

NAG C Library Function Document

nag_legendre_p (s22aac)

1 Purpose

nag_legendre_p (s22aac) returns a sequence of values for either the unnormalized or normalized Legendre functions of the first kind $P_n^m(x)$ or $\overline{P}_n^m(x)$ for real x of a given order m and degree $n = 0, 1, \dots, N$.

2 Specification

```
void nag_legendre_p (Integer mode, double x, Integer m, Integer nl, double p[],
                    NagError *fail)
```

3 Description

This routine evaluates a sequence of values for either the unnormalized or normalized Legendre ($m = 0$) or associated Legendre ($m \neq 0$) functions of the first kind $P_n^m(x)$ or $\overline{P}_n^m(x)$, where x is real with $-1 \leq x \leq 1$, of order m and degree $n = 0, 1, \dots, N$ defined by

$$\begin{aligned} P_n^m(x) &= (1-x^2)^{m/2} \frac{d^m}{dx^m} P_n(x) \text{ if } m \geq 0, \\ P_n^m(x) &= \frac{(n+m)!}{(n-m)!} P_n^{-m}(x) \text{ if } m < 0 \text{ and} \\ \overline{P}_n^m(x) &= \sqrt{\frac{(2n+1)(n-m)!}{2(n+m)!}} P_n^m(x) \end{aligned}$$

respectively; $P_n(x)$ is the (unassociated) Legendre polynomial of degree n given by

$$P_n(x) \equiv P_n^0(x) = \frac{1}{2^n n!} \frac{d^n}{dx^n} (x^2 - 1)^n$$

(the *Rodrigues formula*). Note that some authors (e.g., Abramowitz and Stegun (1972)) include an additional factor of $(-1)^m$ (the *Condon-Shortley Phase*) in the definitions of $P_n^m(x)$ and $\overline{P}_n^m(x)$. They use the notation $P_{mn}(x) \equiv (-1)^m P_n^m(x)$ in order to distinguish between the two cases.

nag_legendre_p is based on a standard recurrence relation given by Abramowitz and Stegun (Abramowitz and Stegun (1972), 8.5.3). Constraints are placed on the values of m and n in order to avoid the possibility of machine overflow. It also sets the appropriate elements of the array **p** (see Section 4) to zero whenever the required function is not defined for certain values of m and n (e.g., $m = -5$ and $n = 3$).

4 Parameters

1: **mode** – Integer *Input*

On entry: indicates whether the sequence of function values is to be returned unnormalized or normalized as follows:

if **mode** = 1, then the sequence of function values is returned unnormalized;

if **mode** = 2, then the sequence of function values is returned normalized.

Constraint: **mode** = 1 or 2.

2: **x** – double *Input*

On entry: the argument x of the function.

Constraint: $\text{abs}(\mathbf{x}) \leq 1.0$.

- 3: **m** – Integer *Input*
On entry: the order m of the function.
Constraint: $\text{abs}(\mathbf{m}) \leq 27$.
- 4: **nl** – Integer *Input*
On entry: the degree N of the last function required in the sequence.
Constraints:
 $\mathbf{nl} \geq 0$,
 $\mathbf{nl} \leq 100$ when $\mathbf{m} = 0$,
 $\mathbf{nl} \leq 55 - \text{abs}(\mathbf{m})$ when $\mathbf{m} \neq 0$.
- 5: **p[nl+1]** – double *Output*
On exit: the required sequence of function values as follows:
if **mode** = 1, **p**(n) contains $P_n^m(x)$, for $n = 0, 1, \dots, N$;
if **mode** = 2, **p**(n) contains $\overline{P}_n^m(x)$, for $n = 0, 1, \dots, N$.
- 6: **fail** – NagError * *Input/Output*
The NAG error parameter (see the Essential Introduction).

5 Error Indicators and Warnings

NE_REAL

On entry, **x** = *<value>*.
Constraint: $\text{abs}(\mathbf{x}) \leq 1.0$.

NE_INT

On entry, **mode** = *<value>*.
Constraint: **mode** = 1 or 2.

On entry, **nl** = *<value>*.
Constraint: $\mathbf{nl} \geq 0$.

On entry, **m** = *<value>*.
Constraint: $\text{abs}(\mathbf{m}) \leq 27$.

NE_INT_2

On entry, **nl** = *<value>*, **m** = *<value>*.
Constraint: $\mathbf{nl} \leq 100$ when $\mathbf{m} = 0$.

On entry, **nl** = *<value>*, **m** = *<value>*.
Constraint: $\mathbf{nl} \leq 55 - \text{abs}(\mathbf{m})$ when $\mathbf{m} \neq 0$.

6 Further Comments

6.1 Accuracy

The computed function values should be accurate to within a small multiple of the *machine precision* except when underflow (or overflow) occurs, in which case the true function values are within a small multiple of the underflow (or overflow) threshold of the machine.

6.2 References

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

7 See Also

None.

8 Example

The following program reads the values of the arguments x , m and N from a file, calculates the sequence of unnormalized associated Legendre function values $P_n^m(x)$, $P_{n+1}^m(x)$, $\dots$, $P_{n+N}^m(x)$, and prints the results.

8.1 Program Text

```
/* nag_legendre_p (s22aac) Example Program.
 *
 * Copyright 2000 Numerical Algorithms Group.
 *
 * NAG C Library
 *
 * Mark 6, 2000.
 */

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

int main(void)
{
    const char fmt_99998[] = "%2ld %12.4e\n";
    const char fmt_99999[] = "%3ld      %5.1f%6ld%6ld\n\n";
    char str[80];
    double p[101];
    double x;
    Integer exit_status=0;
    NagError fail;
    Integer m, mode, n, nl;

    INIT_FAIL(fail);
    Vprintf("s22aac Example Program Results\n\n");

    /*      Skip heading in data file */
    Vscanf("%*[^\\n] ");
    Vscanf("%ld %lf %ld %ld", &mode, &x, &m, &nl);
    if (mode == 1)
    {
        if (m == 0)
        {
            Vstrcpy(str, "Unnormalized Legendre function values\n");
        }
        else
        {
            Vstrcpy(str, "Unnormalized associated Legendre function values\n");
        }
    }
    else if (mode == 2)
    {

```

```

        if (m == 0)
        {
            Vstrcpy(str, "Normalized Legendre function values\n");
        }
        else
        {
            Vstrcpy(str, "Normalized associated Legendre function values\n");
        }
    }

    s22aac (mode, x, m, nl, p, &fail);
    Vprintf("mode      x      m      nl\n\n");
    Vprintf(fmt_99999, mode, x, m, nl);

    if (fail.code == NE_NOERROR)
    {
        Vprintf(str);
        Vprintf("\n");
        Vprintf(" n      P(n)\n");
        for (n = 0; n <= nl; ++n)
        {
            Vprintf(fmt_99998, n, p[n]);
        }
    }
    else
    {
        Vprintf("Error from s22aac.\n%s\n", fail.message);
        exit_status = 1;
        goto END;
    }
END:
    return exit_status;
}

```

8.2 Program Data

s22aac Example Program Data

1 0.5 2 3 : Values of mode, x, m and nl

8.3 Program Results

s22aac Example Program Results

mode	x	m	nl
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1	0.5	2	3
---	-----	---	---

Unnormalized associated Legendre function values

n	P(n)
0	0.0000e+00
1	0.0000e+00
2	2.2500e+00
3	5.6250e+00