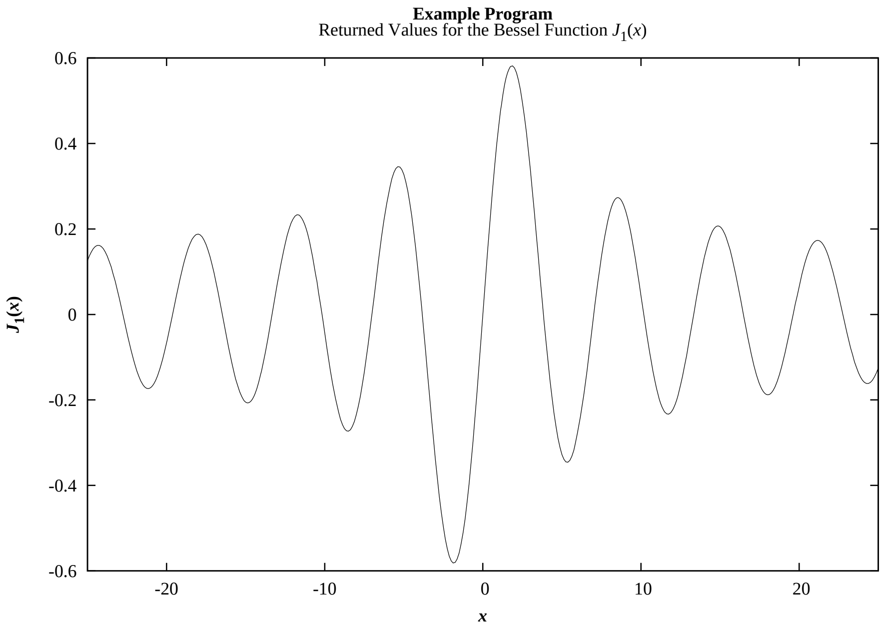
```
  printf("     x           y\n");
  while (scanf("%lf", &x) != EOF)
    {
      /* nag_bessel_j1 (s17afc).
       * Bessel function J_1(x)
       */
      y = nag_bessel_j1(x, &fail);
      if (fail.code != NE_NOERROR)
        {
          printf("Error from nag_bessel_j1 (s17afc).\n%s\n",
                 fail.message);
          exit_status = 1;
          goto END;
        }
      printf("%12.3e%12.3e\n", x, y);
    }

 END:
  return exit_status;
}
```

10.2 Program Data

```
nag_bessel_j1 (s17afc) Example Program Data
             0.0
             0.5
             1.0
             3.0
             6.0
             8.0
             10.0
             -1.0
             1000.0
```

10.3 Program Results

```
nag_bessel_j1 (s17afc) Example Program Results
     x           y
   0.000e+00   0.000e+00
   5.000e-01   2.423e-01
   1.000e+00   4.401e-01
   3.000e+00   3.391e-01
   6.000e+00  -2.767e-01
   8.000e+00   2.346e-01
   1.000e+01   4.347e-02
  -1.000e+00  -4.401e-01
   1.000e+03   4.728e-03
```



Example Program
Returned Values for the Bessel Function $J_1(x)$
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
$J_1(x)$
-20
-10
0
10
20
x