

## NAG Library Function Document

### nag\_matop\_real\_gen\_matrix\_cond\_log (f01jjc)

#### 1 Purpose

nag\_matop\_real\_gen\_matrix\_cond\_log (f01jjc) computes an estimate of the relative condition number  $\kappa_{\log}(A)$  of the logarithm of a real  $n$  by  $n$  matrix  $A$ , in the 1-norm. The principal matrix logarithm  $\log(A)$  is also returned.

#### 2 Specification

```
#include <nag.h>
#include <nagf01.h>
void nag_matop_real_gen_matrix_cond_log (Integer n, double a[], Integer pda,
    double *condla, NagError *fail)
```

#### 3 Description

For a matrix with no eigenvalues on the closed negative real line, the principal matrix logarithm  $\log(A)$  is the unique logarithm whose spectrum lies in the strip  $\{z : -\pi < \text{Im}(z) < \pi\}$ .

The Fréchet derivative of the matrix logarithm of  $A$  is the unique linear mapping  $E \mapsto L(A, E)$  such that for any matrix  $E$

$$\log(A + E) - \log(A) - L(A, E) = o(\|E\|).$$

The derivative describes the first order effect of perturbations in  $A$  on the logarithm  $\log(A)$ .

The relative condition number of the matrix logarithm can be defined by

$$\kappa_{\log}(A) = \frac{\|L(A)\| \|A\|}{\|\log(A)\|},$$

where  $\|L(A)\|$  is the norm of the Fréchet derivative of the matrix logarithm at  $A$ .

To obtain the estimate of  $\kappa_{\log}(A)$ , nag\_matop\_real\_gen\_matrix\_cond\_log (f01jjc) first estimates  $\|L(A)\|$  by computing an estimate  $\gamma$  of a quantity  $K \in [n^{-1}\|L(A)\|_1, n\|L(A)\|_1]$ , such that  $\gamma \leq K$ .

The algorithms used to compute  $\kappa_{\log}(A)$  and  $\log(A)$  are based on a Schur decomposition, the inverse scaling and squaring method and Padé approximants. Further details can be found in Al-Mohy and Higham (2011) and Al-Mohy *et al.* (2012).

#### 4 References

Al-Mohy A H and Higham N J (2011) Improved inverse scaling and squaring algorithms for the matrix logarithm *SIAM J. Sci. Comput.* **34(4)** C152–C169

Al-Mohy A H, Higham N J and Relton S D (2012) Computing the Fréchet derivative of the matrix logarithm and estimating the condition number *MIMS EPrint* **2012.72**

Higham N J (2008) *Functions of Matrices: Theory and Computation* SIAM, Philadelphia, PA, USA

#### 5 Arguments

1: **n** – Integer *Input*  
*On entry:*  $n$ , the order of the matrix  $A$ .  
*Constraint:*  $n \geq 0$ .

- 2: **a**[*dim*] – double *Input/Output*  
**Note:** the dimension, *dim*, of the array **a** must be at least  $\mathbf{pda} \times \mathbf{n}$ .  
The (*i*, *j*)th element of the matrix *A* is stored in  $\mathbf{a}[(j - 1) \times \mathbf{pda} + i - 1]$ .  
*On entry:* the *n* by *n* matrix *A*.  
*On exit:* the *n* by *n* principal matrix logarithm,  $\log(A)$ .
- 3: **pda** – Integer *Input*  
*On entry:* the stride separating matrix row elements in the array **a**.  
**Constraint:**  $\mathbf{pda} \geq \mathbf{n}$ .
- 4: **condla** – double \* *Output*  
*On exit:* with **fail.code** = NE\_NOERROR or NW\_SOME\_PRECISION\_LOSS, an estimate of the relative condition number of the matrix logarithm,  $\kappa_{\log}(A)$ . Alternatively, if **fail.code** = NE\_RCOND, contains the absolute condition number of the matrix logarithm.
- 5: **fail** – NagError \* *Input/Output*  
The NAG error argument (see Section 3.6 in the Essential Introduction).

## 6 Error Indicators and Warnings

### NE\_ALLOC\_FAIL

Dynamic memory allocation failed.

### NE\_BAD\_PARAM

On entry, argument  $\langle \text{value} \rangle$  had an illegal value.

### NE\_INT

On entry,  $\mathbf{n} = \langle \text{value} \rangle$ .  
**Constraint:**  $\mathbf{n} \geq 0$ .

### NE\_INT\_2

On entry,  $\mathbf{pda} = \langle \text{value} \rangle$  and  $\mathbf{n} = \langle \text{value} \rangle$ .  
**Constraint:**  $\mathbf{pda} \geq \mathbf{n}$ .

### 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\_NEGATIVE\_EIGVAL

*A* has eigenvalues on the negative real line. The principal logarithm is not defined in this case; nag\_matop\_complex\_gen\_matrix\_cond\_log (f01kjc) can be used to return a complex, non-principal log.

### NE\_RCOND

The relative condition number is infinite. The absolute condition number was returned instead.

### NE\_SINGULAR

*A* is singular so the logarithm cannot be computed.

## NW\_SOME\_PRECISION\_LOSS

$\log(A)$  has been computed using an IEEE double precision Padé approximant, although the arithmetic precision is higher than IEEE double precision.

## 7 Accuracy

`nag_matop_real_gen_matrix_cond_log (f01jjc)` uses the norm estimation function `nag_linsys_real_gen_norm_rcomm (f04ydc)` to produce an estimate  $\gamma$  of a quantity  $K \in [n^{-1}\|L(A)\|_1, n\|L(A)\|_1]$ , such that  $\gamma \leq K$ . For further details on the accuracy of norm estimation, see the documentation for `nag_linsys_real_gen_norm_rcomm (f04ydc)`.

For a normal matrix  $A$  (for which  $A^T A = A A^T$ ), the Schur decomposition is diagonal and the computation of the matrix logarithm reduces to evaluating the logarithm of the eigenvalues of  $A$  and then constructing  $\log(A)$  using the Schur vectors. This should give a very accurate result. In general, however, no error bounds are available for the algorithm. The sensitivity of the computation of  $\log(A)$  is worst when  $A$  has an eigenvalue of very small modulus or has a complex conjugate pair of eigenvalues lying close to the negative real axis. See Al-Mohy and Higham (2011) and Section 11.2 of Higham (2008) for details and further discussion.

## 8 Parallelism and Performance

`nag_matop_real_gen_matrix_cond_log (f01jjc)` is threaded by NAG for parallel execution in multi-threaded implementations of the NAG Library.

`nag_matop_real_gen_matrix_cond_log (f01jjc)` makes calls to BLAS and/or LAPACK routines, which may be threaded within the vendor library used by this implementation. Consult the documentation for the vendor library for further information.

Please consult the Users' Note for your implementation for any additional implementation-specific information.

## 9 Further Comments

`nag_matop_real_gen_matrix_cond_std (f01jac)` uses a similar algorithm to `nag_matop_real_gen_matrix_cond_log (f01jjc)` to compute an estimate of the *absolute* condition number (which is related to the relative condition number by a factor of  $\|A\|/\|\log(A)\|$ ). However, the required Fréchet derivatives are computed in a more efficient and stable manner by `nag_matop_real_gen_matrix_cond_log (f01jjc)` and so its use is recommended over `nag_matop_real_gen_matrix_cond_std (f01jac)`.

The amount of real allocatable memory required by the algorithm is typically of the order  $10n^2$ .

The cost of the algorithm is  $O(n^3)$  floating-point operations; see Al-Mohy *et al.* (2012).

If the matrix logarithm alone is required, without an estimate of the condition number, then `nag_matop_real_gen_matrix_log (f01ejc)` should be used. If the Fréchet derivative of the matrix logarithm is required then `nag_matop_real_gen_matrix_frcht_log (f01jkc)` should be used. If  $A$  has negative real eigenvalues then `nag_matop_complex_gen_matrix_cond_log (f01kjc)` can be used to return a complex, non-principal matrix logarithm and its condition number.

## 10 Example

This example estimates the relative condition number of the matrix logarithm  $\log(A)$ , where

$$A = \begin{pmatrix} 4 & -1 & 0 & 1 \\ 2 & 5 & -2 & 2 \\ 1 & 1 & 3 & -1 \\ 2 & 0 & 2 & 8 \end{pmatrix}.$$

## 10.1 Program Text

```

/* nag_matop_real_gen_matrix_cond_log (f01jjc) Example Program.
 *
 * Copyright 2013 Numerical Algorithms Group.
 *
 * Mark 24, 2013.
 */
#include <nag.h>
#include <nag_stdlib.h>
#include <nagf01.h>
#include <nagx04.h>

#define A(I,J) a[J*pda + I]

int main(void)
{
    /* Scalars */
    Integer      exit_status = 0;
    Integer      i, j, n;
    Integer      pda;
    double       condla;
    /* Arrays */
    double       *a = 0;
    /* Nag Types */
    Nag_OrderType order = Nag_ColMajor;
    NagError     fail;

    INIT_FAIL(fail);

    /* Output preamble */
    printf("nag_matop_real_gen_matrix_cond_log (f01jjc) ");
    printf("Example Program Results\n\n");

    /* Skip heading in data file */
    scanf("%*[\n] ");

    /* Read in the problem size */
    scanf("%ld%*[\n] ", &n);

    pda = n;
    if (!(a = NAG_ALLOC(pda*n, double))) {
        printf("Allocation failure\n");
        exit_status = -1;
        goto END;
    }

    /* Read in the matrix A from data file */
    for (i = 0; i < n; i++)
        for (j = 0; j < n; j++)
            scanf("%lf", &A(i, j));
    scanf("%*[\n] ");

    /* Find log(A) and the condition number using
     * nag_matop_real_gen_matrix_cond_log (f01jjc)
     * Condition number for real matrix logarithm
     */
    nag_matop_real_gen_matrix_cond_log(n, a, pda, &condla, &fail);
    if (fail.code != NE_NOERROR) {
        printf("Error from nag_matop_real_gen_matrix_cond_log (f01jjc)\n%s\n",
            fail.message);
        exit_status = 1;
        goto END;
    }

    /* Print matrix log(A) using nag_gen_real_mat_print (x04cac)
     * Print real general matrix (easy-to-use)
     */
    nag_gen_real_mat_print(order, Nag_GeneralMatrix, Nag_NonUnitDiag, n, n,
        a, pda, "log(A)", 0, &fail);
    if (fail.code != NE_NOERROR) {

```

```

    printf("Error from nag_gen_real_mat_print (x04cac)\n%s\n", fail.message);
    exit_status = 2;
}

/* Print relative condition number estimate */
printf("Estimated relative condition number is: %7.2f\n", condla);

END:
NAG_FREE(a);

return exit_status;
}

```

## 10.2 Program Data

nag\_matop\_real\_gen\_matrix\_cond\_log (f01jjc) Example Program Data

```

4                               :Value of n

4.0    -1.0    0.0    1.0
2.0     5.0   -2.0    2.0
1.0     1.0    3.0   -1.0
2.0     0.0    2.0    8.0 :End of matrix a

```

## 10.3 Program Results

nag\_matop\_real\_gen\_matrix\_cond\_log (f01jjc) Example Program Results

```

log(A)
      1      2      3      4
1     1.4081  -0.2051  -0.1071  0.1904
2     0.4396   1.7096  -0.5147  0.2226
3     0.2560   0.2613   1.2485  -0.2413
4     0.3030  -0.0107   0.3834   2.0891
Estimated relative condition number is: 5.50

```

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