

# MUESLI

## *Reference Manual*

*Fortran implementation*

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## Introduction

This document describes in details the MUESLI Fortran library routines.

MUESLI is freely available at the following address: <https://perso.univ-rennes1.fr/edouard.canot/muesli>

More information can be found in the following documents:

- *MUESLI Installation Guide*
- *MUESLI User's Guide*
- *MUESLI Inside*

The source code of MUESLI comes with many examples which can also give some help.

MUESLI is split in two parts, which correspond to the following Fortran modules:

- Basically, **FML** (Fortran Muesli Library) contains all necessary materials to numerically work with a dynamic array (dynamic in size, type and structure), called `mfArray`; all available routines are described in the first section of this guide.

To work with FML, your Fortran source code must include the statement:

```
use fml
```

- **FGL** (Fortran Graphics Library) contains graphic routines which use the `mfArray` objects; these routines are described in the second section of this guide.

To work with FGL, your Fortran source code must include the statements:

```
use fml
use fgl
```

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### Typographic convention

In this guide, the colored brackets ('`[`' and '`]`') indicate some optional arguments or other things; similarly, the colored pipe ('`|`') specifies alternates in a choice. These symbols are used only in interface definition of the routines.

Coloring is also used to differentiate source code and execution output. Lines from source code will be always displayed in **this color**, whereas input/output in a terminal will be always displayed in **this color**.

For sake of clarity, array constructors use black brackets '`[`' and '`]`' (Fortran 2003) instead of '`(/`' and '`/)`' (Fortran 95).

### About the name

*Muesli*: loose mixture of mainly rolled oats and often also wheat flakes, together with various pieces of dried fruit, nuts, and seeds. There are many varieties, some of which also contain honey powder, spices, or chocolate. (from <https://en.wikipedia.org/wiki/Muesli>)

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# 1 FML: Numerical Library

FML contains all routines to work with matrices and to do some linear algebra.

Routines beginning with ‘mf’ are functions, whereas those beginning with ‘ms’ are subroutines. Functions are used to return only one object (*e.g.* one `mfArray`); subroutines can also return many objects, but always via the `mfOut` facility.

FML also defines some new derived types: `mfArray`, `mfUnit`, `mf_Out`, `mfMatFactor`, `mfTriConnect`, `mfTetraConnect`, `mf_DE_Options`, `mf_NL_Options`.

Besides, FML defines public constant entities:

- an `integer` parameter:

`MF_DOUBLE`

which defines the working precision in MUESLI. In the current version, it stores the kind of double precision reals. In all this document, when Fortran numerical kind is not specified, `real` and `complex` stands for `real(kind=MF_DOUBLE)` and `complex(kind=MF_DOUBLE)`, respectively.

- some `mfArray` parameters:

`MF_EMPTY`, `MF_COLON` (and its alias `MF_ALL`), `MF_END`, `MF_NO_ARG`

which are, respectively, an empty `mfArray`, the ‘:’ pseudo-operator (as in Fortran 90 or MATLAB, but specific to FML), an automatic index for pointing to the end of a dimension of an `mfArray` and a pseudo-keyword to tell that an argument is not present in `mfOut`.

- some `real(kind=MF_DOUBLE)` parameters:

`MF_PI`  
`MF_EPS`  
`MF_INF`  
`MF_NAN`  
`MF_E`  
`MF_REALMAX`  
`MF_REALMIN`

and some useful mathematical auxiliary constants:

`MF_BESSEL_J0_ROOTS(:)`  
`MF_BESSEL_J1_ROOTS(:)`

(30 first non-zero roots for both Bessel functions  $J_0$  and  $J_1$ , stored in increasing order)

- one `complex(kind=MF_DOUBLE)` parameter:

`MF_I`

- and the `character` parameters:

`MF_MUESLI_VERSION`  
`MF_COMPILER_VERSION`

which store, respectively, the MUESLI library version and the compiler vendor and version. The boolean `mfIsVersion` routine must be used in order to compare each of these parameters with a given version number. Besides, other character functions may be used to retrieve additional information: `MF_LAPACK_VERSION()` (the Blas/Lapack library version) and `MF_COMPILATION_CONFIG()` (the configuration used to compile the whole Muesli library: *Debug* or *Optim*).

`MF_INF` and `MF_NAN` contain special IEEE values (*resp.* Infinity and Not-a-Number).

FML also defines the following global variables:

- `integer` variables:

`STDERR`  
`STDIN`  
`STDOUT`

which can be modified either directly by the user, or via the `msSetStdIO` routine.

- `logical` variables: `MF_NUMERICAL_CHECK` which allows the user to tell Muesli to do additional checks.

The available routines have been arranged into sub-parts:

[Core Routines](#)

[File Input/Output](#)

[Data Analysis Functions](#)

[Operators](#)

[Elementary Math Functions](#)

[Specialized Math Functions](#)

[Elementary Matrix Manipulation Functions](#)

[Matrix Functions](#)

[Polynomial Functions](#)

[Optimization and Function Functions](#)

[Sparse Matrices.](#)

## 1.1 Core Routines

<code>mfArray</code>	automatic and dynamic array ( <i>derived type</i> )
<code>mf</code>	mfArray conversion
<code>=, msAssign</code>	mfArray assignment
<code>msSet, mfGet</code>	mfArray data modification and extraction
<code>mfCount</code>	true values count
<code>msDisplay</code>	mfArray pretty print
<code>mfDisplayColumns</code>	columns used in pretty print
<code>msFormat</code>	mfArray printing format
<code>msRelease</code>	MUESLI objects deallocation
<code>msAutoRelease</code>	mfArray conditional deallocation
<code>mfOut</code>	groups output arguments
<code>mf_Out</code>	set of output arguments ( <i>derived type</i> )
<code>msPointer, msFreePointer</code>	smart pointer between f90 array and mfArray
<code>mfNbPointers</code>	nb of f90 pointers pointing to an mfArray
<code>msEquiv</code>	smart pointer between mfArray and f90 array
<code>mf_Int_List</code>	list of integers ( <i>derived type</i> )
<code>mf_Real_List</code>	list of reals ( <i>derived type</i> )
<code>mfIsEmpty</code>	mfArray empty test
<code>mfIsEqual, mfIsNotEqual</code>	mfArray equality test
<code>mfIsLogical</code>	mfArray boolean test
<code>mfIsReal</code>	mfArray real test
<code>mfIsComplex</code>	mfArray complex test
<code>mfIsNumeric</code>	mfArray numeric test
<code>mfIsDense</code>	mfArray dense storage test
<code>mfIsSparse</code>	mfArray sparsity test
<code>mfIsScalar, mfIsVector, mfIsMatrix</code>	mfArray scalar, vector and matrix test
<code>mfIsRow, mfIsColumn</code>	mfArray kind of vector test
<code>mfIsPerm</code>	mfArray permutation vector test
<code>All, Any</code>	test on boolean mfArray
<code>Shape, mfShape</code>	shape of an mfArray
<code>Size, mfSize</code>	size of an mfArray
<code>mfInt</code>	scalar integer conversion
<code>mfDble</code>	scalar real conversion
<code>mfCmplx</code>	scalar complex conversion
<code>mfGetMsgLevel, msSetMsgLevel</code>	message level tuning
<code>mfGetTrbLevel, msSetTrbLevel</code>	error traceback tuning
<code>msSetColoredMsg</code>	colorize Muesli messages on terminal
<code>msPrintColoredMsg</code>	print a colored user message on terminal
<code>msSetTermColor</code>	set color for printing on terminal
<code>msMuesliTrace</code>	helper for debugging purpose
<code>msGetStdIO, msSetStdIO</code>	usual logical unit inquiry and modification
<code>msFlush</code>	I/O flush
<code>msPause</code>	user pause or timing pause
<code>msSetTermWidth, mfGetTermWidth</code>	set and get terminal character width
<code>msSetAutoFilling, mfGetAutoFilling</code>	set and get out-of-range filling by msSet
<code>msInitArgs, msFreeArgs</code>	mfArray arguments' protection and release
<code>msSetAsParameter</code>	data protection
<code>msReturnArray, mfIsTempoArray</code>	mark and check temporary mfArray
<code>msFlops, mfFlops</code>	nb of floating-point operations
<code>mfIsFlopsOk</code>	inquire if flops is available

<a href="#">mfGetAutoComplex</a> , <a href="#">msSetAutoComplex</a>	conversion to complex
<a href="#">msEnableFPE</a> , <a href="#">msDisableFPE</a>	run-time floating-point exceptions trapping
<a href="#">mfGetRoundingMode</a> , <a href="#">msSetRoundingMode</a>	floating-point rounding mode
<a href="#">MF_NUMERICAL_CHECK</a>	debugging additional checks
<a href="#">mfUnit</a>	physical unit ( <i>derived type</i> )
<a href="#">msUsePhysUnits</a>	Physical units activation
<a href="#">msSetPhysDim</a>	set physical unit
<a href="#">msSetPhysUnitAbbrev</a>	set user physical unit abbreviation
<a href="#">mfHasNoPhysDim</a>	dimensionless test
<a href="#">mfHaveSamePhysDim</a>	dimension equality test
<a href="#">msPrepHashes</a>	hashes print preparation
<a href="#">msPrintHashes</a>	hashes print
<a href="#">msPostHashes</a>	hashes print conclusion
<a href="#">msPrepProgress</a>	percent progress preparation
<a href="#">msPrintProgress</a>	percent progress
<a href="#">msPostProgress</a>	percent progress conclusion
<a href="#">mfReadLine</a>	read a line from terminal with editing and history facilities
<a href="#">msReadHistoryFile</a>	read a 'readline' history file
<a href="#">msWriteHistoryFile</a>	write the 'readline' history in a file
<a href="#">msClearHistory</a>	clear the 'readline' history
<a href="#">msAddEntryInHistory</a>	add an entry in the 'readline' history
<a href="#">msRemoveLastEntryInHistory</a>	remove last entry in the 'readline' history
<a href="#">mfToLower</a>	lowering string's case
<a href="#">mfToUpper</a>	uppering string's case
<a href="#">msFindIOUnit</a>	automatically find a free IO unit number
<a href="#">mfIsVersion</a>	test on version strings
<a href="#">msRequMuesliVer</a>	check for a minimum Muesli version
<a href="#">MF_MUESLI_VERSION</a>	MUESLI version
<a href="#">MF_COMPILER_VERSION</a>	COMPILER version
<a href="#">MF_COMPILATION_CONFIG</a>	Configuration used to compile MUESLI

See also:

- [File Input/Output](#)
- [Data Analysis Functions](#)
- [Operators](#)
- [Elementary Math Functions](#)
- [Specialized Math Functions](#)
- [Elementary Matrix Manipulation Functions](#)
- [Matrix Functions](#)
- [Polynomial Functions](#)
- [Optimization and Function Functions](#)
- [Sparse Matrices](#)

**mfArray** automatic and dynamic array (*derived type*)*Description:*

This is the fundamental derived type in MUESLI. Declaration must be made as follows:

```
type(mfArray) :: A
```

This derived type may contain real or complex numerical values, using a dense or sparse storage. All numerical values are stored in *double precision*, *i. e.* use 8 bytes of memory.

Special data types are:

- permutation vector (integer vector)
- boolean values (in dense storage only)

All possible data types are summarized in figure 1.

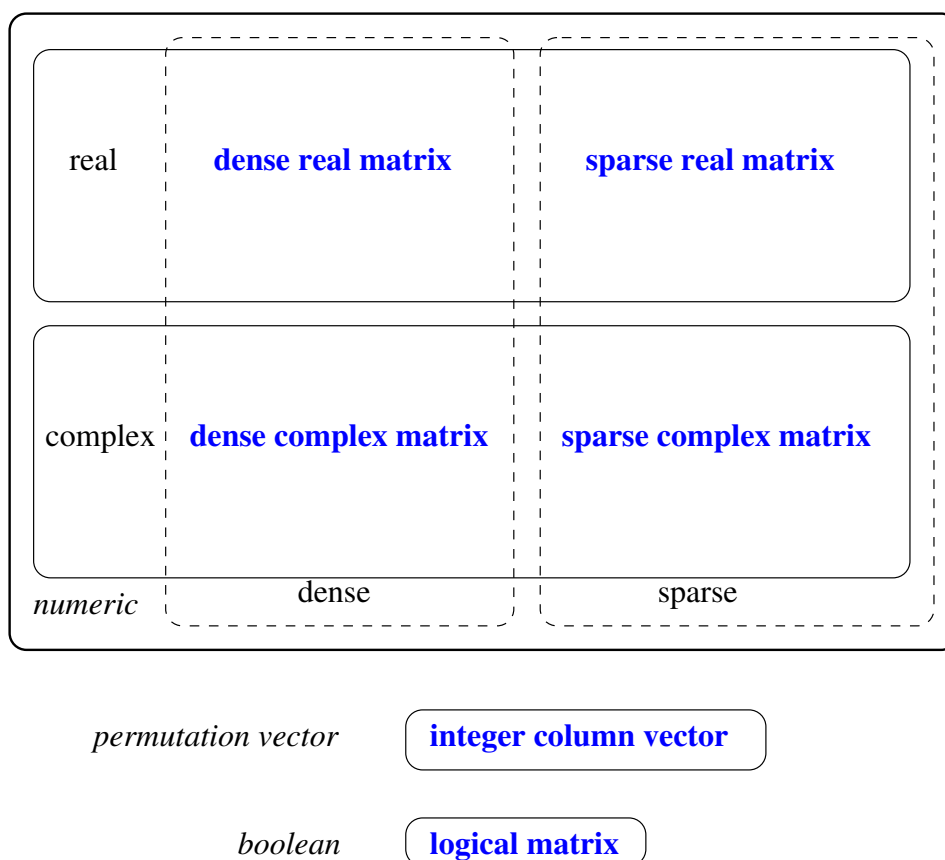


Figure 1: `mfArray` data types

The data type stored in a `mfArray` may be retrieved by the following inquiring functions: `mfIsReal`, `mfIsComplex`, `mfIsDense`, `mfIsSparse`, `mfIsNumeric`, `mfIsPerm`, `mfIsLogical`.

*See also:* `mf`, `msRelease`, `msPointer`, `msEquiv`, `msSaveAscii`



**mf****mfArray conversion***Description:*

This function initializes and returns a temporary `mfArray` from some common Fortran types: integer, real (single or double), complex (single or double), of rank 0 to 2 (scalar, vector or matrix).

For example:

```
mf( [ 1, 3, 5, 7, 11 ] )
```

```
mf( [ 1.3, 2.05, -5.1e-3 ] )
```

Whatever the argument type of `mf` (*integer, single precision real, double precision real*), all numerical numbers are stored in `mfArrays` as `double precision`.

By default, this function creates row vectors, so use the following syntax if you want a column vector (avoiding an unnecessary copy):

```
mf( [ 1, 3, 5, 7, 11 ], transpose=.true. )
```

This latter optional transposition works also for matrices. By default, the transposition is not used (see examples below).

See also: `mfArray`

*Example(s):*

```
real(kind=MF_DOUBLE) :: tab(2,4)
tab(:,:) = reshape( [(1.5d0*i,i=1,8)], [2,4] )
A = mf( tab )
call msDisplay( A, "A" )
At = mf( tab, transpose=.true. )
call msDisplay( At, "At" )
```

output:

A =

```
1.5000    4.5000    7.5000   10.5000
3.0000    6.0000    9.0000   12.0000
```

At =

```
1.5000    3.0000
4.5000    6.0000
7.5000    9.0000
10.5000   12.0000
```

**=** **mfArray assignment**

This Fortran operator has been overloaded in MUESLI to make working with `mfArray` easy.

For example, you can assign any numerical object to `A`, as simply as:

```
A = [ 1, 2, 3, 4, 5 ]
```

The right hand side (*RHS*) can be of type boolean, integer, real (single or double) or complex (single or double), of rank 0 to 2 (scalar, vector or matrix), or of course `mfArray`.

As the allocation of data is automatic during assignment, you should free each `mfArray` as soon as possible (via the `msRelease` routine), in order to decrease the memory usage.

Sometimes, you could be warned that an assignment is inefficient, when the *RHS* is a temporary `mfArray`. In such a case, you could use the `msAssign` routine instead.

Besides, MUESLI allows to assign a dense `mfArray` `A` to a boolean, an integer, a real or a complex. So, a statement like:

```
f90_obj = A
```

is valid under the following assumptions:

- shapes (of *LHS* and *RHS*) must match;
- types must be consistent (*i.e.* numeric `mfArrays` can be assigned to integer or real f90 arrays whereas boolean `mfArrays` must be assigned to logical f90 arrays — `mfArrays` data types are defined in figure 1).

See also: `msPointer`, `msEquiv`

**msAssign****more efficient mfArray assignment***Interface:*

```
subroutine msAssign( dest, source )  
  
    type(mfArray), intent(in) :: source  
    type(mfArray)           :: dest
```

*Description:*

Ordinarily, you should use the simple = form of assignment. The `msAssign` routine is intended to make it efficiently, when the *RHS* is a temporary `mfArray`.

For example, you should write:

```
call msAssign( C, A + B )
```

which avoids a copy of the data contained in `A + B` (an internal pointer is used instead). In comparison, the statement:

```
C = A + B
```

involves such a copy.

*See also:* =

## msSet

## mfArray data modification

*Generic Calling syntax:*

```
call msSet( data, x, a1 [, a2] )
```

*Description:*

This routine is used to modify some elements of the `mfArray` `x`. The indices of these elements are specified by `a1` and `a2` for array sections, or only by `a1` for scattered elements in the whole array (in this case, `a1` is a long-column-index vector).

If `a2` is not present, the `mfArray` `x` may be a vector, because only one index is given to specify which elements have to be changed. Note that if the index `a1` (or `a2`) is out of range, the shape of `x` is modified accordingly, *i. e.* the array is extended (see the remarks at the end of this section).

If `a1` (or `a2`) is a vector, more than one element can be modified; moreover, this vector doesn't need to contain consecutive indices.

If the modification affects more than one element, and if `data` contains only one value, this latter value is spread across all the target elements.

`data` may be of type `real`, `complex` or `mfArray`. It doesn't need to be of same data type as `x`. A conversion is then made, and concerns either `data` or `x`, according to the type.

Usually `a1` and `a2` are integers (scalar or vector), but they may be of type `mfArray` (in this latter case, they cannot be matrices).

In the special case where `a1` (or `a2`) is `MF_COLON` (or its alias `MF_ALL`), then all the specified row(s) (or column(s)) are simultaneously modified. If `data` is empty (*i. e.* equal to `MF_EMPTY`, but only for a dense `mfArray` `x`), then the specified row(s) or column(s) are deleted.

`a1` and/or `a2` may be also special integer sequences, written under the form

```
  i1 .to. i2 [.by. i3]
or i1 .by. i3 .to. i2

[ ( i, i = i1, i2 [, i3] ) ]
```

(The operator named `'step.'` is an alias for `'by.'`)

These special integer sequences can be combined as

```
  int_seq .and. int_seq
or int_seq .but. i1
```

The step `i3` is taken equal to 1 if it is not present. Note that `a1`, `a2`, `i1` and `i2` may also be replaced by an expression using `MF_END` (*e. g.* `MF_END-1`) which is an automatic alias for the end value of the corresponding dimension. Be aware that arithmetic involving `MF_END` can use only addition or subtraction.

Finally, the `mfArray` `x` cannot be temporary.

⋯/⋯

*Remarks:*

- to initialize a whole `mfArray` with 0 or 1, the following routines are available: `mfZeros` and `mfOnes`.
- when the `mfArray` `x` has a sparse structure, `data` may be a scalar or a vector (dense or sparse). In such a case, only whole columns of `x` may be modified. Modifying one element is however allowed, in so far as indices of this element are not out of range (see below, however).
- when the `mfArray` `x` has a dense structure, `data` cannot be sparse.
- not all combinations for the types of `a1` and `a2` are valid. Use preferently the same type for these two arguments.
- out-of-range indices are accepted, except when a long-column index is used. For the dense storage, the `mfArray` is reallocated to the right shape. A message of kind “info” is however emitted (see `msSetMsgLevel`). During the reallocation, the new elements not targeted are initialized by a predefined value (see below). For the sparse storage, the assignment is done only if the value of `nzmax` is sufficient (see `msSpReAlloc`), and, of course, no new elements are added, apart those explicitly targeted by the command.
- the predefined value used to fill the out-of-range indices is by default the *NaN* (special *IEEE* number), but this can be changed by use of the `msSetAutoFilling` routine.

*See also:*`mfGet`

**mfGet****mfArray data extraction**

*Generic Calling syntax:*

```
mfGet( x, a1 [, a2] )
```

*Description:*

This routine extracts some elements (described by the indices **a1** and **a2**, or — when **x** is a matrix — only by the long-column index **a1**) of the **mfArray** **x** and returns them in an **mfArray**. Note that if the index **a1** (or **a2**) is out of range, an error results and an empty **mfArray** is returned.

If **a1** (or **a2**) is a vector, more than one element are extracted; moreover, this vector doesn't need to contain consecutive indices.

Usually **a1** and **a2** are integers (scalar or vector), but they may be of type real or boolean **mfArray**.

In the special case where **a1** (resp. **a2**) is **MF\_COLON** (or its alias **MF\_ALL**), then all the specified columns (resp. rows) are extracted.

**a1** and/or **a2** may be special integer sequences, written under the form

```
  i1 .to. i2 [.by. i3]
or i1 .by. i3 .to. i2

[ ( i, i = i1, i2 [, i3] ) ]
```

(The operator named `‘.step.’` is an alias for `‘.by.’`)

These special integer sequences can be combined as

```
  int_seq .and. int_seq
or int_seq .but. i1
```

The step **i3** is taken equal to 1 if it is not present. Note that **a1**, **a2**, **i1** and **i2** may also be replaced by an expression using **MF\_END** (*e. g.* **MF\_END-1**) which is an automatic alias for the end value of the corresponding dimension. Be aware that arithmetic involving **MF\_END** can use only addition or subtraction.

*Remarks:* Sparse **mfArrays** are partially supported:

- this routine can extract a scalar value, a row or a column, or a submatrix; in this latter case, the submatrix must be contiguous;
- when extracting rows, the indices for these rows must be contiguous (this limitation doesn't hold when extracting columns);
- the above mentioned special integer sequences (built via the `.to.` and `.by.` operators) cannot be used (not yet) for indices **a1** or **a2**;
- when extracting a single row or a single column, resulted **mfArray** has a dense structure.

*See also:* **msSet**

**mfCount****true values count***Interface:*

```

function mfCount( A, dim ) result( out )

    type(mfArray), intent(in) :: A
    integer, intent(in), optional :: dim
    type(mfArray) :: out

```

*Description:*

Returns the number of true values in the columns (or rows) of a boolean `mfArray` (dense or sparse).

If `dim` is present, `A` is always considered as a matrix, and the routine processes each column (if `dim = 1`) or each row (if `dim = 2`).

If `dim` is not present, it returns the number of true values in the whole array.

When `out` is a vector, it is dense.

The behavior of this routine is similar to the *count* Fortran 90 intrinsic function.

*Example(s):*

```

x = mfMagic( 3 )
call msDisplay( x, "x" )
call msDisplay( mfCount(x>5.0d0), "mfCount( x > 5.0d0 )" )
call msDisplay( mfCount(x>4.0d0,dim=1), "mfCount( x > 4.0d0, dim=1 )" )
call msDisplay( mfCount(x>4.0d0,dim=2), "mfCount( x > 4.0d0, dim=2 )" )

```

output:

x =

```

  8   3   4
  1   5   9
  6   7   2

```

mfCount( x &gt; 5.0d0 ) =

4

mfCount( x &gt; 5.0d0, dim=1 ) =

```

  2   1   1

```

mfCount( x &gt; 4.0d0, dim=2 ) =

```

  1
  2
  2

```

## msDisplay

## mfArray pretty print

First calling syntax:

```
call msDisplay( x1 [, string1, x2, string2, ...]           &
                [, unit ] [, head ] [, tail ] )
```

This routine displays an **mfArray** object (and other object types, as described below) on the screen or terminal, in a pretty form which is column oriented. Not all the decimal digits are printed: their number depends on the format used.

The object **x** may also be: a Fortran type, integer, real (single or double), complex (single or double), of rank 0 to 2 (scalar, vector or matrix); a MUESLI derived type, **mfUnit** and **mf\_Int\_List**.

Only for **mfArrays**:

- up to four pairs ( **x**, **string** ) can be simultaneously displayed.
- if the optional integer argument **head** (resp. **tail**) is present, then only the first (resp. last) rows will be printed. These two arguments can be both present. This convenience is useful to see the begin and the end of a very long column vector. For the case of a long row vector, it will display the **head** first values, followed by the **tail** last values, but only if the width of your terminal is sufficient. Internal tests are made about consistency between **head**, **tail** and the shape of the array.

For **mfArrays** (not boolean) and **mfUnits**, the optional argument **unit** allows the user to specify another consistent (*i. e.* of same physical dimension) unit for printing. For example, a length registered in meter (S.I. unit) may be printed in millimeter. The use of the constant parameter **SI\_unit** enforces the routine to display, if possible, the appropriate S.I. unit.

Only for **mf\_Int\_Lists** and vectors of **mf\_Int\_List**:

- only one pair ( **x**, **string** ) can be displayed at a time.
- an additional optional boolean argument (**compact**) may be used to print the integers rows more compactly.

Second calling syntax:

```
call msDisplay( x, string, legend1 [, legend2, ..., legend9 ] )
```

This latter syntax enables the insertion of legends at the head of each column. Note the maximum number possible, 9, and also that it is restricted to real data in the **x** **mfArray**.

*N.B.:* When displaying an object having a great number of columns, this routine will print first the number of columns adapted to the width of your terminal. If the output is redirected to a file, you may want to change this width: then use the **MF\_COLUMNS** environment variable (it is the terminal character width, like in the UNIX command **resize**, and not the matrix column's number).

See also: **msFormat**, **mfDisplayColumns**

*Example(s):* Many outputs from this routine are shown as examples in the *MUESLI User Guide*.



**mfDisplayColumns****columns used in pretty print***Interface:*

```
function mfDisplayColumns( A, unit ) result( out )  
  
  type(mfArray), intent(in) :: A  
  type(mfUnit), intent(in), optional :: unit  
  type(mfArray) :: out
```

*Description:*

**mfDisplayColumns** returns the number of elements printed by the routine **msDisplay** on each row.

*See also:* [msDisplay](#)

**msFormat****mfArray printing format**

*Calling syntax:*

```
call msFormat( [ mantissa, exponent ] )
```

The optional argument `mantissa` may be "short" (5 digits printed), "long" (15 digits printed) or "hex" (hexadecimal output). By default, the short format is used.

The optional argument `exponent` may be:

- "auto" (automatic format: fixed or exponential format);
- "sci" (scientific format: exponent is always printed);
- "eng" (engineer format: if the `mfArray` to be displayed is not a scalar, a scale factor is always used and its exponent is moreover a multiple of three).

By default, the automatic format is used.

In the case where this routine is called without any argument, default values for both keywords are used.

See also: [msDisplay](#)

*Example(s):*

```
x = .t. mfSqrt( mf([ 2, 3, 5 ]) )
call msDisplay( x, "x (short format)" )
call msFormat( "long" )
call msDisplay( x, "x (long format)" )
```

output:

```
x (short format) =

  1.4142
  1.7321
  2.2361
```

```
x (long format) =
```

```
1.41421356237310
1.73205080756888
2.23606797749979
```

```
x = [ 1.5, 2.6E1, 3.7E2, 4.8E4 ]
call msFormat( exponent="sci" )
call msDisplay( x, "x (scientific format)" )
call msFormat( exponent="eng" )
call msDisplay( x, "x (engineer format)" )
```

output:

```
x (scientific format) =

  1.5000E+00  2.6000E+01  3.7000E+02  4.8000E+04

x (engineer format) =

  1.0E+03 *

  0.0015   0.0260   0.3700  48.0000
```

**msRelease****MUESLI objects deallocation**

When you have finished to work with an `mfArray`, you may deallocate its internal array by using:

```
call msRelease( x1 [, x2, x3, x4, x5, x6, x7 ] )
```

Up to seven `mfArrays` can be simultaneously released.

*Remark:* After execution of your program, some compilers or tools may report a warning about some memory leaks. Use of this routine for all of the automatic variables (described below) avoids such warnings.

This routine can be used to free the following derived types: `mfArray`, `mfMatFactor`, `mfTriConnect`, `mfTetraConnect`, `mf_Int_List`, `mf_NL.Options` and `mf_DE.Options` (only one variable may be freed at a time, except for an `mfArray` object).

*See also:* `msAutoRelease`, `msSetAsParameter`, `msExitFgl`

**msAutoRelease****mfArray conditional deallocation**

This routine is similar to `msRelease`:

```
call msAutoRelease( x1 [ , x2, x3, x4, x5, x6, x7 ] )
```

but the deallocation is done only if the `mfArray` is temporary.

Is is used only in the context of a user-routine which takes arguments of type `mfArray` which can be temporary objects.

*See also:* [msRelease](#)

**mfOut****group output arguments**

This function is used to group output arguments in calls of some MUESLI subroutines. For example:

```
call msLU( mfOut(L,U,p), A )
```

This facility is only intended to clearly identify the output arguments from the input ones. It is reminiscent of the Matlab syntax:

```
[L,U,p] = lu( A )
```

Arguments of `mfOut` match always the following MUESLI derived types: `mfArray` or `mfMatFactor`.

*Case of optional arguments:* If some of these arguments are optional, they must be called in order, not by use of keyword as in Fortran 90 syntax. Moreover, for multiple optional arguments, one of them can be omitted by using the special `mfArray MF_NO_ARG`, as in the following example:

```
call msOdeSolve( mfOut( y, status, tolout, MF_NO_ARG, solve_log),      &  
                deriv, t_span, y_0 )
```

Indeed, referring to the `msOdeSolve` routine, the `yp` and `solve_log` are both optional, and if the user wants to retrieve only the second one, he has to use `MF_NO_ARG` instead of `yp`.

*Remarks:* actually, the `mfOut` function returns an object of type `mf_Out`. You don't need to use this latter derived type unless you want to define yourself new routines which use `mfOut` to group output arguments.

*See also:* `mfArray`, `mfMatFactor`, `mf_Out`

**mf\_Out****set of output arguments (*derived type*)***Description:*

This is a derived type in MUESLI. You need to employ this type only if you wish to define yourself subroutines whose output arguments are grouped with the **mfOut** function.

*See also:* **mfArray**, **mfOut**

**msPointer** **smart pointer between f90 array and mfArray**

*Generic Interface:*

```
subroutine msPointer( A, f90_ptr )

  type(mfArray) :: A

  real(kind=MF_DOUBLE), pointer :: f90_ptr(:,:)
  or complex(kind=MF_DOUBLE), pointer :: f90_ptr(:,:)
```

*Description:*

This routine is approximately equivalent to:

```
f90_ptr => A
```

and then, you can access the internal data of **A** via a classical Fortran array. This association is not always possible, because the types of **A** and **f90\_ptr** must match. Ranks however doesn't need to match: you may have a rank-1 array pointing to a rank-2 array; in this latter case, we could see **f90\_ptr** as a "long column pointer".

**A** cannot be temporary, because at any time it can be deleted, and then **f90\_ptr** would become hanging.

*Warning:*

During all the time when **f90\_ptr** points to **A**, some internal properties of **A** are locked. So, it is strongly recommended to use the routine **msFreePointer**: (i) to nullify the pointer **f90\_ptr** and (ii) to unlock properties of **A**. Be aware that

```
f90_ptr => null()
```

is not sufficient (this way will not unlock the internal **mfArray** properties of **A**).

*See also:* [mfNbPointers](#), [msFreePointer](#), [msEquiv](#)

**msFreePointer****smart pointer release***Generic Interface:*

```
subroutine msFreePointer( A, f90_ptr )

  type(mfArray) :: A

  real(kind=MF_DOUBLE), pointer :: f90_ptr(:,:)
or complex(kind=MF_DOUBLE), pointer :: f90_ptr(:,:)
```

*Description:*

This routine releases the link made by `msPointer`, and unlocks the internal properties of A.

*See also:* [mfNbPointers](#), [msPointer](#)



`mfNbPointers` **nb of f90 pointers pointing to an mfArray**

*Generic Interface:*

```
function mfNbPointers( A ) result( n )
```

```
    type(mfArray) :: A
```

```
    integer       :: n
```

*Description:*

This routine returns the number of Fortran 90 pointers pointing to A.

*See also:* [msPointer](#), [msFreePointer](#)

**msEquiv** smart pointer between mfArray and f90 array*Generic Interface:*

```
subroutine msEquiv( f90_array, A )  
  
    real(kind=MF_DOUBLE), target :: f90_array(:, :)  
    or complex(kind=MF_DOUBLE), target :: f90_array(:, :)  
  
    type(mfArray) :: A
```

*Description:*

This routine is approximately equivalent to

```
A => f90_array
```

but the mfArray A becomes *restricted*, in the sense that you can modify the data but not the shape of your f90\_array, nor its allocation status. As a consequence, you can use most of (but not all) MUESLI routines to work with your f90\_array, via the mfArray A.

When f90\_array is a rank-1 array (here, renamed as f90\_vector), the mfArray A is by default a column vector. Use the optional argument `new_shape` to specify the new virtual dimensions of A, as follows:

```
call msEquiv( f90_vector, A, new_shape=[n1,n2] )
```

Of course, you must have consistence, *i. e.* the product  $n_1 n_2$  must be equal to the number of elements of f90\_vector.

*Remark:*

To release the link between A and f90\_array, you *must* use the `msRelease` routine. Don't write

```
A => null()
```

because usually A is not a pointer, it is just a derived type, *i. e.* a structure which includes the numerical data in a manner that is hidden to the user. Even if A has been declared as a pointer to an mfArray, this is not the good way to release properly A). If you forget to release this link, you could obtain an error when trying an assignment with A.

*See also:* `msPointer`

**mf\_Int\_List****list of integers (*derived type*)***Description:*

This is a derived type in MUESLI. You may employ it for storing a list of integers of arbitrary length. Its definition is:

```

type, public :: mf_Int_List
  integer, allocatable :: list(:)
end type mf_Int_List

```

You must allocate yourself the internal component `list`, which is an ordinary Fortran array of integers. Also, you may declare and use an array of `mf_Int_List`, which is useful to work with a set of varying length lists (see the second example below).

`msDisplay` and `msRelease` routines may be used to, respectively, print and free this derived type. These two routines can be also used with an array of `mf_Int_List`.

*Example(s):*

```

! type(mf_Int_List) :: int_list
allocate( int_list%list(7) )
int_list%list(:) = [ (i, i = 1, 7) ]
call msDisplay( int_list, "int_list" )
! call msRelease( int_list )

```

output:

int\_list =

1 2 3 4 5 6 7

```

! type(mf_Int_List) :: int_list_vec(5)
n = 6
allocate( int_list_vec(1)%list(n) )
int_list_vec(1)%list(:) = [ (i, i = 1, n) ]
n = 15
allocate( int_list_vec(3)%list(n) )
int_list_vec(3)%list(:) = [ (i, i = 100+1, 100+n) ]
n = 9
allocate( int_list_vec(5)%list(n) )
int_list_vec(5)%list(:) = [ (i, i = 100000+1, 100000+n) ]
call msDisplay( int_list_vec, "int_list_vec" )
! call msRelease( int_list_vec )

```

output:

int\_list\_vec =

1 2 3 4 5 6

&lt;EMPTY&gt;

101 102 103 104 105 106 107 108 109 110 111 112 113 114 115

&lt;EMPTY&gt;

100001 100002 100003 100004 100005 100006 100007 100008 100009

**mf\_Real\_List****list of reals (*derived type*)***Description:*

This is a derived type in MUESLI. You may employ it for storing a list of reals of arbitrary length. It's definition is:

```

type, public :: mf_Real_List
  integer, allocatable :: list(:)
end type mf_Real_List

```

You must allocate yourself the internal component `list`, which is an ordinary Fortran array of reals. Also, you may declare and use an array of `mf_Real_List`, which is useful to work with a set of varying length lists (see the second example below).

`msDisplay` and `msRelease` routines may be used to, respectively, print and free this derived type. These two routines can be also used with an array of `mf_Real_List`.

*Example(s):*

```

! type(mf_Real_List) :: real_list
allocate( real_list%list(7) )
real_list%list(:) = [ (i+0.5d0, i = 1, 7) ]
call msDisplay( real_list, "real_list" )
! call msRelease( real_list )

```

output:

int\_list =

1.500 2.500 3.500 4.500 5.500 6.500 7.500

```

! type(mf_Real_List) :: int_real_vec(5)
n = 6
allocate( real_list_vec(1)%list(n) )
real_list_vec(1)%list(:) = [ (i+0.5d0, i = 1, n) ]
n = 11
allocate( real_list_vec(3)%list(n) )
real_list_vec(3)%list(:) = [ (i+0.5d0, i = 10+1, 10+n) ]
n = 9
allocate( real_list_vec(5)%list(n) )
real_list_vec(5)%list(:) = [ (i+0.5d0, i = 100+1, 100+n) ]
call msDisplay( real_list_vec, "int_list_vec" )
! call msRelease( real_list_vec )

```

output:

int\_list\_vec =

1.500 2.500 3.500 4.500 5.500 6.500

&lt;EMPTY&gt;

11.500 12.500 13.500 14.500 15.500 16.500 17.500 18.500 19.500 20.500 21.500

&lt;EMPTY&gt;

101.500 102.500 103.500 104.500 105.500 106.500 107.500 108.500 109.500

**mfIsEmpty****mfArray empty test***Interface:*

```
function mfIsEmpty( A ) result( bool )  
  
  type(mfArray), intent(in) :: A  
  logical :: bool
```

*Description:*

Tests if the **mfArray** **A** is empty, *i. e.* has a null size (number of rows multiplied by number of columns).

Note that an sparse matrix (non empty) may have a number of nonzero elements (see **mfNnz**) that is zero.

*See also:* [Shape](#), [Size](#)

**mfIsEqual****mfArray equality test***Interface:*

```
function mfIsEqual( A1, A2 ) result( bool )  
  
    type(mfArray), intent(in) :: A1, A2  
    logical :: bool
```

*Description:*

Tests if two **mfArrays** are numerically equal, whatever the structure is (*i. e.* sparse or dense, real or complex). The shapes can even mismatch, and can take the zero value.

Comparison between boolean **mfArray** are excluded: **All** combined with `.eqv.` should be used instead.

*Remarks:* This function returns a scalar logical, whereas `'=='` returns a boolean **mfArray**.

For example:

```
mfIsEqual( A1, A2 )
```

is equivalent to:

```
All( A1 == A2 )
```

but the former statement is much more efficient for sparse **mfArrays**.

*See also:* `==`, **All**, **mfAll**, `.eqv.`

**mfIsNotEqual****mfArray equality test***Interface:*

```
function mfIsNotEqual( A1, A2 ) result( bool )  
  
  type(mfArray), intent(in) :: A1, A2  
  logical :: bool
```

*Description:*

Returns the negation of `mfIsEqual(A1,A2)`.

*See also:* [mfIsEqual](#)

**mfIsLogical****mfArray boolean test***Interface:*

```
function mfIsLogical( A ) result( bool )  
  
    type(mfArray), intent(in) :: A  
    logical :: bool
```

*Description:*

Returns `.true.` if the `mfArray` `A` is boolean, *i. e.* if `A` results from any boolean operation (`'=='`, `'>`, *etc.*) on `mfArrays`.

*See also:* `==`



**mfIsReal****mfArray real test***Interface:*

```
function mfIsReal( A ) result( bool )  
  
    type(mfArray), intent(in) :: A  
    logical :: bool
```

*Description:*

Returns `.true.` if the `mfArray` `A` is numeric, but not complex. The internal structure of `A` may be dense or sparse.

*See also:* [mfIsNumeric](#), [mfIsComplex](#)

mfIsComplex

mfArray complex test

*Interface:*

```
function mfIsComplex( A ) result( bool )
```

```
    type(mfArray), intent(in) :: A
```

```
    logical :: bool
```

*Description:*

Returns `.true.` if the `mfArray` `A` is numeric and complex. The internal structure of `A` may be dense or sparse.

*See also:* [mfIsNumeric](#), [mfIsReal](#)

**mfIsNumeric****mfArray numeric test***Interface:*

```
function mfIsNumeric( A ) result( bool )  
  
    type(mfArray), intent(in) :: A  
    logical :: bool
```

*Description:*

Returns `.true.` if the `mfArray` `A` is numeric (real or complex). The internal structure of `A` may be dense or sparse.

*See also:* [mfIsReal](#), [mfIsComplex](#)

**mfIsDense****mfArray dense storage test***Interface:*

```
function mfIsDense( A ) result( bool )  
  
    type(mfArray), intent(in) :: A  
    logical :: bool
```

*Description:*

Returns `.true.` if internal structure of **A** is dense. The data may be boolean, real or complex.

*See also:* [mfIsSparse](#)

**mfIsSparse****mfArray sparsity test***Interface:*

```
function mfIsSparse( A ) result( bool )  
  
    type(mfArray), intent(in) :: A  
    logical :: bool
```

*Description:*

Returns `.true.` if internal structure of **A** is sparse. The data may be real or complex.

*See also:* [mfIsDense](#)

**mfIsScalar****mfArray scalar test***Interface:*

```
function mfIsScalar( A ) result( bool )  
  
    type(mfArray), intent(in) :: A  
    logical :: bool
```

*Description:*

Returns `.true.` if A is a scalar.

See also: [mfIsVector](#), [mfIsMatrix](#)

**mfIsVector****mfArray vector test***Interface:*

```
function mfIsVector( A ) result( bool )  
  
    type(mfArray), intent(in) :: A  
    logical :: bool
```

*Description:*

Returns `.true.` if A is a vector.

*Remark:* A scalar is not a vector, neither a matrix.

*See also:* [mfIsScalar](#), [mfIsMatrix](#), [mfIsRow](#), [mfIsColumn](#)

**mfIsMatrix****mfArray vector test***Interface:*

```
function mfIsMatrix( A ) result( bool )  
  
    type(mfArray), intent(in) :: A  
    logical :: bool
```

*Description:*

Returns `.true.` if A is a matrix.

*Remark:* A vector is not a matrix.

*See also:* [mfIsScalar](#), [mfIsVector](#)



**mfIsRow****mfArray kind of vector test***Interface:*

```
function mfIsRow( A ) result( bool )  
  
    type(mfArray), intent(in) :: A  
    logical :: bool
```

*Description:*

Returns `.true.` if A is a row vector.

See also: [mfIsVector](#), [mfIsColumn](#)

**mfIsColumn****mfArray kind of vector test***Interface:*

```
function mfIsColumn( A ) result( bool )  
  
    type(mfArray), intent(in) :: A  
    logical :: bool
```

*Description:*

Returns `.true.` if A is a column vector.

*See also:* [mfIsVector](#), [mfIsRow](#)

**mfIsPerm****mfArray permutation vector test***Interface:*

```
function mfIsPerm( A ) result( bool )  
  
    type(mfArray), intent(in) :: A  
    logical :: bool
```

*Description:*

Returns `.true.` if A has the type “permutation vector”.

To make a real checking for a valid permutation, use [mfCheckPerm](#).

*See also:* [mfIsLogical](#), [mfIsNumeric](#)

All

test on boolean mfArray

*Interface:*

```
function All( A ) result( bool )  
  
  type(mfArray), intent(in) :: A  
  logical :: bool
```

*Description:*

Returns `.true.` if all elements of the `mfArray` `A` are *TRUE* (therefore, `A` must be a boolean `mfArray`).

*See also:* [mfAll](#), [Any](#)

**Any****test on boolean mfArray***Interface:*

```
function Any( A ) result( bool )  
  
    type(mfArray), intent(in) :: A  
    logical :: bool
```

*Description:*

Returns `.true.` if at least one element of the `mfArray` `A` is `TRUE` (therefore, `A` must be a boolean `mfArray`).

*See also:* [mfAny](#), [All](#)

Shape, mfShape

shape of an mfArray

*First interface:*

```
function Shape( A ) result( out )  
  
    type(mfArray), intent(in) :: A  
    integer :: out(2)
```

*Description:*

Returns the shape of the `mfArray` `A` (dense or sparse); the returned integer array is always of rank 2, because `A` is a matrix.

*Other interface:*

```
function Shape( Qhouse ) result( out )  
  
    type(mfMatFactor), intent(in) :: Qhouse  
    integer :: out(2)
```

*Description:*

Returns the shape of the `mfMatFactor` `Qhouse`, which comes from the **QR** decomposition of a sparse matrix; the returned integer array is always of rank 2, because an `A` is a matrix.

*Remark:* the `mfShape` routine is similar, but returns an `mfArray` instead.

*See also:* [Size](#), [mfMatFactor](#)

Size, mfSize

size of an mfArray

*First interface:*

```
function Size( A, idim ) result( out )

    type(mfArray), intent(in) :: A
    integer, intent(in), optional :: idim
    integer :: out
```

*Description:*

If `idim` is not present, returns the total number of elements of the `mfArray` `A` (dense or sparse).

If `idim` is present (1 or 2), returns the specified dimension.

*Other interface:*

```
function Size( A, idim ) result( out )

    type(mfMatFactor), intent(in) :: A
    integer, intent(in), optional :: idim
    integer :: out
```

*Description:*

If `idim` is not present, returns the total number of elements of the `mfMatFactor` `A` (which comes from some decomposition of a sparse matrix).

If `idim` is present (1 or 2), returns the specified dimension.

*Remarks:*

- the `mfSize` routine is similar, but returns an `mfArray` instead;
- for a sparse matrix, the size returned includes the zero elements: it is the logical size, not the physical size; so, for any storage kind, the size is always the product of the two dimensions returned by `shape`. Use the `mfNnz` routine to get the number of non zeros.

See also: [Shape](#)

**mfInt****scalar integer conversion***Interface:*

```
function mfInt( A ) result( out )  
  
    type(mfArray), intent(in) :: A  
    integer :: out
```

*Description:*

This routine is a facility to convert a scalar `mfArray` `A` in an ordinary f90 integer.

A warning is emitted during conversion, in case of loss of precision.

*See also:* [mfDble](#), [mfCmplx](#)



**mfDble****scalar real conversion***Interface:*

```
function mfDble( A ) result( out )  
  
    type(mfArray), intent(in) :: A  
    real(kind=MF_DOUBLE) :: out
```

*Description:*

This routine is a facility to convert a scalar `mfArray` `A` in an ordinary `f90` real.

If `A` is complex, returns only the real part.

*See also:* [mfInt](#), [mfCmplx](#)

**mfCmplx****scalar complex conversion***Interface:*

```
function mfCmplx( A ) result( out )  
  
    type(mfArray), intent(in) :: A  
    complex(kind=MF_DOUBLE) :: out
```

*Description:*

This routine is a facility to convert a scalar `mfArray` `A` in a complex.

*See also:* [mfInt](#), [mfDble](#)

**mfGetMsgLevel****message level tuning***Calling syntax:*

```
level = mfGetMsgLevel( )
```

returns an integer, ranged from 0 to 3, which is the current message level. See the [msSetMsgLevel](#) routine for a description of the message level.

*See also:* [mfGetTrbLevel](#), [msSetTrbLevel](#), [msMuesliTrace](#)

**msSetMsgLevel****message level tuning**

*Calling syntax:*

```
call msSetMsgLevel( level )
```

where `level` is an integer, ranged from 0 to 3, which specifies the message level, described as follows:

- message level = 3: all messages are printed (verbose mode)
- message level = 2: messages of kind 'ERROR' and 'Warning' are printed [default]
- message level = 1: only messages of kind 'ERROR' are printed
- message level = 0: nothing is printed (quiet mode)

There exists three kinds of messages emitted by the MUESLI library; they are tagged as “info”, “Warning” and “ERROR”. Only the last kind (the most important) stops temporarily the run-time execution via a “pause” statement, which requires the action of the user to resume the execution. The cause of these errors are generally due to a programming fault; this is the reason why the program stops.

As usual for *IEEE-754* arithmetic, floating-point exceptions give *Inf* and *NaN* values which quietly propagate. See [msEnableFPE](#) to change this default behavior.

*N.B.:* when message level is equal to 0, programming errors (of kind “ERROR”) kill the program. This may be useful when the executable must be launched via a batch system.

*See also:* [mfGetMsgLevel](#), [mfGetTrbLevel](#), [msSetTrbLevel](#), [msMuesliTrace](#)

**mfGetTrbLevel****error traceback tuning***Calling syntax:*

```
when = mfGetTrbLevel( )
```

returns a `character(len=4)`, which is the current error traceback policy. See the `msSetTrbLevel` routine for a description of the error traceback policy.

*See also:* `mfGetMsgLevel`, `msSetMsgLevel`, `msMuesliTrace`

`msSetTrbLevel`

error traceback tuning

*Calling syntax:*

```
call msSetTrbLevel( when | level )
```

where `when` is a `character(len=4)` which specifies the error traceback policy, described as follows:

- `when = "all"`: error traceback is produced for all kind of messages (*i. e.* ERRORS, Warnings and infos)
- `when = "auto"`: error traceback is produced only for ERRORS [default]
- `when = "none"`: no error traceback

An alternative is to use the integer `level` argument, which can be equal to 0, 1, 2 or 3. A message level which is greater than or equal to `level` triggers the traceback. For example, when `level` is used with the value 2, only messages of kind 'ERROR' and 'Warning' produce a traceback.

*N.B.:* not all compilers are able to produce an error traceback on demand. See the *MUESLI Inside* document for more information.

*See also:* `mfGetTrbLevel`, `mfGetMsgLevel`, `msSetMsgLevel`, `msMuesliTrace`

**msSetColorMsg****colorize messages on terminal***Calling syntax:*

```
call msSetColorMsg( "on" | "off" )
```

*Description:*

Colorizes all the Muesli messages written on the terminal. Four colours are used:

- red for the ERRORS;
- orange for the Warnings;
- yellow for the infos;
- grey-italic for the traceback.

Disabling the colors are useful before redirecting the program output to a file. Default is "on".

*See also:* [mfGetMsgLevel](#), [msSetMsgLevel](#), [msMuesliTrace](#)

`msPrintColoredMsg` **print a colored user message on terminal**

*Interface:*

```
subroutine msPrintColoredMsg( fmt, msg, color )  
    character(len=*), intent(in) :: fmt, msg, color
```

*Description:*

Prints the string `msg` in this `color` and using format `fmt`.

Colors are limited to the following ones: "green", "red", "orange", "yellow" and "grey".

*See also:* [msSetTermColor](#)



`msSetTermColor`**set color for printing on terminal***Interface:*

```
subroutine msSetTermColor( color )  
  
character(len=*), intent(in) :: color
```

*Description:*

Sets the color for printing user message with `msPrintColoredMsg`.

Colors are limited to the following ones: "green", "red", "orange", "yellow" and "grey".

To revert to the default color, set color to "normal".

**msGetStdIO****usual logical unit inquiry***Interface:*

```
subroutine msGetStdIO( stdin, stdout, stderr )  
  
integer, intent(out), optional :: stdin, stdout, stderr
```

*Description:*

Gets the Fortran unit for `stdin` (usually 5), `stdout` (usually 6) and `stderr` (usually 0).

*See also:* [msSetStdIO](#)

**msSetStdIO****usual logical unit modification***Interface:*

```
subroutine msSetStdIO( stdin, stdout, stderr )  
  
    integer, intent(in), optional :: stdin, stdout, stderr
```

*Description:*

Used to change the Fortran units.

*See also:* [msGetStdIO](#)

**msFlush****I/O flush***Interface:*

```
subroutine msFlush( unit )  
    integer, intent(in) :: unit
```

*Description:*

Flushes the I/O unit `unit`.

**msPause****user pause or timing pause***Calling syntax:*

```
call msPause( [message] [, duration] )
```

If the optional argument **message** is present (**character(len=\*)**), this routine prints the message and waits for a [RETURN] from the user.

If the optional argument **duration** is present (**real**), this routine sleeps for the specified number of seconds. If this second argument is alone, the keyword **duration=** must appear in front of it.

**msSetTermWidth****set terminal character width***Syntax:*

```
call msSetTermWidth( width | "auto" )
```

*Description:*

Set manually the character width of the terminal, for pretty print with the `msDisplay` routine. The argument `width` must be an integer greater than 40.

If the character string `"auto"` is used as argument, then the character width of the terminal will be determined automatically, either from the `MF_COLUMNS` environment variable, or from the actual value (using the `'resize'` shell command).

*See also:* [mfGetTermWidth](#), [msDisplay](#), [mfDisplayColumns](#)

`mfGetTermWidth`**get terminal character width***Interface:*

```
function mfGetTermWidth() result ( out )  
  
    integer :: out
```

*Description:*

Get the character width of the terminal. The returned value is actually an internal value used for pretty print in the `msDisplay` routine. This last value is obtained from:

- first, the value set manually via the `msSetTermWidth` routine;
- then, from the `MF_COLUMNS` environment variable;
- last, via the ‘resize’ Unix command; if this latter command is not available on your system, an information message is displayed and the default value 80 is used.

*See also:* [msSetTermWidth](#), [msDisplay](#), [mfDisplayColumns](#)

**msSetAutoFilling****set out-of-range filling by msSet***Syntax:*

```
call msSetAutoFilling( r )
```

*Description:*

Set manually the value of the real used to fill the elements of an `mfArray` by `msSet` when the indices are out-of-range.

Default value is the special *IEEE* number *NaN*, which means *Not-a-Number*.

*See also:* `mfGetAutoFilling`



**mfGetAutoFilling****get out-of-range filling by msSet***Interface:*

```
function mfGetAutoFilling() result ( r )  
  
    real(kind=MF_DOUBLE) :: r
```

*Description:*

Get the value of the real used to fill the elements of an `mfArray` by `msSet` when the indices are out-of-range.

Default value is the special *IEEE* number *NaN*, which means *Not-a-Number*, but this number may be changed by use of `msSetAutoFilling`.

**msInitArgs****mfArray arguments' protection***Interface:*

```
subroutine msInitArgs( x1,                                &
                      x2, x3, x4, x5, x6, x7 )

type(mfArray) :: x1
type(mfArray), optional :: x2, x3, x4, x5, x6, x7
```

*Description:*

Inside a user-defined routine, this routine protects some `mfArray` arguments against a (library) deallocation, in case where they are temporary.

This routine should always be paired with the other routine `msFreeArgs`.

msFreeArgs

mfArray arguments' release

*Interface:*

```
subroutine msFreeArgs( x1,                                &
                      x2, x3, x4, x5, x6, x7 )

type(mfArray) :: x1
type(mfArray), optional :: x2, x3, x4, x5, x6, x7
```

*Description:*

Inside a user-defined routine, this routine ends the argument's protection set by `msInitArgs`.

This routine should always be paired with the other routine `msInitArgs`.

**msSetAsParameter****data protection***Interface:*

```
subroutine msSetAsParameter( x1, x2, x3, x4, x5, x6, x7, param )

  type(mfArray)           :: x1
  type(mfArray), optional :: x2, x3, x4, x5, x6, x7
  logical                 :: param
```

*Description:*

When used with “`param=.true.`”, protects the data (and type) inside each `mfArrays`. Lets the user creating pseudo parameters `mfArrays`, because the Fortran attribute *parameter* cannot be used in any circumstances.

Up to seven `mfArrays` can be simultaneously set.

Before freeing an `mfArray` via the `msRelease` routine, the user must apply `msSetAsParameter` with “`param=.false.`”.

Of course, by default, an `mfArray` is not data-protected.

**msReturnArray****temporary mfArray mark***Interface:*

```
subroutine msReturnArray( A )  
  
    type(mfArray) :: A
```

*Description:*

At the end of a user-defined function returning an `mfArray`, marks this object as temporary.

Avoids memory leaks during the execution of your program.

*See also:* [msInitArgs](#), [msFreeArgs](#), [mfIsTempoArray](#)

**mfIsTempoArray****temporary mfArray check***Interface:*

```
function mfIsTempoArray( A ) result( bool )  
  
  type(mfArray), intent(in) :: A  
  logical :: bool
```

*Description:*

Check if the mfArray A is marked as temporary.

See also: [msInitArgs](#), [msFreeArgs](#), [msReturnArray](#)

**msFlops****nb of floating-point operations***Interface:*

```
subroutine msFlops( count )  
  
integer*8, intent(out) :: count
```

*Description:*

Returns the number of floating-point operations made by the processor, since the last initialization.

Initialization must be made by:

```
call msFlops( init=0 )
```

The other call:

```
call msFlops( count )
```

returns the flops count since the initialization.

`count`  $\geq 0$ , except if the program has been linked with the dummy version of PAPI (`dummy_papi.o`), or if the OS doesn't support hardware counting (*e.g.* the linux kernel has not been patched for use of the PERFCTR library); in the latter case, `msFlops` always returns the value `-1`.

*Remarks:* requires a specific version of the PAPI library (cf. in `papi/version`)

*See also:* [mfFlops](#), [mfIsFlopsOk](#)

**mfFlops****nb of floating-point operations***Calling syntax:*

```
count = mfFlops( )
```

*Description:*

Returns the number of floating-point operations made by the processor, since the last initialization, in the `mfArray` count.

Initialization must be made by:

```
call msFlops( init=0 )
```

`count`  $\geq 0$ , except if the program has been linked with the dummy version of PAPI (`dummy_papi.o`), or if the OS doesn't support hardware counting (*e.g.* the linux kernel has not been patched for use of the PERFCTR library); in the latter case, `mfFlops` always returns the value  $-1$ .

*Remarks:* requires a specific version of the PAPI library (cf. in `papi/version`)

*See also:* [msFlops](#), [mfIsFlopsOk](#)



**mfIsFlopsOk****inquire if flops is available***Calling syntax:*

```
bool = mfIsFlopsOk( )
```

*Description:*

Returns a `logical` revealing the availability of the `mfFlops` routine.

*See also:* [mfFlops](#), [msFlops](#)

**msSetAutoComplex****set auto conversion to complex***Syntax:*

```
call msSetAutoComplex( .true. | .false. )
```

*Description:*

By default, real `mfArrays` are automatically converted in complex when operation like  $\sqrt{-1}$  are made.

When calling this routine with argument equal to `.false.`, conversion to complex is not done, then resulting to a special *IEEE* value (*Inf* or *NaN*, according to the operation used).

*See also:* [mfGetAutoComplex](#)

`mfGetAutoComplex`**get auto conversion to complex***Interface:*

```
function mfGetAutoComplex() result( bool )  
  
logical, intent(in) :: bool
```

*Description:*

Returns a boolean specifying whether MUESLI convert real to complex for some operation (like  $\sqrt{-1}$ ).

*See also:* [msSetAutoComplex](#)

`msEnableFPE`

run-time floating-point exceptions trapping

*Interface:*

```
subroutine msEnableFPE( exception, full_trapping )

character(len=*), intent(in)          :: exception
logical,          intent(in), optional :: full_trapping
```

*Description:*

Enables, at run-time, the trapping for a given floating-point exception, *i. e.* the program stops when the specified exception(s) is (are) encountered.

exception may be one of: "overflow", "zero\_divide", "invalid", "underflow" or "usual\_exceptions".

"usual\_exceptions" is a shortcut for the main three traditional exceptions: "overflow", "zero\_divide", "invalid".

full\_trapping is an optional argument which allows the trapping inside the MUESLI library sources (default is `.false.`). Note that this features is usually reserved to the MUESLI developpers.

*Remark:* The call may be located anywhere in the program. Usually, it is added at the beginning of the program. However, exceptions' trapping may be added or removed later on.

*See also:* `msDisableFPE`

**msDisableFPE****run-time floating-point exceptions trapping***Interface:*

```
subroutine msDisableFPE( exception )  
  
character(len=*), intent(in) :: exception
```

*Description:*

Disables, at run-time, the trapping for a given floating-point exception, *i. e.* the program doesn't stop when the specified exception(s) is (are) encountered, but produces accordingly *Infs* and *NaNs*.

`exception` may be one of: `"overflow"`, `"zero_divide"`, `"invalid"`, `"underflow"` or `"usual_exceptions"`.

`"usual_exceptions"` is a shortcut for the main three traditional exceptions: `"overflow"`, `"zero_divide"`, `"invalid"`.

*See also:* [msEnableFPE](#)

`mfGetRoundingMode`

floating-point rounding mode

*Calling syntax:*

```
rounding_mode = mfGetRoundingMode( )
```

*Description:*

Returns the floating-point rounding mode in a character string. The *IEEE-754* rounding mode may be equal to:

- "to\_zero": *IEEE-754* rounding to zero
- "nearest": *IEEE-754* rounding to nearest
- "up": *IEEE-754* rounding to pos. infinity
- "down": *IEEE-754* rounding to neg. infinity

See also: [msSetRoundingMode](#)

**msSetRoundingMode****floating-point rounding mode***Interface:*

```
subroutine msSetRoundingMode( rounding_mode )  
  
character(len=*) :: rounding_mode
```

*Description:*

Set the floating-point rounding mode to the specified mode. The *IEEE-754* rounding mode may be equal to:

- "to\_zero": *IEEE-754* rounding to zero
- "nearest": *IEEE-754* rounding to nearest
- "up": *IEEE-754* rounding to pos. infinity
- "down": *IEEE-754* rounding to neg. infinity

*Warning:* The ISO/IEC TR 15580:1998(E) Technical Report, concerning the behavior of Fortran programs, specifies (Section 2.4): “In a procedure, the processor ensures that the flags for rounding have the same values on return as on entry.” In the current MUESLI implementation, the rounding mode is set via a C routine, and can violate the preceding requirement; then the use of the `msSetRoundingMode` routine is left to the programmer responsibility.

*See also:* `mfGetRoundingMode`

MF\_NUMERICAL\_CHECK

debugging additional checks

*Interface:*

```
logical :: MF_NUMERICAL_CHECK
```

*Description:*

This logical global variable is used by the library to do additional checks (validity of certain results, presence of *NaN* and, if required, precision of the jacobian matrix provided by the user, ...).

When Muesli is compiled in *DEBUG* mode (usually by the developers of Muesli), this variable is initially set to *TRUE*. Otherwise, for ordinary users of the library (which certainly compile it in *OPTIM* mode), it is initially set to *FALSE*.

For debugging purpose, you can set its value temporarily to *TRUE*, especially when using the ODE/DAE solvers ([msOdesolve](#), [msDaesolve](#)), or the minimization routines ([mf/msLsqNonLin](#)).

*See also:* [mf.DE.Options](#)



**mfUnit****physical unit (*derived type*)***Description:*

The Fortran derived type `mfUnit` (hidden) contains some usual physical units and constants. It can be used to initialize the physical unit of an `mfArray`, via the operators `*` and `=`.

No declarations has to be done. Instead, the program may refer to some predefined `mfUnits`, as *e.g.*:

```
y = 0.25d0*u_kg
```

```
v = 0.10d0*c_speed_of_light
```

*Remarks:*

- see the *MUESLI User Guide* document for a complete list of the available physical units, physical constants and multipliers.
- physical units begin with `'u_'`, multipliers begin with `'m_'`, whereas physical constants begin with `'c_'`.

*See also:* `*`, `=`, `msUsePhysUnits`, `msSetPhysDim`, `mfHasNoPhysDim`, `mfHaveSamePhysDim`

`msUsePhysUnits`**Physical units activation***Interface:*

```
subroutine msUsePhysUnits( mode )  
  
    character(len=*), intent(in) :: mode
```

*Description:*

Activates or de-activates the computation of physical units; `mode` must be "on" or "off".

Default is "off".

*See also:* [mfUnit](#), [msSetPhysDim](#)

## msSetPhysDim

## set physical unit

The first interface:

```
subroutine msSetPhysDim( A,                               &
                        Mass, Length, Time,              &
                        Temp, Electr_Intens, Mole, Lumin )

type(mfArray), intent(in out) :: A
real(kind=MF_DOUBLE), intent(in), optional :: Mass,      &
                                             Length,      &
                                             Time,        &
                                             Temp,        &
                                             Electr_Intens, &
                                             Mole,        &
                                             Lumin
```

is used for setting the physical unit of the `mfArray` `A`, from some basic physical quantities.

The second interface:

```
subroutine msSetPhysDim( A, B )

type(mfArray), intent(in out) :: A
type(mfArray), intent(in) :: B
```

allows the user to set the physical unit of the `mfArray` `A`, by copying that of the `mfArray` `B`.

*See also:* [mfUnit](#), [msUsePhysUnits](#), [mfHasNoPhysDim](#), [mfHaveSamePhysDim](#)

**msSetPhysUnitAbbrev****set user physical unit abbreviation***Interface:*

```
subroutine msSetPhysUnitAbbrev( user_unit, abbrev )
```

```
    type(mfUnit) :: user_unit
```

```
    character(len=*) :: abbrev
```

is used for setting the abbreviation of a user physical unit.

*See also:* [mfUnit](#), [msUsePhysUnits](#),

**mfHasNoPhysDim****dimensionless test***Interface:*

```
function mfHasNoPhysDim( A ) result( bool )  
  
    type(mfArray), intent(in) :: A  
    logical :: bool
```

*Description:*

Tests if the mfArray A is dimensionless.

*See also:* [mfUnit](#), [msUsePhysUnits](#), [msSetPhysDim](#) [mfHaveSamePhysDim](#)

**mfHaveSamePhysDim****dimension equality test***Interface:*

```
function mfHaveSamePhysDim( A, B ) result( bool )  
  
    type(mfArray), intent(in) :: A, B  
    logical :: bool
```

*Description:*

Tests if the `mfArrays` A and B have the same physical dimensions.

*See also:* [mfUnit](#), [msUsePhysUnits](#), [msSetPhysDim](#), [mfHasNoPhysDim](#)

**msPrepHashes****hashes print preparation***Calling syntax:*

```
call msPrepHashes( start, end )
```

*Description:*

Prepares data before calls to `msPrintHashes`.

`start` and `end` are numerical values used to monitor the progress bar. They must be both of integer or real (double) type.

*See also:* [msPrintHashes](#), [msPostHashes](#)

**msPrintHashes****hashes print**

*Calling syntax:*

```
call msPrintHashes( val )
```

*Description:*

Makes on the terminal a progress bar by printing hashes (#).

Usually, the call is located inside a loop; `val` is the numerical value (either integer or real double) monitoring the progression. It's numerical extremum values have to be passed as arguments of `msPrepHashes`.

*See also:* `msPostHashes`, `msPrintProgress`

*Example(s):*

```
integer :: i_start, i_end, i
...
call msPrepHashes( i_start, i_end )
do i = i_start, i_end
  ...
  <some computation>
  ...
  call msPrintHashes( i )
end do
call msPostHashes( )
```

or:

```
double precision :: time_start, time_end, time
...
call msPrepHashes( time_start, time_end )
time = time_start
do while( time <= time_end)
  ...
  <some computation>
  ...
  call msPrintHashes( time )
  time = <new value of time, increasing but may be not linear with iterations>
end do
call msPostHashes( )
```



**msPostHashes****hashes print conclusion***Calling syntax:*

```
subroutine msPostHashes()
```

*Description:*

Should be added after the loop containing the call to `msPrintHashes`.

*See also:* [msPrepHashes](#), [msPrintHashes](#)

**msPrepProgress****percent progress preparation***Calling syntax:*

```
call msPrepProgress( start, end [, disp_times, estimator] )
```

*Description:*

Prepares data before calls to `msPrintProgress`.

`start` and `end` are numerical values used to monitor the progress bar. They must be both of integer or real (double) type.

If the logical optional argument `disp_times` is set to `.false.`, time values (left time and estimated remaining time – wall clock time is used, not CPU time) are not displayed (default is `TRUE`).

The string optional argument `estimator` prescribes the method to be used to estimate the remaining time. Default is "GLE" (Global Linear Estimator), which corresponds to a fast method but with the assumption of a linear behavior of the cost along all the iterations. The other available method is "LPE" (Local Power Estimator), which involves a Least Square problem, and assumes that the behavior of the cost is under a power form; this latter method is more expensive but should work well with a larger class of problems than "GLE".

*See also:* [msPrintProgress](#), [msPostProgress](#)

**msPrintProgress****percent progress***Calling syntax:*

```
call msPrintProgress( val )
```

*Description:*

Print on STDOUT the percentage of the work already done. According to the setting used during initialization via `msPrepProgress`, the estimated remaining time may also be displayed.

Usually, the call is located inside a loop (at the end); `val` is the numerical value (either integer or real double) monitoring the progression. It's numerical extremum values have to be passed as arguments of `msPrepProgress`.

See also: `msPostProgress`, `msPrintHashes`

*Example(s):*

```
integer :: i_start, i_end, i
...
call msPrepProgress( i_start, i_end )
do i = i_start, i_end
  ...
  <some computation>
  ...
  call msPrintProgress( i )
end do
call msPostProgress( )
```

or:

```
double precision :: time_start, time_end, time
...
call msPrepProgress( time_start, time_end )
time = time_start
do while( time <= time_end)
  ...
  <some computation>
  ...
  call msPrintProgress( time )
  time = <new value of time, increasing but may be not linear with iterations>
end do
call msPostProgress( )
```

**msPostProgress****percent progress conclusion***Interface:*

```
subroutine msPostProgress()
```

*Description:*

Should be added after the loop containing the call to `msPrintProgress`.

*See also:* [msPrepProgress](#), [msPrintProgress](#)

**mfToLower****lowering string's case***Calling syntax:*

```
s2 = mfToLower( s1 )
```

*Description:*

Returns the input strings **s1** with each letter converted to lower case.

*See also:* [mfToUpper](#)

**mfToUpper****uppering string's case***Calling syntax:*

```
s2 = mfToUpper( s1 )
```

*Description:*

Returns the input strings **s1** with each letter converted to upper case.

*See also:* [mfToLower](#)

**msFindIOUnit****automatically find a free IO unit number***Interface:*

```
subroutine msFindIOUnit( unit )  
  
integer, intent(out) :: unit
```

*Description:*

Returns an integer IO unit which can be used for opening a file.

**mfIsVersion****test on version strings***Calling syntax:*

```
bool = mfIsVersion( v_1, op, v_2 )
```

*Description:*

Compares the two version strings `v_1` and `v_2` with the operator `op` ("`==`", "`>`", "`>=`", "`<`", "`<=`"). The version string is a character string, of size at most 8, matching the rule `a.b.c`, where `a`, `b` and `c` are integers ranged from 0 to 99.

This function returns a logical and is usually applied to strings as `MF_MUESLI_VERSION` or `MF_LAPACK_VERSION`.

*See also:* `msRequMuesliVer`



`msRequMuesliVer`

check for a minimum Muesli version

*Interface:*

```
subroutine msRequMuesliVer( version )  
  
character(len=*) :: version
```

*Description:*

Checks that the current Muesli version used at run-time is at least equal to that provided in the "version" argument. This argument must be a string of the form a.b.c, where a, b and c are integers ranged from 0 to 99.

*See also:* [MF\\_MUESLI\\_VERSION](#), [mfIsVersion](#)

MF\_COMPILER\_VERSION

**compiler vendor and version***Calling syntax:*

```
string = MF_COMPILER_VERSION
```

returns the compiler vendor and version used during the compilation of the MUESLI library.

*See also:* [MF\\_MUESLI\\_VERSION](#), [MF\\_COMPILATION\\_CONFIG](#), [MF\\_LAPACK\\_VERSION](#)

MF\_COMPILATION\_CONFIG

Configuration used to compile MUESLI

*Calling syntax:*

```
string = MF_COMPILATION_CONFIG()
```

returns either "Debug" or "Optim".

**Note** the parenthesis used after the name of the variable, because it is implemented as a function.

*See also:* [MF\\_MUESLI\\_VERSION](#), [MF\\_COMPILER\\_VERSION](#), [MF\\_LAPACK\\_VERSION](#)

**MF\_MUESLI\_VERSION****MUESLI version***Calling syntax:*

```
string = MF_MUESLI_VERSION
```

returns the MUESLI version used during the link of the executable.

The returned `string` may be used by the `mfIsVersion` boolean function.

*See also:* [MF\\_COMPILER\\_VERSION](#), [MF\\_COMPILATION\\_CONFIG](#), [MF\\_LAPACK\\_VERSION](#)

**msMuesliTrace****helper for debugging purpose***Interface:*

```
subroutine msMuesliTrace( pause )  
  
    character(len=*), intent(in) :: pause
```

*Description:* Basically, this subroutine helps the user by printing, if available, a traceback of the program; optionally, it can make a pause (only if the `pause` argument is equal to "yes").

Contrary to the internal traceback routine, the behavior of this routine depends only on the value of the *message level* global MUESLI property.

*Remark:* In order to be useful, the use of this routine requires that the Muesli library has been compiled with debugging turned *On*. This is the case if the library is used in the *DEBUG* mode. On the contrary, it suffices that the user adds the appropriate option (*e.g.* `-g` for most of compilers) for its own source files.

*See also:* [mfGetMsgLevel](#), [msSetMsgLevel](#)

**mfReadLine**        **reads a line from terminal with editing and history facilities**

*Interface:*

```
function mfReadLine( prompt ) result( string )  
  
    character(len=*), intent(in), optional :: prompt  
    character(len=1024) :: res
```

*Description:* This function prompts the string `prompt` and waits the user to input a character string, using the readline library. As a result, the user can navigate in an history, recall any previous input and modify it.

It returns the string `string`, which is automatically added in the history only if it differs from the last entry.

The history can be saved with the use of the `msWriteHistoryFile` routine.

A small example of call can be found in the *Muesli User's Guide*.

See also:        `msReadHistoryFile`,        `msClearHistory`,        `msAddEntryInHistory`,  
`msRemoveLastEntryInHistory`

**msReadHistoryFile****read a 'readline' history file***Interface:*

```
subroutine msReadHistoryFile( filename )  
  
    character(len=*), intent(in), optional :: filename
```

*Description:* Reads an 'history' file previously stored by the `msWriteHistoryFile` routine.

If the optional `filename` is not present, 'history' is read from the file: `/.mfreadline.history`

*See also:* `mfReadLine`, `msClearHistory`, `msAddEntryInHistory`, `msRemoveLastEntryInHistory`

**msWriteHistoryFile****write a 'readline' history file***Interface:*

```
subroutine msWriteHistoryFile( filename )  
  
    character(len=*), intent(in), optional :: filename
```

*Description:* Writes an 'history' file in filename. This 'history' contains all entries read by the `mfReadLine` routine.

*See also:* `msReadHistoryFile`, `msClearHistory`, `msAddEntryInHistory`, `msRemoveLastEntryInHistory`



**msClearHistory****clear the 'readline' history***Interface:*

```
subroutine msClearHistory( )
```

*Description:* Clears all entries read by the [mfReadLine](#) routine.*See also:* [msReadHistoryFile](#), [msWriteHistoryFile](#), [msAddEntryInHistory](#),  
[msRemoveLastEntryInHistory](#)

**msAddEntryInHistory****add an entry in the 'readline' history***Interface:*

```
subroutine msAddEntryInHistory( string )  
  
character(len=*) :: string
```

*Description:* Adds the entry specified by the `string` argument in the 'readline' history.*See also:* [mfReadLine](#), [msReadHistoryFile](#), [msWriteHistoryFile](#), [msClearHistory](#), [msRemoveLastEntryInHistory](#)

`msRemoveLastEntryInHistory`            **remove last entry in the 'readline' history**

*Interface:*

```
subroutine msRemoveLastEntryInHistory( )
```

*Description:* Remove last entry read by the `mfReadLine` routine.

*See also:* `msReadHistoryFile`, `msWriteHistoryFile`, `msClearHistory`, `msAddEntryInHistory`

## 1.2 File Input/Output

<a href="#">msSaveAscii</a>	ASCII file saving
<a href="#">mfLoadAscii</a>	ASCII file loading
<a href="#">msSaveSparse</a>	Sparse ASCII file saving
<a href="#">mfLoadSparse</a>	Sparse ASCII file loading
<a href="#">msLoadSparse</a>	Sparse ASCII file (with Right-Hand-Side) loading
<a href="#">msSave</a>	Binary file saving
<a href="#">mfLoad</a>	Binary file loading
<a href="#">mfLoadTriConnect</a>	Connectivity Binary file loading
<a href="#">msSaveHDF5</a>	HDF5 file saving
<a href="#">mfLoadHDF5</a>	HDF5 file loading
<a href="#">msMedit</a>	graphic mfArray editor

*See also:*

[Core Routines](#)

[Data Analysis Functions](#)

[Operators](#)

[Elementary Math Functions](#)

[Specialized Math Functions](#)

[Elementary Matrix Manipulation Functions](#)

[Matrix Functions](#)

[Polynomial Functions](#)

[Optimization and Function Functions](#)

[Sparse Matrices](#)

## msSaveAscii

## ASCII file saving

*Interface:*

```
subroutine msSaveAscii( filename, A, append, format )

    character(len=*), intent(in)          :: filename
    type(mfArray),    intent(in)          :: A
    logical,          intent(in), optional :: append
    character(len=*), intent(in), optional :: format
```

*Description:*

Saves under ASCII form the dense `mfArray` `A` in the file named `filename`.

`A` is saved via a full 2D format, *i.e.* the number of lines of `filename` is exactly the number of rows of `A`. Special IEEE values (*NaN* and *Infs*) are written also in ASCII form (using the strings "NaN", "Infinity" and "-Infinity").

If the boolean `append` is present and *TRUE* then the data is written at the end of the (previously written) file. The default is to overwrite a pre-existing file.

If the character string `format` is present, it specifies the *Fortran format* used during the write of individual numbers (for example "E13.6"). It must be of course a non-empty valid format for writing numerical real values. As usual, if the format is not sufficient to write the required number of digits, stars will be printed out instead (for example, "F3.0" is the shortest format if your are sure that all numbers in the `mfArray` are integers; and even "F2.0" if they are all positive).

`msSaveAscii` doesn't store the internal properties of `A`, so writing a boolean `mfArray` converts it in real. Another limitation is that only the real part of complex numbers is written; to save the imaginary part, use:

```
call msSaveAscii( filename, mfImag(A) )
```

*Remarks:*

- if `A` contains a permutation, it will be written as a column vector, using integers (the optional argument `format` will be discarded). However, reading again the same file with `mfLoadAscii` will convert it into real numbers, as ordinary matrices; `msSave` is therefore recommended to save a permutation vector.
- to avoid loss of precision during the read of `filename`, a sufficient number of decimal digits is used to print each real when the optional argument `format` is not present.
- do not use the optional arguments `append` and `format` if you plan to read the file with `mfLoadAscii`.
- to save sparse matrices, use the `msSaveSparse` routine.

See also: `mfLoadAscii`, `msSave`, `msSaveHDF5`

## mfLoadAscii

## ASCII file loading

*Interface:*

```

function mfLoadAscii( filename,                                     &
                    ieee, comment, rect, row_max, col_max ) result( out )

    character(len=*) , intent(in)                               :: filename
    logical,          intent(in), optional :: ieee, rect
    character(len=1) , intent(in), optional :: comment
    integer,          intent(in), optional :: row_max, col_max

    type(mfArray) :: out

```

*Description:*

Reads data from an ASCII file named `filename` and copy it in an `mfArray`. Inside the file, numerical data are separated by one or more space(s) and tabulation(s). Usually, this file has been created by the `msSaveAscii` routine but actually, nearly all kinds of ASCII file may be read by `mfLoadAscii`: see below.

If `ieee` is present and equal to `.true.`, this routine is able to read special IEEE values, such as `NaN` and `Inf` (but this feature makes the read not very efficient for some compilers). The default behavior is to rise an error if any non numeric value is found.

If `comment` is present, all lines beginning (at any position) by this character are skipped (of course, this character must be different from: a space, a tabulation, a carriage-return, a digit, the signs `+` and `-`, the letters `I` and `N` which begin `Inf` and `NaN`); comments after data are also ignored. Empty lines are treated as commented. The default behavior assumes that the file contains only numerical values and no empty lines.

If `rect` is present and equal to `.false.`, the file read may contain data which are not under a rectangular layout. In this latter case, the routine returns a column vector `mfArray`. By default, this routine expects a rectangular layout, *i. e.* the same number of reals stored in each row.

For the standard case only (*i. e.*, `rect` is equal to `.true.`, or not present), the optional arguments `row_max` and `col_max` allow the user to read partially the data file. These two arguments are not dependent (and do not need to be both present). Note also that the whole data file may have a non-rectangular layout: it is sufficient that (`row_max`, `col_max`) covers a rectangular subpart of the data file.

*Remark:* DOS or UNIX text files are supported.

*See also:* [msSaveAscii](#), [mfLoad](#), [mfLoadHDF5](#)

## msSaveSparse

## Sparse ASCII file saving

*Interface:*

```
subroutine msSaveSparse( filename, A, format )

  character(len=*), intent(in) :: filename
  type(mfArray), intent(in) :: A
  character(len=3), intent(in), optional :: format
```

*Description:*

Saves the sparse matrix `mfArray A` in the file `filename`, using the (optionally) specified ASCII format:

- "CSC": Compact Sparse Column (default)

The first line contains exactly five items, which are the numbers of rows and columns (`nrow` and `ncol`), an integer (1 or 0) specifying whether the entries are row-sorted or not in each column, the tag "CSC" and the type of data ("real" or "complex");

the following line(s) contains the integer vector of the pointers to the columns;

the following line(s) contains the integer vector of the row indices;

the remaining line(s) contains the floating-point values.

- "CSR": Compact Sparse Row

Very close to the previous format, except that row and column role are exchanged.

- "HBO": Harwell-Boeing

A commonly used format for sparse matrices, described at: <http://math.nist.gov/MatrixMarket/formats.html#hb>

- "MTX": Matrix Market (also called "Coordinates format", or "COO")

A commonly used format for sparse matrices, described at: <http://math.nist.gov/MatrixMarket/formats.html#MMformat>

If `format` is not present, this routine uses the "CSC" format.

The routine always overwrites a pre-existing file.

*See also:* [mfLoadSparse](#)

## mfLoadSparse

## Sparse ASCII file loading

*Interface:*

```
function mfLoadSparse( filename, format, duplicated_entries ) result( out )

    character(len=*) , intent(in)           :: filename
    character(len=3) , intent(in), optional :: format
    character(len=*) , intent(in), optional :: duplicated_entries
    type(mfArray)    :: out
```

*Description:*

Reads the file `filename` and copy the sparse matrix it contains in an `mfArray`.

When reading the file, it uses the (optionally) specified ASCII format:

- "CSC": Compact Sparse Column
- "CSR": Compact Sparse Row
- "HBO": Harwell-Boeing (without Right Hand Side; on the contrary, use `msLoadSparse` instead)
- "MTX": Matrix Market (also called "Coordinates format", or "COO")

If `format` is not present, this routine tries to auto-detect the used format.

The description of these different formats can be found at the `msSaveSparse` entry.

After reading the matrix:

- eventual duplicated entries are treated according to the optional character argument `duplicated_entries`. When this argument is present and equal to "ignored", duplicated entries are ignored; when it is equal to "added" (default value), duplicated entries are added; when it is equal to "replaced", last entries found overwrite previous one.
- entries containing a null value are removed.

*See also:* `msLoadSparse`, `msSaveSparse`, `mfSpImport`



**msLoadSparse**                      **Sparse ASCII file (with Right-Hand-Side) loading**

*Calling syntax:*

```
call msLoadSparse( mfOut(A[,RHS]), filename [, format, duplicated_entries] )
```

*Description:*

Similar to **mfLoadSparse** but allows the user to retrieve a Right-Hand-Side (HBO format only) together with the sparse matrix.

The input arguments are described in the **mfLoadSparse** description.

A and RHS are both **mfArrays** and, after reading the file, contain respectively the sparse matrix and the Right-Hand-Side (dense or sparse, according to the file content).

*See also:* **mfLoadSparse**, **msSaveSparse**, **mfSpImport**

**msSave****Binary file saving***Interface:*

```
subroutine msSave( filename, A, compressed )

    character(len=*), intent(in) :: filename

    type(mfArray), intent(in) :: A
or type(mfTriConnect), intent(in) :: A

    logical, optional :: compressed
```

*Description:*

Saves under a binary form the `mfArray` (or `mfTriConnect`) `A` in the file named `filename`. The MUESLI Binary Format (MBF) used is specific to the current library. Any filename extension is supported; the ".mbf" used in the MUESLI examples just helps to remind that it is a MUESLI binary file.

If `compressed` is present and true, or if the specified filename ends with the extension ".gz", then `msSave` directly stores the file in the 'gzip' compressed format.

*Remarks:*

- to read the created file, you must use `mfLoad` (or `mfLoadTriConnect`), because a special format is used to organize data inside it. MUESLI add a special tag to help with compatibility between versions.
- `msSave` takes care of endianness of your architecture, so read/write this kind of file should be possible across big endian and little endian machines.
- `msSave` stores all the internal properties of `A`, including its dynamic type, structure and data, hidden matrix properties and physical units; so `mfLoad` (or `mfLoadTriConnect`) should restore exactly the same `mfArray` (but for sparse structure, internal arrays will have the minimal size).
- `msSave` always overwrites a pre-existing file.

See also: [msSaveAscii](#), [msSaveHDF5](#)

mfLoad

Binary file loading

*Interface:*

```
function mfLoad( filename ) result( out )  
  
    character(len=*) , intent(in) :: filename  
    type(mfArray) :: out
```

*Description:*

Reads a matrix previously stored in the file named `filename` (MUESLI Binary Format) by the routine `msSave`, and copy it in an `mfArray`.

This routine is able to read directly a compressed gzipped file, as stored by `msSave`.

*See also:* `mfLoadAscii`

mfLoadTriConnect

## Connectivity Binary file loading

*Interface:*

```
function mfLoadTriConnect( filename ) result( out )
```

```
character(len=*) , intent(in) :: filename
```

```
type(mfTriConnect) :: out
```

*Description:*

Reads a connectivity structure previously stored in the file named `filename` (MUESLI Binary Format) by the routine `msSave`, and copy it in an `mfArray`.

*See also:* `mfLoadAscii`

## msSaveHDF5

## HDF5 file saving

*Interface:*

```

subroutine msSaveHDF5( filename, A,                                &
                    name, file_access, mfarray_overwrite, status )

character(len=*), intent(in)          :: filename
type(mfArray),   intent(in)           :: A
character(len=*), intent(in), optional :: name
character(len=*), intent(in), optional :: file_access
logical,         intent(in), optional :: mfarray_overwrite
integer,        intent(out), optional :: status

```

*Description:*

By default (or if `file_access` is present and equal to "trunc"), this routine creates a new HDF5 file (or overwrites a pre-existing one) and writes the `mfArray` `A` (dense or sparse) in it.

If `file_access` is present and equal to "append", it tries to add in the existing HDF5 file a new group for `A`. In the case where a group with the same name already exists, the group will be overwritten only if `mfarray_overwrite` is present and equal to true; on the contrary, it will return a non zero value in the `status` flag (if this later optional argument is present).

The `mfArray` `A` is written as one group (named from the optional argument `name`, or "untitled `mfArray`" by default), with all its MUESLI properties, stored as group attributes.

The created file can be read in MUESLI by the routine `mfLoadHDF5`; moreover, it can be browsed by a specific viewer, as 'hdfview' for example.

*Remark:* No specific extension is required for the "filename", nevertheless ".h5" or ".hdf5" are often used.

*See also:* `msSave`, `msSaveAscii`

## mfLoadHDF5

## HDF5 file loading

*Interface:*

```
function mfLoadHDF5( filename, name ) result( out )

    character(len=*), intent(in)           :: filename
    character(len=*), intent(in), optional :: name
    type(mfArray)                          :: out
```

*Description:*

Reads from an HDF5 file and tries to find an `mfArray` named from the optional argument `name`. If this latter is not present, it tries to get the first group which has an attribute named `MF_MUESLI_VERSION`. It doesn't enter in any group: the searched `mfArray` must be located just under the root structure ("/") of the HDF5 file.

The file `filename` must have been created by `msSaveHDF5`.

*See also:* `mfLoad`, `mfLoadAscii`

**msMedit****graphic mfArray editor***Interface:*

```
subroutine msMedit( A )  
  
    type(mfArray), intent(in out) :: A
```

*Description:*

This routine allows the user to interactively modify a real **mfArray**, with a small graphical Matrix-editor.

Actually, it launch another X11 (Qt4-based) application, named ‘**meditor**’ (spreadsheet-like), which displays a table containing initially the matrix **A**. The user can modify the values and extend the shape of the matrix. When the window is closed, new data are automatically saved in the **mfArray A**.

Special IEEE values can be entered in cells, by typing their ASCII names, *NaN* and *Inf* (‘**meditor**’ is not case-sensitive). Bad entries are ignored.

To extend the matrix, click anywhere outside the matrix and enter a value (empty cells of the new matrix will be filled with 0).

*Remarks:*

- complex numeric matrices, or containing boolean values, are not accepted;
- if **A** is a sparse matrix, it is first converted to a dense one before display, but the new modified matrix will be converted back to sparse storage;
- the run of the ‘**meditor**’ tool blocks the calling program till it’s window is closed by the user;
- the size of **A** is limited to  $200 \times 200$ : it can be changed in the file ‘**meditor.cpp**’ if needed (of course, the ‘**meditor**’ tool has to be compiled again).

### 1.3 Data Analysis Functions

<code>mfMax</code> , <code>msMax</code>	<code>mfArray</code> max
<code>mfMin</code> , <code>msMin</code>	<code>mfArray</code> min
<code>mfSum</code>	columns sum
<code>mfExtrema</code>	data extrema
<code>mfProd</code>	columns product
<code>mfSort</code> , <code>msSort</code>	columns/rows sort
<code>mfIsSorted</code>	vector sort test
<code>mfSortRows</code>	sort whole rows of a matrix
<code>mfDiff</code>	difference and approximate derivative
<code>mfGradient</code>	approximate 1D gradient
<code>msGradient</code>	approximate 2D gradient
<code>mfMean</code>	columns mean
<code>mfMedian</code>	columns median
<code>mfVar</code>	columns variance
<code>mfStd</code>	columns standard deviation
<code>mfRMS</code>	root mean square
<code>msHist</code>	data histogram
<code>mfMoments</code>	few first moments of a distribution
<code>mfSmooth</code>	smoothing of vector values
<code>mfFFT</code> , <code>mfInvFFT</code>	discrete Fast Fourier transformation
<code>mfFFT2</code> , <code>mfInvFFT2</code>	2D discrete Fast Fourier transformation
<code>mfFourierCos</code> , <code>mfInvFourierCos</code>	discrete Fourier cosine transformation
<code>mfFourierSin</code> , <code>mfInvFourierSin</code>	discrete Fourier sine transformation
<code>mfFourierLeg</code> , <code>mfInvFourierLeg</code>	discrete Fourier-Legendre transformation

*See also:*

Core Routines

File Input/Output

Operators

Elementary Math Functions

Specialized Math Functions

Elementary Matrix Manipulation Functions

Matrix Functions

Polynomial Functions

Optimization and Function Functions

Sparse Matrices



**mfMax****mfArray max**

**mfMax** has two forms. The first one is used to compute the maximum value of the columns (default behavior) or of the rows of an **mfArray**. The second one compares two matrices.

*First interface:*

```
function mfMax( A, dim, nanflag ) result( out )

    type(mfArray),    intent(in)           :: A
    integer,          intent(in), optional :: dim
    character(len=*), intent(in), optional :: nanflag
    type(mfArray)     :: out
```

If **dim** is present, **A** is always considered as a matrix, and the returned vector contains the maximum of each column (if **dim** = 1) or the maximum of each row (if **dim** = 2).

If **dim** is not present: if **A** is a vector, **mfMax** returns the largest element; otherwise it returns the max of each columns.

If the string **nanflag** is present, it must be equal to either "omitNaN", or "includeNaN" (practically, the argument is not case sensitive). By default, NaN values are discarded (see examples below), so "omitNaN" is implied.

For a sparse **mfArray** **A**, the result is exactly the same as for the full corresponding matrix. In all cases (sparse or dense), it must contain real values.

*Second interface:*

```
function mfMax( A, B, nanflag ) result( out )

    type(mfArray), intent(in) :: A

    type(mfArray), intent(in) :: B
    or real(kind=MF_DOUBLE), intent(in) :: B

    character(len=*), intent(in), optional :: nanflag
    type(mfArray) :: out
```

When the two arguments **A** and **B** are **mfArrays** (sparse storage is allowed), they must have the same shape and must contain real values; in this case, the *max* operation is applied element-wise. Otherwise, the second argument **B** may be a scalar **real**.

The optional argument **nanflag** has the same meaning as in the first interface.

See also: [mfMin](#), [msMax](#), [mfExtrema](#)

*Example(s):*

```
x = [ 1.0d0, MF_NAN, 5.0d0, 2.0d0, 4.0d0 ]
call msDisplay( mfMax(x), "mfMax(x)" )
```

output:

```
mfMax(x) =
5.0000
```

⋯/⋯

```
x = [ 1.0d0, MF_NAN, 5.0d0, 2.0d0, 4.0d0 ]  
call msDisplay( mfMax(x,nanflag='includeNaN'), "mfMax(x,nanflag='includeNaN')" )
```

output:

```
mfMax(x,nanflag='includeNaN') =
```

```
NaN
```

```
x = [ MF_NAN, MF_NAN ]  
call msDisplay( mfMax(x), "mfMax(x)" )
```

output:

```
mfMax(x) =
```

```
NaN
```

**msMax****mfArray max***Calling syntax:*

```
call msMax( mfOut(v,i), A [, dim, nanflag] )
```

*Description:*

Computes the maximum value of the columns (default behavior) or of the rows of the **mfArray** **A** (real values only) and shows where this maximum occurs.

If **dim** is present, **A** is always considered as a matrix, and the vector **v** contains the maximum of each column (if **dim** = 1) or the maximum of each row (if **dim** = 2). indices of these maxima are returned in the vector **i**.

If **dim** is not present: if **A** is a vector, **msMax** returns the largest element in **v** and the corresponding index in **i**; otherwise it returns the max of each columns in **v** and the corresponding indices in **i**.

The optional argument **nanflag** has the same meaning as in the **mfMax** routine.

For a sparse **mfArray** **A**, the result is exactly the same as for the full corresponding matrix. In all cases (sparse or dense), it must contain real values.

See also: **mfOut**, **msMin**, **mfExtrema**

*Example(s):*

```
x = [ 1.0d0, MF_NAN, 5.0d0, 2.0d0, 4.0d0 ]
call msDisplay( x, "x" )
call msMax( mfOut(a,i), x )
call msDisplay( a, "max" )
call msDisplay( i, "for index" )
```

output:

```
x =
    1.0000      NaN      5.0000      2.0000      4.0000

max =
    5

for index =
    3

call msMax( mfOut(a,i), x, nanflag='includeNaN' )
call msDisplay( a, "max" )
call msDisplay( i, "for index" )
```

output:

```
max =
    NaN

for index =
    2
```

**mfMin****mfArray min**

**mfMin** has two forms. The first one is used to compute the minimum value of the columns (default behavior) or of the row of an **mfArray**. The second one compares two matrices.

*First interface:*

```
function mfMin( A, dim, nanflag ) result( out )

    type(mfArray),    intent(in)           :: A
    integer,          intent(in), optional :: dim
    character(len=*), intent(in), optional :: nanflag
    type(mfArray)     :: out
```

If **dim** is present, **A** is always considered as a matrix, and the returned vector contains the minimum of each column (if **dim** = 1) or the minimum of each row (if **dim** = 2).

If **dim** is not present: if **A** is a vector, **mfMin** returns the smallest element; otherwise it returns the min of each columns.

If the string **nanflag** is present, it must be equal to either "omitNaN", or "includeNaN" (practically, the argument is not case sensitive). By default, NaN values are discarded (see examples below), so "omitNaN" is implied.

For a sparse **mfArray** **A**, the result is exactly the same as for the full corresponding matrix. In all cases (sparse or dense), it must contain real values.

*Second interface:*

```
function mfMin( A, B, nanflag ) result( out )

    type(mfArray), intent(in) :: A

    type(mfArray), intent(in) :: B
    or real(kind=MF_DOUBLE), intent(in) :: B

    character(len=*), intent(in), optional :: nanflag
    type(mfArray) :: out
```

When the two arguments **A** and **B** are **mfArrays** (sparse storage is allowed), they must have the same shape and must contain real values; in this case, the *min* operation is applied element-wise. Otherwise, the second argument **B** may be a scalar **real**.

The optional argument **nanflag** has the same meaning as in the first interface.

*See also:* [mfMax](#), [msMin](#), [mfExtrema](#)

*Example(s):*

```
x = [ 1.0d0, MF_NAN, 5.0d0, 2.0d0, 4.0d0 ]
call msDisplay( mfMin(x), "mfMin(x)" )
```

output:

```
mfMin(x) =
1.0000
```

⋯/⋯

```
x = [ 1.0d0, MF_NAN, 5.0d0, 2.0d0, 4.0d0 ]  
call msDisplay( mfMin(x,nanflag='includeNaN'), "mfMin(x,nanflag='includeNaN')" )
```

output:

```
mfMin(x,nanflag='includeNaN') =
```

```
NaN
```

```
x = [ MF_NAN, MF_NAN ]  
call msDisplay( mfMin(x), "mfMin(x)" )
```

output:

```
mfMin(x) =
```

```
NaN
```

**msMin****mfArray min**

*Calling syntax:*

```
call msMin( mfOut(v,i), A [, dim, nanflag] )
```

*Description:*

Computes the minimum value of the columns (default behavior) or of the rows of the **mfArray** **A** (real values only) and shows where this minimum occurs.

If **dim** is present, **A** is always considered as a matrix, and the vector **v** contains the minimum of each column (if **dim** = 1) or the minimum of each row (if **dim** = 2). indices of these minima are returned in the vector **i**.

If **dim** is not present: if **A** is a vector, **mfMax** returns the smallest element in **v** and the corresponding index in **i**; otherwise it returns the min of each columns in **v** and the corresponding indices in **i**.

The optional argument **nanflag** has the same meaning as in the **mfMin** routine.

For a sparse **mfArray** **A**, the result is exactly the same as for the full corresponding matrix. In all cases (sparse or dense), it must contain real values.

See also: **mfOut**, **msMax**, **mfExtrema**

*Example(s):*

```
x = [ 1.0d0, MF_NAN, 5.0d0, 2.0d0, 4.0d0 ]
call msDisplay( x, "x" )
call msMin( mfOut(a,i), x )
call msDisplay( a, "min" )
call msDisplay( i, "for index" )
```

output:

```
x =
    1.0000      NaN    5.0000    2.0000    4.0000

min =
    1

for index =
    1
call msMin( mfOut(a,i), x, nanflag='includeNaN' )
call msDisplay( a, "min" )
call msDisplay( i, "for index" )
```

output:

```
min =
    NaN

for index =
    2
```

## mfExtrema

## data extrema

*Interface:*

```
function mfExtrema( A, nanflag ) result( out )

    type(mfArray),    intent(in)           :: A
    character(len=*), intent(in), optional :: nanflag
    type(mfArray)     :: out
```

*Description:*

Returns in an mfArray the two extreme values of an mfArray, in ascent order, *i. e.* the couple (*min*, *max*).

The optional argument `nanflag` has the same meaning as in the `mfMin` and `mfMax` routines.

See also: `msMin`, `msMax`

*Example(s):*

```
x = [ 5, 9, 3, 6, 0, 2 ]
call msDisplay( x, "x" )
call msDisplay( mfExtrema(x), "extrema" )
```

output:

```
x =
    5    9    3    6    0    2

extrema =
    0    9
```

```
x = [ 5, 9, MF_NAN, 6, 0, 2 ]
call msDisplay( x, "x" )
call msDisplay( mfExtrema(x,nanflag='includeNaN'), "extrema (include NaN)" )
```

output:

```
x =
    5    9   NaN    6    0    2

extrema (include NaN) =
    NaN   NaN
```

**mfSum****columns sum***Interface:*

```
function mfSum( A, dim ) result( out )  
  
    type(mfArray), intent(in)      :: A  
    integer,       intent(in), optional :: dim  
    type(mfArray)      :: out
```

*Description:*

Computes the sum of the columns (or rows) of an `mfArray`.

If `dim` is present, `A` is always considered as a matrix, and the output contains the sum of each column (if `dim = 1`) or the sum of each row (if `dim = 2`).

If `dim` is not present: if `A` is a vector, `mfSum` returns the sum of all elements; otherwise it returns the sum of each columns.

*See also:* [mfProd](#)



mfProd

columns product

*Interface:*

```
function mfProd( A, dim ) result( out )  
  
    type(mfArray), intent(in)           :: A  
    integer,       intent(in), optional :: dim  
    type(mfArray)           :: out
```

*Description:*

Computes the product of the columns (or rows) of an `mfArray`. The behavior of this routine is similar to the *product* Fortran 90 intrinsic function.

If `dim` is present, `A` is always considered as a matrix, and the output contains the product of each column (if `dim = 1`) or the product of each row (if `dim = 2`).

If `dim` is not present: if `A` is a vector, `mfSum` returns the product of all elements; otherwise it returns the product of each columns.

*Remarks:* this routine cannot be applied to a boolean `mfArray`.

Warning: this function cannot be applied to sparse matrices.

*See also:* [mfSum](#)

## mfSort

## columns sort

*Interface:*

```
function mfSort( A, dim, mode ) result( out )

    type(mfArray),    intent(in)           :: A
    integer,          intent(in), optional :: dim
    character(len=*), intent(in), optional :: mode
    type(mfArray)    :: out
```

*Description:*

If `dim` is not present, sorts the values of the vector `A`, and returns the sorted vector in an `mfArray`.

If `dim` is present, `A` may be a matrix. In this case, the sort is applied to the columns if `dim` is equal to 1, and to the rows if `dim` is equal to 2.

*Remarks:*

- this routine use a quick sort algorithm. By default, or if the optional argument `mode` is equal to "ascending" values are sorted in increasing order; on the contrary, if the optional argument `mode` is equal to "descending" values are sorted in decreasing order.
- currently, only rank-1 `mfArrays` (*i. e.* vectors) may contain `NaN` values. These `NaN`s are moved to the tail of the sorted vector.
- see `msSort` for an 'in-place' version.

*Warning:* If the `mfArray` `A` is a matrix, it must be real; for a complex vector `mfArray`, the sort is applied first on the module values, then on the phase-angle.

See also: `msSort`, `mfSortRows`

*Example(s):*

```
x = mf( [ 1.0d0, MF_NAN, 5.0d0, MF_NAN, 2.0d0, 4.0d0 ] )
call msDisplay( x, "x" )
call msDisplay( mfSort(x), "mfSort(x)" )
call msDisplay( mfSort(x,'descending'), "mfSort(x,'descending')" )
```

output:

```
x =
    1.0000    NaN    5.0000    NaN    2.0000    4.0000

mfSort(x) =
    1.0000    2.0000    4.0000    5.0000    NaN    NaN

mfSort(x,'descending') =
    5.0000    4.0000    2.0000    1.0000    NaN    NaN
```

**msSort****columns sort**

*First calling syntax:*

```
call msSort ( A [, dim, mode ] )
```

This is the 'in-place' version of **mfSort**.

*Second calling syntax:*

```
call msSort ( mfOut(v,i), A [, dim, mode ] )
```

The use of this subroutine is similar to **mfSort** but the result is returned in the **mfArray** **v**; in addition, indices of the sort are stored in the vector **i**.

See also: **mfOut**, **mfSortRows**

*Example(s):*

```
x = mfMagic(3)
call msDisplay( x, "x" )
call msSort( mfOut(a,i), x, dim=1 )
call msDisplay( a, "ascending column sort" )
call msDisplay( i, "with indices" )
call msSort( mfOut(a,i), x, dim=2, mode="descending" )
call msDisplay( a, "descending row sort" )
call msDisplay( i, "with indices" )
```

output:

x =

```
  8   3   4
  1   5   9
  6   7   2
```

ascending column sort =

```
  1   3   2
  6   5   4
  8   7   9
```

with indices =

```
  2   1   3
  3   2   1
  1   3   2
```

descending row sort =

```
  8   4   3
  9   5   1
  7   6   2
```

with indices =

```
  1   3   2
  3   2   1
  2   1   3
```

**mfIsSorted****vector sort test***Interface:*

```
bool = mfIsSorted( v, mode )
```

*Description:*

Checks that the `mfArray` vector `v` is sorted, according the mode, which can be equal to "ascend", "descend" or "either".

If the optional argument `mode` is not present, then an ascending sort is presumed.

This function returns a logical.

*Remarks:*

- currently, only rank-1 `mfArrays` (*i. e.* vectors) can be checked.
- the vector `v` may contain *NaN* values. The vector is considered as sorted if all *NaN*s are located at the end.
- for a complex vector `mfArray`, sorting concerns first the module, then the phase-angle.

*See also:* [mfSort](#)

## mfSortRows

## sort whole rows of a matrix

*Interface:*

```
function mfSortRows( A, col, mode ) result( out )

    type(mfArray),    intent(in)           :: A
    integer,          intent(in), optional :: col
    character(len=*), intent(in), optional :: mode
    type(mfArray)    :: out
```

*Description:*

If `col` is not present, sorts the rows of the matrix `A` according to the first column, and returns the result in an `mfArray`.

If `col` is present, the rows of `A` are sorted according to the column number `col`.

*Remarks:*

- this routine use a quick sort algorithm. By default, or if the optional argument `mode` is equal to "ascending" values are sorted in increasing order; on the contrary, if the optional argument `mode` is equal to "descending" values are sorted in decreasing order.
- currently, the matrix `A` should not contain *NaN* values.

*Warning:* The `mfArray` `A` must be real.

*See also:* [mfSort](#), [msSort](#)

*Example(s):*

```
x = mfMagic(3)
call msDisplay( x, "x" )
call msDisplay( mfSortRows(x,3), "mfSortRows(x,3)" )
call msDisplay( mfSortRows(x,1,"descending"), "mfSortRows(x,1,'descending')" )
```

output:

`x =`

```
8   3   4
1   5   9
6   7   2
```

`mfSortRows(x,3) =`

```
6   7   2
8   3   4
1   5   9
```

`mfSortRows(x,1,'descending') =`

```
6   7   2
1   5   9
8   3   4
```

mfDiff

difference and approximate derivative

*Interface:*

```
function mfDiff( A, dim ) result( out )

    type(mfArray), intent(in)           :: A
    integer,       intent(in), optional :: dim
    type(mfArray)  :: out
```

*Description:*

Computes the difference of two consecutive values of the columns (or rows) of an `mfArray` `A`.

If `dim` is present, `A` is always considered as a matrix, and the routine computes the difference of two consecutive values for each column (if `dim = 1`) or for each row (if `dim = 2`).

If `dim` is not present: if `A` is a vector, then `mfDiff` computes the difference of two consecutive values in the natural way; otherwise the same process is applied for each columns.

*Remark:* this function cannot be applied to sparse matrices.

*See also:* [mfGradient](#), [msGradient](#)

*Example(s):*

```
x = mf( [ 1, 2, 3, 2, 1 ] )
call msDisplay( x, "x" )
call msDisplay( mfDiff(x), "mfDiff(x)" )
```

output:

```
x =
  1   2   3   2   1
mfDiff(x) =
  1   1  -1  -1
```

**mfGradient****approximate 1D gradient***Calling syntax:*

```
D = mfGradient( F, h [, dim, location] )
```

*Description:*

Computes the gradient  $D$  of the rank-1 `mfArray`  $F$ .

If `dim` is present,  $F$  is always considered as a matrix, and the routine computes the gradient for each column (if `dim = 1`) or for each row (if `dim = 2`).

If `dim` is not present: if  $F$  is a vector, then `mfGradient` computes the gradient in the natural way; otherwise the same process is applied for each columns.

The data is supposed to be equally spaced with  $h$  as increment.  $h$  may be a double precision real or a scalar `mfArray`; it may have negative values.

If the optional argument `location` (character string) is equal to "centered" then the gradient is computed on an internal centered, staggered grid; otherwise it is computed at the same points as  $F$ .

*Remark:* The gradient is computed using second order formulæ.

*See also:* `msGradient`, `mfDiff`, `mfOut`

*Example(s):*

```
integer :: nx = 5
real(kind=MF_DOUBLE) :: lx = 1.0d0, hx
x = mfLinSpace(0.0d0, lx, nx)
F = x**2
call msDisplay( F, "F" )
hx = lx/(nx-1)
Fx = mfGradient( F, hx )
call msDisplay( Fx, "Fx = grad_x(F)" )
```

output:

```
F =
0.0000    0.0625    0.2500    0.5625    1.0000
```

```
Fx = grad_x(F) =
0.0000    0.5000    1.0000    1.5000    2.0000
```

```
fx = mfGradient( F, hx, "centered" )
call msDisplay( fx, "grad_x(F)" )
```

output:

```
grad_x(z) =
0.2500    0.7500    1.2500    1.7500
```

## msGradient

## approximate 2D gradient

Calling syntax:

```
call msGradient( mfOut( Fi, Fj ), F, hi, hj [, location] )
```

Description:

Computes the gradient of the rank-2 mfArray F, along the two dimensions. The data are supposed to be equally spaced in both direction, with hi and hj as increments, which may have negative values.

As a result, Fi is the gradient of F with respect to increasing indices *i* (i.e. along the rows) and Fj is the gradient of F with respect to increasing indices *j* (i.e. along the columns).

If the optional argument location (character string) is equal to "centered" then the two components of the gradient are computed on an internal centered, staggered grid; otherwise they are computed at the same points as F.

Remarks:

- this function cannot be applied to sparse matrices. For all cases and all points, the gradient is computed using second order formulæ.
- if the data matrix F is associated to coordinates X and Y, hi and hj may be chosen to give directly the two components  $F_x$  and  $F_y$  (see the *Muesli User Guide*, section entitled "Data Analysis with mfArrays").

See also: [mfGradient](#), [mfDiff](#), [mfOut](#)

Example(s):

```
integer :: nx = 5, ny = 5
real(kind=MF_DOUBLE) :: lx = 1.0d0, ly = 2.0d0, hx, hy
call msMeshGrid( mfOut(x,y), mfLinSpace(0.0d0,lx,nx),      &
                 .t. mfLinSpace(ly,0.0d0,ny) )
call msDisplay( x, "x", y, "y" )
F = (2*x+y)**2
call msDisplay( F, "F" )
hx = lx/(nx-1)
hy = -ly/(ny-1)
call msGradient( mfOut(Fy,Fx), F, hy, hx )
call msDisplay( Fx, "Fx = grad_x(F)", Fy, "Fy = grad_y(F)" )
```

output:

```
x =
0.0000    0.2500    0.5000    0.7500    1.0000
0.0000    0.2500    0.5000    0.7500    1.0000
0.0000    0.2500    0.5000    0.7500    1.0000
0.0000    0.2500    0.5000    0.7500    1.0000
0.0000    0.2500    0.5000    0.7500    1.0000
```

⋯/⋯



y =

```

2.0000  2.0000  2.0000  2.0000  2.0000
1.5000  1.5000  1.5000  1.5000  1.5000
1.0000  1.0000  1.0000  1.0000  1.0000
0.5000  0.5000  0.5000  0.5000  0.5000
0.0000  0.0000  0.0000  0.0000  0.0000

```

F =

```

4.0000  6.2500  9.0000  12.2500  16.0000
2.2500  4.0000  6.2500  9.0000  12.2500
1.0000  2.2500  4.0000  6.2500  9.0000
0.2500  1.0000  2.2500  4.0000  6.2500
0.0000  0.2500  1.0000  2.2500  4.0000

```

Fx = grad\_x(F) =

```

8  10  12  14  16
6  8  10  12  14
4  6  8  10  12
2  4  6  8  10
0  2  4  6  8

```

Fy = grad\_y(F) =

```

4  5  6  7  8
3  4  5  6  7
2  3  4  5  6
1  2  3  4  5
0  1  2  3  4

```

```

call msGradient( mfOut(Fy,Fx), F, hy, hx, "centered" )
call msDisplay( Fx, "Fx = grad_x(F)", Fy, "Fy = grad_y(F)" )

```

output:

Fx = grad\_x(F) =

```

8  10  12  14
6  8  10  12
4  6  8  10
2  4  6  8

```

Fy = grad\_y(F) =

```

4  5  6  7
3  4  5  6
2  3  4  5
1  2  3  4

```

**mfMean****columns mean***Interface:*

```
function mfMean( A, dim ) result( out )  
  
    type(mfArray), intent(in)      :: A  
    integer,       intent(in), optional :: dim  
    type(mfArray)      :: out
```

*Description:*

Computes the mean of the columns (or rows) of an `mfArray`, as  $\frac{1}{N} \sum_{i=1}^N a_i$ .

If `dim` is present, `A` is always considered as a matrix, and the output contains the mean of each column (if `dim = 1`) or the mean of each row (if `dim = 2`).

If `dim` is not present: if `A` is a vector, `mfMean` returns the mean of all elements; otherwise it returns the mean of each columns.

*Warning:*

- this function cannot be applied to sparse matrices;
- the user must take care that the `mfArray` `A` doesn't contain any `NaN` values.

See also: [mfMedian](#), [mfVar](#), [mfStd](#), [mFRMS](#), [mfMoments](#)

**mfMedian****columns median***Interface:*

```
function mfMedian( A, dim ) result( out )  
  
    type(mfArray), intent(in)      :: A  
    integer,       intent(in), optional :: dim  
    type(mfArray)  :: out
```

*Description:*

Computes the median of the columns (or rows) of an `mfArray`. The median value of a vector is, after sorting this vector, the value located in the middle.

If `dim` is present, `A` is always considered as a matrix, and the output contains the median of each column (if `dim = 1`) or the median of each row (if `dim = 2`).

If `dim` is not present: if `A` is a vector, `mfMedian` returns the median of all elements; otherwise it returns the median of each columns.

*Warning:*

- this function cannot be applied to sparse matrices;
- the user must take care that the `mfArray` `A` doesn't contain any `NaN` values.

See also: [mfMean](#), [mfVar](#), [mfStd](#), [mfMoments](#)

**mfVar****columns variance***Interface:*

```
function mfVar( A, dim ) result( out )  
  
    type(mfArray), intent(in)      :: A  
    integer,       intent(in), optional :: dim  
    type(mfArray)  :: out
```

*Description:*

Computes the variance of the columns (or rows) of an **mfArray**, as  $\frac{1}{N} \sum_{i=1}^N (a_i - \bar{a})^2$ , with  $\bar{a} = \frac{1}{N} \sum_{i=1}^N a_i$ .

If **dim** is present, **A** is always considered as a matrix, and the output contains the variance of each column (if **dim** = 1) or the variance of each row (if **dim** = 2).

If **dim** is not present: if **A** is a vector, **mfVar** returns the variance of all elements; otherwise it returns the variance of each columns.

*Warning:*

- this function cannot be applied to sparse matrices;
- the user must take care that the **mfArray** **A** doesn't contain any *NaN* values.

See also: [mfMean](#), [mfMedian](#), [mfStd](#), [mfMoments](#)

**mfStd****columns standard deviation***Interface:*

```
function mfStd( A, dim ) result( out )  
  
    type(mfArray), intent(in)      :: A  
    integer,       intent(in), optional :: dim  
    type(mfArray)      :: out
```

*Description:*

Computes the standard deviation of the columns (or rows) of an `mfArray`. The standard deviation is the square root of the variance.

If `dim` is present, `A` is always considered as a matrix, and the output contains the standard deviation of each column (if `dim = 1`) or the standard deviation of each row (if `dim = 2`).

If `dim` is not present: if `A` is a vector, `mfStd` returns the standard deviation of all elements; otherwise it returns the standard deviation of each columns.

*Warning:*

- this function cannot be applied to sparse matrices;
- the user must take care that the `mfArray` `A` doesn't contain any `NaN` values.

See also: [mfMean](#), [mfRMS](#), [mfMedian](#), [mfVar](#), [mfMoments](#)

mfRMS

root mean square

*Interface:*

```
function mfRMS( A, dim ) result( out )

    type(mfArray), intent(in)      :: A
    integer,        intent(in), optional :: dim
    type(mfArray)   :: out
```

*Description:*

Computes the Root-Mean-Square of the columns (or rows) of an `mfArray`.

The RMS is defined by:

$$a_{RMS} = \sqrt{\frac{1}{N} \sum_{i=1}^N a_i^2}$$

where  $N$  is the number of elements  $x_i$ . The following relation holds:

$$a_{RMS}^2 = \bar{a}^2 + \sigma_a^2$$

so the RMS of a signal is synonym to its standard deviation only when the mean is zero.

If `dim` is present, `A` is always considered as a matrix, and the output contains the mean of each column (if `dim = 1`) or the RMS of each row (if `dim = 2`).

If `dim` is not present: if `A` is a vector, `mfRMS` returns the RMS of all elements; otherwise it returns the RMS of each columns.

*Warning:*

- this function can be applied only to real, dense matrices;
- the user must take care that the `mfArray` `A` doesn't contain any `NaN` values.

See also: [mfMean](#), [mfMedian](#), [mfVar](#), [mfStd](#), [mfMoments](#)

**msHist****data histogram**

*Calling syntax:*

```
call msHist( mfOut( num [ , x_bin ] ), x, x_min, x_max, n_bin )
```

computes a data histogram.

The vector `mfArray x` contains the data. The histogram is computed for data ranged from `x_min` to `x_max` using a number of bins equal to `n_bin`.

The output `mfArray num` is a vector of the bins values (length equal to `n_bin`).

If present, the output `mfArray x_bin` is a vector containing the abscissas of the bins (length equal to `n_bin+1`).

*Note:* to process discrete data, it is recommended to choose `x_min` as the minimum integer value minus 1/2, and `x_max` as the maximum integer value plus 1/2 (see example below).

*See also:* [mf/msPlotHist](#), [msCumulHist](#), [mfOut](#)

*Example(s):*

```
x = .t. mf( [ 12, 11, 8, 10, 6, 8, 9, 10, 12, 9, 10, 8, 6, 10 ] )
call msHist( mfOut( y, z ), x, 6.0d0-0.5d0, 12.0d0+0.5d0, 7 )
call msDisplay( y, "y (hist)", z, "z (x_bin)" )
```

output:

```
y (hist) =
```

```
  2
  0
  3
  2
  4
  1
  2
```

```
z (x_bin) =
```

```
 5.5000
 6.5000
 7.5000
 8.5000
 9.5000
10.5000
11.5000
12.5000
```

**mfMoments****few first moments of a distribution***Interface:*

```
function mfMoments( v ) result( out )  
  
    type(mfArray), intent(in) :: v  
    type(mfArray)           :: out
```

*Description:*

Computes some moments of the data distribution provided in the vector `mfArray v`.

It returns a vector `mfArray` of length 6, containing in order:

- the mean value of data
- the average deviation
- the standard deviation
- the variance
- the skewness
- the kurtosis

*Warning:*

- this function cannot be applied to sparse matrices;
- the user must take care that the `mfArray v` doesn't contain any *NaN* values.

*See also:* [mfMean](#), [mfMedian](#), [mfVar](#), [mfStd](#)



**mfSmooth****smoothing of vector values***Interface:*

```
function mfSmooth( v [, span ] ) result( out )  
  
    type(mfArray), intent(in)           :: v  
    integer,       intent(in), optional :: span  
    type(mfArray)           :: out
```

*Description:*

Applies the moving average method to the vector `mfArray` `v`. It is equivalent to a lowpass filter.

The width of the sliding window is `span` which must be a non negative integer. The `span` value should not be greater than the number of elements in `v`. The default value is 5.

*See also:* [mfSpline](#)

mfFFT

discrete Fast Fourier transformation

*Interface:*

```
function mfFFT( A, dim ) result( out )  
  
    type(mfArray), intent(in)           :: A  
    integer,       intent(in), optional :: dim  
    type(mfArray)  :: out
```

*Description:*

Applies a Fast Fourier transformation to the columns (or rows) of an `mfArray`, real or complex. The output `mfArray` is always complex.

If `dim` is present, `A` is always considered as a matrix, and the output contains the transformation coefficients of each column (if `dim = 1`) or the transformation of each row (if `dim = 2`).

If `dim` is not present: if `A` is a vector, `mfFFT` returns the transformation of all elements; otherwise it returns the transformation of each columns.

*Warning:* this function cannot be applied to sparse matrices.

*Remarks:* abscissa are supposed to be equally spaced.

*See also:* `mfInvFFT`, `mfFFT2`, `mfFourierCos`, `mfFourierSin`, `mfFourierLeg`

**mfInvFFT****inverse Fast Fourier transformation***Interface:*

```
function mfInvFFT( A, dim ) result( out )  
  
    type(mfArray), intent(in)      :: A  
    integer,       intent(in), optional :: dim  
    type(mfArray)                :: out
```

*Description:*

This is the inverse transformation of `mfFFT`. So, for any vector `v`, we have:

```
v = mfInvFFT(mfFFT(v))
```

See also: [mfFFT](#), [mfFFT2](#), [mfFourierCos](#), [mfFourierSin](#), [mfFourierLeg](#)

mfFFT2

**2D discrete Fast Fourier transformation***Interface:*

```
function mfFFT2( A ) result( out )  
  
    type(mfArray), intent(in) :: A  
    type(mfArray)           :: out
```

*Description:*

Applies a two dimensional Fast Fourier transformation to the `mfArray` `A`, real or complex. The output `mfArray` is always complex.

*Warning:* this function cannot be applied to sparse matrices.

*Remarks:* abscissa are supposed to be equally spaced for both dimensions.

*See also:* `mfInvFFT2`, `mfFFT`, `mfFourierCos`, `mfFourierSin`, `mfFourierLeg`

**mfInvFFT2****inverse 2D Fast Fourier transformation***Interface:*

```
function mfInvFFT2( A ) result( out )  
  
    type(mfArray), intent(in) :: A  
    type(mfArray)           :: out
```

*Description:*

This is the inverse transformation of `mfFFT2`. So, for any complex matrix `A`, we have:

```
A = mfInvFFT(mfFFT(A))
```

*See also:* [mfFFT2](#), [mfFFT](#), [mfFourierCos](#), [mfFourierSin](#), [mfFourierLeg](#)

mfFourierCos

discrete Fourier cosine transformation

*Interface:*

```
function mfFourierCos( A, dim ) result( out )  
  
    type(mfArray), intent(in)           :: A  
    integer,       intent(in), optional :: dim  
    type(mfArray)           :: out
```

*Description:*

Applies a discrete Fourier cosine transformation to the columns (or rows) of an `mfArray`.

If `dim` is present, `A` is always considered as a matrix, and the output contains the transformation coefficients of each column (if `dim = 1`) or the transformation of each row (if `dim = 2`).

If `dim` is not present: if `A` is a vector, `mfFourierCos` returns the transformation of all elements; otherwise it returns the transformation of each columns.

*Warning:* this function cannot be applied to sparse matrices. Moreover, the array must contain real values.

*Remarks:*

- abscissa are supposed to be equally spaced;
- actually, data are already considered symmetric on the interval  $[-n + 1, n + 1]$ ; therefore, there doesn't exist any constraint on the value of the data vector.

See also: [mfInvFourierCos](#), [mFFT](#), [mFFT2](#), [mfFourierSin](#), [mfFourierLeg](#)

`mfInvFourierCos`**inverse Fourier cosine transformation***Interface:*

```
function mfInvFourierCos( A, dim ) result( out )  
  
    type(mfArray), intent(in)      :: A  
    integer,       intent(in), optional :: dim  
    type(mfArray)  :: out
```

*Description:*

This is the inverse transformation of `mfFourierCos`. So, for any vector `v`, we have:

```
v = mfInvFourierCos(mfFourierCos(v))
```

See also: [mfFourierCos](#), [mFFT](#), [mFFT2](#), [mfFourierSin](#), [mfFourierLeg](#)

## mfFourierSin

## Fourier sine transformation

*Interface:*

```
function mfFourierSin( A, dim ) result( out )  
  
    type(mfArray), intent(in)           :: A  
    integer,       intent(in), optional :: dim  
    type(mfArray)  :: out
```

*Description:*

Applies a discrete Fourier sine transformation to the columns (or rows) of an `mfArray`.

If `dim` is present, `A` is always considered as a matrix, and the output contains the transformation coefficients of each column (if `dim = 1`) or the transformation of each row (if `dim = 2`).

If `dim` is not present: if `A` is a vector, `mfFourierSin` returns the transformation of all elements; otherwise it returns the transformation of each columns.

*Warning:* this function cannot be applied to sparse matrices. Moreover, the array must contain real values.

*Remarks:*

- abscissa are supposed to be equally spaced;
- actually, data are already considered antisymmetric on the interval  $[-n + 1, n + 1]$ ; therefore, there exists some constraints: the conditions  $y(1) = y(n + 1) = 0$  are required.

*See also:* [mfInvFourierSin](#), [mFFT](#), [mFFT2](#), [mfFourierCos](#), [mfFourierLeg](#)



`mfInvFourierSin`**inverse Fourier sine transformation***Interface:*

```
function mfInvFourierSin( A, dim ) result( out )  
  
    type(mfArray), intent(in)      :: A  
    integer,       intent(in), optional :: dim  
    type(mfArray)  :: out
```

*Description:*

This is the inverse transformation of `mfFourierSin`. So, for any vector `v`, we have:

```
v = mfInvFourierSin(mfFourierSin(v))
```

*See also:* `mfFourierSin`, `mFFT`, `mFFT2`, `mfFourierCos`, `mfFourierLeg`

## mfFourierLeg

## Fourier-Legendre transform

*Interface:*

```
function mfFourierLeg( A, dim ) result( out )  
  
    type(mfArray), intent(in)           :: A  
    integer,       intent(in), optional :: dim  
    type(mfArray)  :: out
```

*Description:*

Applies a discrete Fourier-Legendre transformation to the columns (or rows) of an `mfArray`.

This transformation is also called “discrete spherical Fourier transform”.

If `dim` is present, `A` is always considered as a matrix, and the output contains the transformation coefficients of each column (if `dim = 1`) or the transformation of each row (if `dim = 2`).

If `dim` is not present: if `A` is a vector, `mfFourierLeg` returns the transformation of all elements; otherwise it returns the transformation of each columns.

*Warning:* this function cannot be applied to sparse matrices. Moreover, the array must contain real values.

*Remarks:*

- abscissa are supposed to be spanned over  $[-1, 1]$  like a  $\cos(\theta)$  function, with  $\theta$  equally spaced;
- actually, data are already considered symmetric on the interval  $[-n + 1, n + 1]$ ; therefore, there doesn't exist any constraint on the value of the data vector.

*See also:* [mfInvFourierLeg](#), [mfLegendre](#), [mFFT](#), [mFFT2](#), [mfFourierSin](#), [mfFourierCos](#)

`mfInvFourierLeg`**inverse Fourier-Legendre transform***Interface:*

```
function mfInvFourierLeg( A, dim ) result( out )  
  
    type(mfArray), intent(in)           :: A  
    integer,       intent(in), optional :: dim  
    type(mfArray)  :: out
```

*Description:*

This is the inverse transformation of `mfFourierLeg`. So, for any vector `v`, we have:

```
v = mfInvFourierLeg(mfFourierLeg(v))
```

See also: [mfFourierLeg](#), [mfLegendre](#), [mfFFT](#), [mfFFT2](#), [mfFourierSin](#), [mfFourierCos](#)

## 1.4 Operators

<code>+</code>	mfArray sum
<code>-</code>	mfArray difference
<code>mfMul, .x.</code>	mfArray product
<code>mfCross</code>	cross-product of two vectors
<code>mfKron</code>	Kronecker tensor product
<code>*</code>	mfArray element-wise product
<code>/</code>	mfArray element-wise quotient
<code>**</code>	mfArray element-wise exponentiation
<code>.t.</code>	mfArray transposition
<code>.h.</code>	mfArray conjugate transposition
<code>.vc.</code>	vertical concatenation
<code>.hc.</code>	horizontal concatenation
<code>msHorizConcat</code>	sparse matrix horizontal concatenation
<code>mfColPerm, msColPerm</code>	columns permutation
<code>mfRowPerm, msRowPerm</code>	rows permutation
<code>mfColScale, msColScale</code>	columns scaling
<code>mfRowScale, msRowScale</code>	rows scaling
<code>mfInvPerm</code>	inverse of a permutation
<code>&gt;=, &gt;</code>	mfArray relational operator
<code>&lt;=, &lt;</code>	mfArray relational operator
<code>==, /=</code>	mfArray relational operator
<code>mfAll, mfAny</code>	mfArray boolean operator
<code>mfColon</code>	mfArray sequence constructor
<code>.not., .and., .or.</code>	mfArray logical operator
<code>.eqv., .neqv.</code>	mfArray logical operator
<code>mfIsMember</code>	elements members of a set
<code>mfIntersect</code>	common elements of two sets
<code>mfUnion</code>	all elements of two sets
<code>mfUnique</code>	unique elements of a set

See also:

[Core Routines](#)

[File Input/Output](#)

[Data Analysis Functions](#)

[Elementary Math Functions](#)

[Specialized Math Functions](#)

[Elementary Matrix Manipulation Functions](#)

[Matrix Functions](#)

[Polynomial Functions](#)

[Optimization and Function Functions](#)

[Sparse Matrices](#)

+

**mfArray sum***Calling syntax:*
$$C = A + B$$
*Description:*

Computes the sum of two **mfArrays** of same shape.

One of them may be a scalar of type **real** (single or double) or **complex**; in such a case, if the **mfArray** is not a scalar, then the operation is made on all elements.

*Remarks:* A and B may have a dense or sparse structure.

*See also:* -

-

**mfArray difference**

*Calling syntax:*

$$C = A - B$$

*Description:*

Computes the difference of two **mfArrays** of same shape.

One of them may be a scalar of type **real** (single or double) or **complex**; in such a case, if the **mfArray** is not a scalar, then the operation is made on all elements.

*Remarks:* **A** and **B** may have a dense or sparse structure.

*See also:* [+](#)

`mfMul, .x.`**mfArray product***Interface:*

```
function mfMul( A, B, transp ) result( out )  
  
    type(mfArray), intent(in)      :: A, B  
    integer,       intent(in), optional :: transp  
    type(mfArray)  :: out
```

`A .x. B` is a shortcut for writing: `mfMul( A, B )`

*Description:*

Computes the matrix product  $A * B$  (which is not commutative).

When the optional argument `transp` is present, it computes  $A' * B$  (`transp=1`) or  $A * B'$  (`transp=2`). This latter option is valid only for dense `mfArrays`.

The shape of the two matrices must respect the classical matrix-product rule, according to the value of `transp`.

*Remarks:* the element-wise operation is done with the operator `'*'`.

This routine can be applied to dense or sparse `mfArrays` of any type (real or complex).

*See also:* [mfCross](#)

**mfCross****cross-product of two vectors***Interface:*

```
function mfCross( u, v ) result( out )  
  
    type(mfArray), intent(in) :: u, v  
    type(mfArray)           :: out
```

*Description:*

Computes the cross-product of two vectors in  $R^3$ .

*See also:* [mfMul](#)



mfKron

Kronecker tensor product

*Interface:*

```
function mfKron( A, B ) result( out )  
  
    type(mfArray), intent(in) :: A, B  
    type(mfArray)           :: out
```

*Description:*

Computes the Kronecker product of **A** and **B**. If the shape of **A** is  $(m, n)$  and the shape of **B** is  $(p, q)$ , then the shape of the Kronecker product will be  $(m\ p, n\ q)$ .

The **mfArrays** **A** and **B** may be dense or sparse.

*Remark:* Currently, only real **mfArrays** are accepted.

*See also:* [mfMul](#)

**\*** **mfArray element-wise product**

*Calling syntax:*

$$C = A * B$$

*Description:*

Computes the product (element-wise) of two `mfArrays` of same shape.

One of them may be a scalar of type `real` (single or double) or `complex`; in such a case, if the `mfArray` is not a scalar, then the operation is made on all elements.

Only for this routine, `B` may be of type `mfUnit`. This feature allows the user to change the physical unit of the `mfArray` `A`.

*Remarks:* `A` and `B` may have a dense or sparse structure.

*See also:* `mfMul`, /

/

**mfArray element-wise quotient***Calling syntax:*

$$C = A / B$$

*Description:*

Computes the division (element-wise) of two `mfArrays` of same shape.

One of them may be a scalar of type `real` (single or double) or `complex`; in such a case, if the `mfArray` is not a scalar, then the operation is made on all elements.

*Remarks:* `A` and `B` may have a dense or sparse structure.

*See also:* `mfLDiv`, `mfRDiv`, `*`

**\*\*****mfArray element-wise exponentiation***Calling syntax:*
$$C = A ** i$$
*Description:*

Computes the power (element-wise) of the `mfArray` `A` to the exponent `i`, which must be a scalar, of type `integer` or `real`.

*Remarks:* `A` may have a dense or sparse structure.

`.t.`

## **mfArray transposition**

*Calling syntax:*

```
C = .t. A
```

*Description:*

The prefixed operator `' .t. '` transposes the `mfArray` `A`.

A warning is emitted if this routine is applied to a complex `mfArray` (in this case, the operator `' .h. '` should be used instead).

Remarks: `A` may have a dense or sparse structure. This operator can also be applied to `integer` or `real` arrays, of rank 1 or 2 (*i. e.* vector or matrix); in all cases it returns an `mfArray`.

`.h.`

## **mfArray conjugate transposition**

*Calling syntax:*

```
C = .h. A
```

*Description:*

The prefixed operator ‘`.h.`’ returns the conjugate transpose of the `mfArray` `A`.

Remarks: `A` may have a dense or sparse structure. This operator should be applied to `complex` arrays, of rank 1 or 2 (*i. e.* vector or matrix); in all cases it returns an `mfArray`. If `A` is a real `mfArray`, it is converted in a `complex mfArray`.

*See also:* `.t.`

`.vc.`

## vertical concatenation

*Calling syntax:*

```
C = A .vc. B
```

*Description:*

Vertical concatenation of `mfArrays` (dense and/or sparse).

A and B must have the same number of columns.

One of the two `mfArrays` can be empty: it enables the construction of a matrix inside a loop, from an empty one.

*Remark:* This operator also accepts usual Fortran 90 1-rank numeric array (*i. e.* either real or complex).

*See also:* [.hc.](#)

`.hc.`

## horizontal concatenation

*Calling syntax:*

```
C = A .hc. B
```

*Description:*

Horizontal concatenation of `mfArrays` (dense and/or sparse).

A and B must have the same number of rows.

One of the two `mfArrays` can be empty: it enables the construction of a matrix inside a loop, from an empty one.

*Remarks:*

- when working with sparse `mfArrays`, the subroutine `msHorizConcat` is much more efficient.
- this operator also accepts usual Fortran 90 1-rank numeric array (*i. e.* either real or complex).

*See also:* `msHorizConcat`, `.vc.`



**msHorizConcat****sparse matrix horizontal concatenation***Interface:*

```
subroutine msHorizConcat( A, data )  
  
    type(mfArray), intent(in out) :: A  
    type(mfArray), intent(in)     :: data
```

*Description:*

This subroutine version of `operator(.hc.)` is intended to be more efficient, because: (i) modifications of `A` are made “in place” and (ii) allocation of space is anticipated and over-dimensioned.

`A` can be empty: it enables the construction of a matrix inside a loop, from an empty one.

The `mfArrays` `A` must be sparse; the `mfArray` `data` must be sparse if it is a matrix, but can be dense if it is a vector.

Restrictions: the two `mfArrays` must have the same data type.

*Remarks:* use `operator(.hc.)` instead of for dense matrices.

*See also:* `.hc.`, `.vc.`

mf/msColPerm,

columns permutation

*First calling syntax:*

```
B = mfColPerm( A, p )
```

*Description:*

Returns the columns permutation of the `mfArray` A (may be of any type, dense or sparse), using the permutation `p`: the  $j^{\text{th}}$  column of B is the  $p(j)^{\text{th}}$  column of A.

In Matlab syntax or Fortran 90 notation, it computes  $B = A(:, p)$ .

`p` is either an ordinary vector `mfArray`, containing the (integer) indices of the permutation, or a true permutation `mfArray` (see `mfPerm`).

*The second calling syntax:*

```
call msColPerm( A, p )
```

applies the same operation, but in-place.

*Remark:* This routine is much more efficient than computing a column's permutation by calling `mfGet(A,MF_ALL,p)`.

*See also:* `mf/msRowPerm`, `mf/msColScale`, `mf/msRowScale`

`mf/msRowPerm,`**rows permutation***First calling syntax:*

```
B = mfRowPerm( A, p )
```

*Description:*

Returns the rows permutation of the `mfArray` `A` (may be of any type, dense or sparse), using the permutation `p`: the  $i^{\text{th}}$  row of `B` is the  $p(i)^{\text{th}}$  row of `A`.

In Matlab syntax or Fortran 90 notation, it computes  $B = A(p, :)$ .

`p` is either an ordinary vector `mfArray`, containing the (integer) indices of the permutation, or a true permutation `mfArray` (see `mfPerm`).

*The second calling syntax:*

```
call msRowPerm( A, p )
```

applies the same operation, but in-place.

*Remark:* This routine is much more efficient than computing a row's permutation by calling `mfGet(A,p,MF_ALL)`.

*See also:* `mf/msColPerm`, `mf/msColScale`, `mf/msRowScale`

`mf/msColScale`,

**columns scaling**

*First calling syntax:*

```
B = mfColScale( A, s )
```

*Description:*

Returns the columns scaling of the `mfArray` `A` (must be numeric, dense or sparse), using the dense vector `s`: the  $j^{\text{th}}$  column of `B` is the  $j^{\text{th}}$  column of `A` multiplied by  $s(j)$ .

In Matlab syntax, it computes  $B = A * \text{diag}(s)$ .

Restrictions: the vector `s` must be a real `mfArray`.

*The second calling syntax:*

```
call msColScale( A, s )
```

applies the same operation, but in-place.

*See also:* [mf/msColPerm](#), [mf/msRowPerm](#), [mf/msRowScale](#)

**mf/msRowScale,****rows scaling***First calling syntax:*

```
B = mfRowScale( A, s )
```

*Description:*

Returns the rows scaling of the **mfArray** **A** (must be numeric, dense or sparse), using the dense vector **s**: the  $i^{th}$  row of **B** is the  $i^{th}$  row of **A** multiplied by  $s(i)$ .

In Matlab syntax, it computes  $B = \text{diag}(s) * A$ .

Restrictions: the vector **s** must be a real **mfArray**.

*The second calling syntax:*

```
call msRowScale( A, s )
```

applies the same operation, but in-place.

*See also:* [mf/msColPerm](#), [mf/msRowPerm](#), [mf/msColScale](#)

`mfInvPerm,`

**inverse of a permutation**

*Calling syntax:*

```
p_inv = mfInvPerm( p )
```

*Description:*

Inverts the permutation `p`.

*See also:* [mf/msColPerm](#), [mf/msRowPerm](#)

&gt;=

mfArray relational operator

*Calling syntax:*
$$C = A \geq B$$
*Description:*

Returns a boolean `mfArray` from two dense `mfArrays`, by making the comparison element-wise.

A and B must have the same shape and must be, of course, of type `real`.

B may be a scalar, `real` or even `integer`.

*Remarks:* a boolean `mfArray` contains `TRUE` and `FALSE` values only. It can be displayed as any `mfArray` and can occur in logical operators (`.not.`, `.and.`, `.or.`, etc.).

*See also:* `>`, `<=`, `<`, `==`, `/=`

&gt;

**mfArray relational operator***Calling syntax:*
$$C = A > B$$
*Description:*

Returns a boolean `mfArray` from two dense `mfArrays`, by making the comparison element-wise.

A and B must have the same shape and must be, of course, of type real.

B may be a scalar, `real` or even `integer`.

*Remarks:* a boolean `mfArray` contains `TRUE` and `FALSE` values only. It can be displayed as any `mfArray` and can occur in logical operators (`.not.`, `.and.`, `.or.`, etc.).

*See also:* `>=`, `<=`, `<`, `==`, `/=`



&lt;=

mfArray relational operator

*Calling syntax:*
$$C = A \leq B$$
*Description:*

Returns a boolean mfArray from two dense mfArrays, by making the comparison element-wise.

A and B must have the same shape and must be, of course, of type real.

B may be a scalar, real or even integer.

*Remarks:* a boolean mfArray contains *TRUE* and *FALSE* values only. It can be displayed as any mfArray and can occur in logical operators (*.not.*, *.and.*, *.or.*, etc.).

*See also:* <, >=, >, ==, /=

&lt;

**mfArray relational operator***Calling syntax:*
$$C = A < B$$
*Description:*

Returns a boolean `mfArray` from two dense `mfArrays`, by making the comparison element-wise.

A and B must have the same shape and must be, of course, of type real.

B may be a scalar, `real` or even `integer`.

*Remarks:* a boolean `mfArray` contains `TRUE` and `FALSE` values only. It can be displayed as any `mfArray` and can occur in logical operators (`.not.`, `.and.`, `.or.`, etc.).

*See also:* `<=`, `>=`, `>`, `==`, `/=`

==

**mfArray relational operator***Calling syntax:*
$$C = A == B$$
*Description:*

Returns a boolean `mfArray` from two dense `mfArrays`, by making the comparison element-wise.

A and B must have the same shape and must be, of course, of type `real`.

B may be a scalar, `real` or even `integer`.

*Remarks:* a boolean `mfArray` contains `TRUE` and `FALSE` values only. It can be displayed as any `mfArray` and can occur in logical operators (`.not.`, `.and.`, `.or.`, etc.).

*See also:* `/=`, `mfIsEqual`, `<=`, `<`, `>=`, `>`

/=

mfArray relational operator

*Calling syntax:*
$$C = A \neq B$$
*Description:*

Returns a boolean mfArray from two dense mfArrays, by making the comparison element-wise.

A and B must have the same shape and must be, of course, of type real.

B may be a scalar, real or even integer.

*Remarks:* a boolean mfArray contains *TRUE* and *FALSE* values only. It can be displayed as any mfArray and can occur in logical operators (*.not.*, *.and.*, *.or.*, etc.).

*See also:* *==*, *mfIsEqual*, *<=*, *<*, *>=*, *>*

**mfAll****mfArray boolean operator***Interface:*

```
function mfAll( A, dim ) result( out )  
  
    type(mfArray), intent(in)      :: A  
    integer,       intent(in), optional :: dim  
    type(mfArray)                :: out
```

*Description:*

If **A** is a vector **mfArray**, returns a scalar boolean **mfArray** which is *TRUE* (*i. e.* 1) if all elements are *TRUE*.

If **A** is a matrix, the routine works down the columns, returning a row vector **mfArray**.

If **dim** is present, it indicates on which dimension the routine must be applied.

*See also:* [All](#), [mfAny](#)

**mfAny****mfArray boolean operator***Interface:*

```
function mfAny( A, dim ) result( out )  
  
    type(mfArray), intent(in)      :: A  
    integer,       intent(in), optional :: dim  
    type(mfArray)                :: out
```

*Description:*

If **A** is a vector **mfArray**, returns a scalar boolean **mfArray** which is *TRUE* (*i. e.* 1) if at least one element is *TRUE*.

If **A** is a matrix, the routine works down the columns, returning a row vector **mfArray**.

If **dim** is present, it indicates on which dimension the routine must be applied.

*See also:* [Any](#), [mfAll](#)

**mfColon****mfArray sequence constructor***Interface:*

```
A = mfColon( start, end [, step, tol ] )
```

*Description:*

Returns an `mfArray` containing a sequence: a list of reals equally spaced, from `start` to `end`, with the specified `step`.

By default (*i. e.* when `step` is not present), increment is unity.

Arguments `start`, `end` and `step` may be of type integer or real (single or double precision), but all of same kind and precision.

Because of the rounding errors, the last number of the sequence seldom matches to the specified value of `end`, especially when `step` is not an integer. To avoid this unrequired behavior, the tolerance `tol` can be used to round the resulting numbers in the sequence to a relative precision equal to `tol`. Therefore, the tolerance `tol` should be present only in the case where the first three arguments are reals, all of them having the same precision; moreover, it should be a negative power of ten, *e. g.* 0.001.

When `step` is not present, the value of `end` must be greater than that of `start`. When `step` is present, its sign must be the same as that of `end-start`. `step` cannot have a zero value.

See also: [mfLinSpace](#), [mfLogSpace](#)

*Example(s):*

```
call msDisplay( mfColon(1,15,step=3), "mfColon(1,15,step=3)" )
```

output:

```
mfColon(1,15,step=3) =  
    1    4    7   10   13
```

```
call msDisplay( mfColon(1.0,3.0,step=0.3333,tol=0.001),           &  
                "mfColon(1.0,3.0,step=0.3333,tol=0.001)" )
```

output:

```
mfColon(1.0,3.0,step=0.3333,tol=0.001) =  
    1.0000    1.3330    1.6670    2.0000    2.3330    2.6670    3.0000
```

.../...

```
call msDisplay( mfColon( 0.1, 1.3, step=0.2 ),           &  
                "mfColon( 0.1, 1.3, step=0.2 )" )
```

output:

```
mfColon( 0.1, 1.3, step=0.2 ) =  
0.1000  0.3000  0.5000  0.7000  0.9000  1.1000
```

```
call msDisplay( mfColon( 0.1, 1.3, step=0.2, tol=0.0001 ),           &  
                "mfColon( 0.1, 1.3, step=0.2, tol=0.0001 )" )
```

output:

```
mfColon( 0.1, 1.3, step=0.2, tol=0.0001 ) =  
0.1000  0.3000  0.5000  0.7000  0.9000  1.1000  1.3000
```



`.not.`

**mfArray logical operator**

*Calling syntax:*

```
C = .not. A
```

*Description:*

Takes the negation (element-wise) of a boolean `mfArray`.

*Remarks:* a boolean `mfArray` is of type real and contains 1 for `emphTRUE` and 0 for `FALSE`. It can be displayed as any `mfArray`; it is usually built from relational operators (`'=='`, `'/='`, `'>'`, *etc.*).

*See also:* `.and.`, `.or.`, `.eqv.`, `.neqv.`

`.and.`

**mfArray logical operator**

*Calling syntax:*

```
C = A .and. B
```

*Description:*

Composes (element-wise) two boolean `mfArrays`.

*Remarks:* a boolean `mfArray` is of type real and contains 1 for `emphTRUE` and 0 for `FALSE`. It can be displayed as any `mfArray`; it is usually built from relational operators (`'=='`, `'/='`, `'>'`, *etc.*).

*See also:* `.not.`, `.or.`, `.eqv.`, `.neqv.`

`.or.`

**mfArray logical operator**

*Calling syntax:*

`C = A .or. B`

*Description:*

Composes (element-wise) two boolean `mfArrays`.

*Remarks:* a boolean `mfArray` is of type real and contains 1 for `emphTRUE` and 0 for `FALSE`. It can be displayed as any `mfArray`; it is usually built from relational operators (`'=='`, `'/='`, `'>'`, *etc.*).

*See also:* `.not.`, `.and.`, `.eqv.`, `.neqv.`

`.eqv.`

**mfArray logical operator**

*Calling syntax:*

`C = A .eqv. B`

*Description:*

Composes (element-wise) two boolean `mfArrays`.

*Remarks:* a boolean `mfArray` is of type real and contains 1 for `emphTRUE` and 0 for `FALSE`. It can be displayed as any `mfArray`; it is usually built from relational operators (`'=='`, `'/='`, `'>'`, *etc.*).

*See also:* `.not.`, `.and.`, `.or.`, `.neqv.`

`.neqv.`

**mfArray logical operator**

*Calling syntax:*

```
C = A .neqv. B
```

*Description:*

Composes (element-wise) two boolean `mfArrays`.

*Remarks:* a boolean `mfArray` is of type real and contains 1 for `emphTRUE` and 0 for `FALSE`. It can be displayed as any `mfArray`; it is usually built from relational operators (`'=='`, `'/='`, `'>'`, *etc.*).

*See also:* `.not.`, `.and.`, `.or.`, `.eqv.`

`mfIsMember`

elements members of a set

*Calling syntax:*

```
E = mfIsMember( A, set [, tol ] )
```

*Description:*

Returns a boolean `mfArray` which shows which elements of the `mfArray` `A` are member of the `mfArray` `set`.

`E` has the same shape as `A`.

The `tol` optional argument is the tolerance used in the comparison test. By default, tolerance is zero, *i. e.* a strict equality is used to discard elements.

*Remark:* `mfArrays` `A` and `set` must be real with a dense structure.

*See also:* `mfIntersect`, `mfUnion`, `mfUnique`

*Example(s):*

```
a = mf([ 1, 2, 3 ]) .vc. mf([ 4, 5, 6 ])
set = [ 0, 12, 8, 6, 2, 10, 4 ]
call msDisplay( a, "a", set, "set" )
call msDisplay( mfIsMember(a,set), "mfIsMember(a,set)" )
```

output:

`a =`

```
  1   2   3
  4   5   6
```

`set =`

```
  0  12   8   6   2  10   4
```

`mfIsMember(a,set) =`

```
  F   T   F
  T   F   T
```

`mfIntersect`

common elements of two sets

*Calling syntax:*

```
E = mfIntersect( A, B [, tol ] )
```

*Description:*

Returns an `mfArray` containing all elements common to the `mfArrays` A and B. Duplicated elements are discarded; the result is a sorted row vector.

The `tol` optional argument is the tolerance used in the equality test to discard duplicated elements, if any. By default, tolerance is zero, *i. e.* a strict equality is used to discard elements.

*Remark:* `mfArrays` A and B must be both real with a dense structure.

*See also:* `mfIsMember`, `mfUnion`, `mfUnique`

*Example(s):*

```
A = reshape( [ 9, 7, 20, 4, 1, 5, 9, 7, 21, 1, 5, 25 ], [ 3, 4 ] )
B = reshape( [ 25, 15, 8, 8, 6, 5, 5, 4, 20, 10 ], [ 5, 2 ] )
call msDisplay( A, "A", B, "B" )
call msDisplay( mfIntersect(A,B), "mfIntersect(A,B)" )
```

output:

A =

```
  9   4   9   1
  7   1   7   5
 20   5  21  25
```

B =

```
 25   5
 15   5
  8   4
  8  20
  6  10
```

`mfIntersect(A,B) =`

```
  4   5  20  25
```

**mfUnion****all elements of two sets***Calling syntax:*

```
E = mfUnion( A, B [, tol ] )
```

*Description:*

Returns an `mfArray` containing all elements of to the `mfArrays` A and B. Duplicated elements are discarded; the result is a sorted row vector.

The `tol` optional argument is the tolerance used in the equality test to discard duplicated elements, if any. By default, tolerance is zero, *i. e.* a strict equality is used to discard elements.

*Remark:* `mfArrays` A and B must be both real with a dense structure.

*See also:* `mfIsMember`, `mfIntersect`, `mfUnique`

*Example(s):*

```
A = reshape( [ 9, 7, 20, 4, 1, 5, 9, 7, 21, 1, 5, 25 ], [ 3, 4 ] )
B = reshape( [ 25, 15, 8, 8, 6, 5, 5, 4, 20, 10 ], [ 5, 2 ] )
call msDisplay( A, "A", B, "B" )
call msDisplay( mfIntersect(A,B), "mfIntersect(A,B)" )
```

output:

A =

```
  9   4   9   1
  7   1   7   5
 20   5  21  25
```

B =

```
 25   5
 15   5
  8   4
  8  20
  6  10
```

mfIntersect(A,B) =

```
  1   4   5   6   7   8   9  10  15  20  21  25
```



## mfUnique

## unique elements of a set

*Interface:*

```
function mfUnique( A, order, occurrence, tol ) result( out )

    type(mfArray)                :: A
    character(len=*), intent(in), optional :: order, occurrence
    real(kind=MF_DOUBLE), intent(in), optional :: tol
    type(mfArray) :: out
```

*Description:*

Returns the unique elements of the `mfArray` `A`. `A` must be a vector (either row or column).

By default, the returned elements are sorted in increasing order. However, their layout may be changed by using the following optional parameters:

- the `order` optional argument (= "asc", "des" or "no") may be used to specify the ordering.
- if `order="no"`, no ordering is applied to the resulting elements but it is required to add the other `occurrence` optional argument (value may be "first" or "last") to specify if the selected element is the first one or the last one.

The `tol` optional argument is the tolerance used in the equality test to discard duplicated elements, if any. By default, tolerance is zero, *i. e.* a strict equality is used to discard elements.

*Remark:* the `mfArray` `A` must be real with a dense structure.

*See also:* [mfIsMember](#), [mfUnion](#), [mfIntersect](#)

*Example(s):*

```
a = [ 2, 4, 6, 8, 9, 8, 7, 1, 5, 3, 6, 2, 4 ]
call msDisplay( a, "a" )
call msDisplay( mfUnique(a), "mfUnique(a)" )
call msDisplay( mfUnique(a,order="des"), 'mfUnique(a,order="des")' )
call msDisplay( mfUnique(a,order="no",occurrence="first"),      &
                'mfUnique(a,order="no",occurrence="first")' )
call msDisplay( mfUnique(a,order="no",occurrence="last"),      &
                'mfUnique(a,order="no",occurrence="last")' )
```

output:

```
a =
    2    4    6    8    9    8    7    1    5    3    6    2    4

mfUnique(a) =
    1    2    3    4    5    6    7    8    9

mfUnique(a,order="des") =
    9    8    7    6    5    4    3    2    1
```

⋯/⋯

```
mfUnique(a,order="no",occurrence="first") =
```

```
  2   4   6   8   9   7   1   5   3
```

```
mfUnique(a,order="no",occurrence="last") =
```

```
  9   8   7   1   5   3   6   2   4
```

**1.5 Elementary Math Functions**

<code>mfACos</code>	inverse cosine
<code>mfACosh</code>	inverse hyperbolic cosine
<code>mfACot</code>	inverse cotangent
<code>mfACoth</code>	inverse hyperbolic cotangent
<code>mfACsc</code>	inverse cosecant
<code>mfACsch</code>	inverse hyperbolic cosecant
<code>mfASec</code>	inverse secant
<code>mfASech</code>	inverse hyperbolic secant
<code>mfASin</code>	inverse sine
<code>mfASinh</code>	inverse hyperbolic sine
<code>mfATan</code>	inverse tangent
<code>mfATan2</code>	four quadrant inverse tangent
<code>mfATanh</code>	inverse hyperbolic tangent
<code>mfCos</code>	cosine
<code>mfCosh</code>	hyperbolic cosine
<code>mfCot</code>	cotangent
<code>mfCoth</code>	hyperbolic cotangent
<code>mfCsc</code>	cosecant
<code>mfCsch</code>	hyperbolic cosecant
<code>mfSec</code>	secant
<code>mfSech</code>	hyperbolic secant
<code>mfSin</code>	sine
<code>mfSinh</code>	hyperbolic sine
<code>mfTan</code>	tangent
<code>mfTanh</code>	hyperbolic tangent
<code>mfSqrt</code>	square root
<code>mfExp</code>	exponential
<code>mfExpM1</code>	exponential minus one
<code>mfLog</code>	natural logarithm
<code>mfLog1p</code>	natural logarithm of $1 + x$
<code>mfLog10</code>	base 10 logarithm
<code>mf/msLog2</code>	base 2 logarithm
<code>mfPow10</code>	base 10 power
<code>mfPow2</code>	base 2 power
<code>mfFun, mfFun2</code>	general function (one or two arguments)
<code>mfGridFun</code>	general function (two arguments) applied to coords matrices
<code>mfAbs</code>	absolute value
<code>mfAngle</code>	phase angle
<code>mfComplex</code>	complex conversion
<code>mfConj</code>	complex conjugate
<code>mfImag</code>	complex imaginary part
<code>mfReal</code>	complex real part
<code>mfHypot</code>	hypotenuse
<code>mfRound</code>	round towards nearest integer
<code>mfCeil</code>	round towards plus infinity
<code>mfFix</code>	round towards zero
<code>mfFloor</code>	round towards minus infinity
<code>mfMod</code>	modulus after division
<code>mfRem</code>	remainder after division
<code>mfSign</code>	signum function
<code>mfCSign</code>	complex signum function

*See also:*

Core Routines

File Input/Output

Data Analysis Functions

Operators

Specialized Math Functions

Elementary Matrix Manipulation Functions

Matrix Functions

Polynomial Functions

Optimization and Function Functions

Sparse Matrices

**mfACos****inverse cosine***Calling syntax:*
$$C = \text{mfACos}( A )$$
*Description:*

Returns the inverse cosine (element-wise) of the **mfArray** **A** (numerical dense only).

*See also:* [mfCos](#), [mfACosh](#), [mfCosh](#)

**mfACosh****inverse hyperbolic cosine***Calling syntax:*

```
C = mfACosh( A )
```

*Description:*

Returns the inverse hyperbolic cosine (element-wise) of the `mfArray` `A` (numerical dense only).

*See also:* [mfCos](#), [mfACos](#), [mfCosh](#)

**mfACot****inverse cotangent***Calling syntax:*
$$C = \text{mfACot}( A )$$
*Description:*

Returns the inverse cotangent (element-wise) of the `mfArray` `A` (numerical dense only).

*See also:* [mfCot](#), [mfACoth](#), [mfCoth](#)

**mfACoth****inverse hyperbolic cotangent***Calling syntax:*

```
C = mfACoth( A )
```

*Description:*

Returns the inverse hyperbolic cotangent (element-wise) of the **mfArray** **A** (numerical dense only).

*See also:* [mfCot](#), [mfACot](#), [mfCoth](#)



**mfACsc****inverse cosecant***Calling syntax:*
$$C = \text{mfACsc}( A )$$
*Description:*

Returns the inverse cosecant (element-wise) of the `mfArray` `A` (numerical dense only).

*See also:* [mfCsc](#), [mfACsch](#), [mfCsch](#)

**mfACsch****inverse hyperbolic cosecant***Calling syntax:*

```
C = mfACsch( A )
```

*Description:*

Returns the inverse hyperbolic cosecant (element-wise) of the `mfArray` `A` (numerical dense only).

*See also:* [mfCsc](#), [mfACsc](#), [mfCsch](#)

**mfASec****inverse secant***Calling syntax:*
$$C = \text{mfASec}( A )$$
*Description:*

Returns the inverse secant (element-wise) of the `mfArray` `A` (numerical dense only).

*See also:* [mfSec](#), [mfASech](#), [mfSech](#)

**mfASech****inverse hyperbolic secant***Calling syntax:*

```
C = mfASech( A )
```

*Description:*

Returns the inverse hyperbolic secant (element-wise) of the `mfArray` `A` (numerical dense only).

*See also:* [mfSec](#), [mfASec](#), [mfSech](#)

**mfASin****inverse sine***Calling syntax:*

```
C = mfASin( A )
```

*Description:*

Returns the inverse sine (element-wise) of the mfArray A (numerical dense only).

*See also:* [mfSin](#), [mfASinh](#), [mfSinh](#)

**mfASinh****inverse hyperbolic sine***Calling syntax:*

```
C = mfASinh( A )
```

*Description:*

Returns the inverse hyperbolic sine (element-wise) of the `mfArray` `A` (numerical dense only).

*See also:* [mfSin](#), [mfASin](#), [mfSinh](#)

**mfATan****inverse tangent***Calling syntax:*

```
C = mfATan( A )
```

*Description:*

Returns the inverse tangent (element-wise) of the `mfArray` `A` (numerical dense only).

*See also:* [mfATan2](#), [mfTan](#), [mfATanh](#), [mfTanh](#)

**mfATan2****four quadrant inverse tangent***Calling syntax:*

```
C = mfATan2( Y, X )
```

*Description:*

Returns the four quadrant inverse tangent (element-wise) of the quotient  $Y/X$ , and the result is in  $(-\pi, \pi]$ .

**X** and **Y** must be numerical, dense **mfArrays**.

*See also:* [mfATan](#), [mfTan](#), [mfATanh](#), [mfTanh](#)



**mfATanh****inverse hyperbolic tangent***Calling syntax:*
$$C = \text{mfATanh}( A )$$
*Description:*

Returns the inverse hyperbolic tangent (element-wise) of the `mfArray` `A` (numerical dense only).

*See also:* [mfTan](#), [mfATan](#), [mfTanh](#)

**mfCos****cosine***Calling syntax:*
$$C = \text{mfCos}( A )$$
*Description:*

Returns the cosine (element-wise) of the `mfArray` `A` (numerical dense only).

*See also:* [mfACos](#), [mfACosh](#), [mfCosh](#)

**mfCosh****hyperbolic cosine***Calling syntax:*

```
C = mfCosh( A )
```

*Description:*

Returns the hyperbolic cosine (element-wise) of the `mfArray` `A` (numerical dense only).

*See also:* [mfCos](#), [mfACos](#), [mfACosh](#)

**mfCot****cotangent***Calling syntax:*
$$C = \text{mfCot}( A )$$
*Description:*

Returns the cotangent (element-wise) of the `mfArray` `A` (numerical dense only).

*See also:* [mfACot](#), [mfACoth](#), [mfCoth](#)

**mfCoth****hyperbolic cotangent***Calling syntax:*
$$C = \text{mfCoth}( A )$$
*Description:*

Returns the hyperbolic cotangent (element-wise) of the `mfArray` `A` (numerical dense only).

*See also:* [mfCot](#), [mfACot](#), [mfACoth](#)

**mfCsc****cosecant***Calling syntax:*
$$C = \text{mfCsc}( A )$$
*Description:*

Returns the cosecant (element-wise) of the `mfArray` `A` (numerical dense only).

*See also:* [mfACsc](#), [mfACsch](#), [mfCsch](#)

**mfCsch****hyperbolic cosecant***Calling syntax:*
$$C = \text{mfCsch}( A )$$
*Description:*

Returns the hyperbolic cosecant (element-wise) of the mfArray A (numerical dense only).

*See also:* [mfCsc](#), [mfACsc](#), [mfACsch](#)

**mfSec****secant***Calling syntax:*

```
C = mfSec( A )
```

*Description:*

Returns the secant (element-wise) of the `mfArray` `A` (numerical dense only).

*See also:* [mfASec](#), [mfASech](#), [mfSech](#)



**mfSech****hyperbolic secant***Calling syntax:*

```
C = mfSech( A )
```

*Description:*

Returns the hyperbolic secant (element-wise) of the `mfArray` `A` (numerical dense only).

*See also:* [mfASech](#), [mfASec](#), [mfSec](#)

**mfSin****sine***Calling syntax:*

```
C = mfSin( A )
```

*Description:*

Returns the sine (element-wise) of the **mfArray** **A** (numerical dense only).

*See also:* [mfASin](#), [mfASinh](#), [mfSinh](#)

**mfSinh****hyperbolic sine***Calling syntax:*

```
C = mfSinh( A )
```

*Description:*

Returns the hyperbolic sine (element-wise) of the **mfArray** **A** (numerical dense only).

*See also:* [mfASin](#), [mfASinh](#), [mfSin](#)

**mfTan****tangent***Calling syntax:*
$$C = \text{mfTan}( A )$$
*Description:*

Returns the tangent (element-wise) of the `mfArray` `A` (numerical dense only).

*See also:* [mfATan](#), [mfATanh](#), [mfTanh](#)

**mfTanh****hyperbolic tangent***Calling syntax:*
$$C = \text{mfTanh}( A )$$
*Description:*

Returns the hyperbolic tangent (element-wise) of the `mfArray` `A` (numerical dense only).

*See also:* [mfATan](#), [mfATanh](#), [mfTan](#)

**mfSqrt****square root***Calling syntax:*
$$C = \text{mfSqrt}( A )$$
*Description:*

Returns the square root (element-wise) of the `mfArray` `A` (dense or sparse, real or complex).

The returned `mfArray` may be of type complex if any element has a negative value.

*See also:* [mfSqrtm](#)

**mfExp****exponential***Calling syntax:*
$$C = \text{mfExp}( A )$$
*Description:*

Returns the exponential (element-wise) of the `mfArray` `A` (numerical dense only).

*See also:* [mfLog](#), [mfLog1p](#), [mfExpn1](#), [mfExpn](#)

**mfExp1****exponential minus one***Calling syntax:*

```
C = mfExp1( A )
```

*Description:*

Returns the value of  $\exp(x)-1$ , for each  $x$  element of the `mfArray` `A`. This operation is made element-wise.

*See also:* [mfExp](#), [mfLog](#), [mfLog1p](#), [mfExp1](#)



**mfLog****natural logarithm***Calling syntax:*
$$C = \text{mfLog}( A )$$
*Description:*

Returns the natural logarithm (element-wise) of the **mfArray** **A** (numerical dense only).

*See also:* [mfLog1p](#), [mfExp](#), [mfExp1](#), [mfLogm](#)

**mfLog1p****natural logarithm of  $1 + x$** *Calling syntax:*

```
C = mfLog1p( A )
```

*Description:*

Returns the value of  $\log(1 + x)$ , for each  $x$  element of the `mfArray` `A` (numerical dense only). This operation is made element-wise.

*See also:* [mfLog](#), [mfExp](#), [mfExpn1](#), [mfExpn](#)

**mfLog10****base 10 logarithm***Calling syntax:*
$$C = \text{mfLog10}( A )$$
*Description:*

Returns the base 10 logarithm (element-wise) of the **mfArray** **A** (numerical dense only).

*See also:* [mfLog](#), [mf/msLog2](#)

mf/msLog2

**base 2 logarithm***Calling syntax:*

```
C = mfLog2( A )
```

*Description:*

Returns the base 2 logarithm (element-wise) of the mfArray A (numerical dense only).

The subroutine version returns two mfArrays:

```
call msLog2( mfOut(M,E), A )
```

The mantissa M has its element ranged in  $[0.5, 1[$ , whereas elements of E are integer exponents.

Each element of A verifies:  $a = m2^e$

*See also:* [mfPow2](#), [mfLog](#), [mfLog10](#), [mfOut](#)

**mfPow10****base 10 power***Calling syntax:*

```
C = mfPow10( A )
```

*Description:*

Returns the base 10 power (element-wise) of the `mfArray` A (numerical dense only).

*See also:* [mfLog10](#)

**mfPow2****base 2 power***First usage:*
$$C = \text{mfPow2}( A )$$
*Description:*

Returns the base 2 power (element-wise) of the `mfArray` `A` (numerical dense only).

*Second usage:*
$$C = \text{mfPow2}( M, E )$$
*Description:*

Returns numbers which write:  $m2^e$ , for each (real)  $m$  of `M` and each (integer)  $e$  of `E`. `M` and `E` are two `mfArrays`.

*See also:* [mfLog2](#)

**mfFun****general function (one arg.)***Usage:*

```
C = mfFun( A, fun )
```

*Description:*

Apply the user-defined function (element-wise) `fun` to the `mfArray` `A` (numerical dense only).

`fun` is a real or complex function having the following interface:

```
real(kind=MF_DOUBLE) function fun( x1 )
  real(kind=MF_DOUBLE), intent(in) :: x1
end function
```

or

```
complex(kind=MF_DOUBLE) function fun( x1 )
  complex(kind=MF_DOUBLE), intent(in) :: x1
end function
```

*See also:* [mfFunm](#), [mfFun2](#)

**mfFun2****general function (two args)***Usage:*

```
C = mfFun2( A, B, fun )
```

*Description:*

Apply the user-defined function (element-wise) `fun` to the `mfArrays` `A` and `B` (numerical dense only).

`fun` is a real or complex function having the following interface:

```
real(kind=MF_DOUBLE) function fun( x1, x2 )
  real(kind=MF_DOUBLE), intent(in) :: x1, x2
end function
```

or

```
complex(kind=MF_DOUBLE) function fun( x1, x2 )
  complex(kind=MF_DOUBLE), intent(in) :: x1, x2
end function
```

*See also:* [mfFun](#), [mfGridFun](#)



`mfGridFun`                      **general function (two args) applied to coords matrices**

*Usage:*

```
Z = mfGridFun( v_x, v_y, fun )
```

applies the 2-argument function `fun` to the couple of coordinate matrices  $(X, Y)$  generated by the vectors `v_x` and `v_y`, without building  $X$  and  $Y$  (see `msMeshGrid` about constraints concerning `v_x` and `v_y`). It aims at economize memory for large grids.

`fun` is either a character string giving the name of a 2-arg function (as *complex*, *hypot*, *atan2*, ...), or the name of a user defined function. In this latter case, the user function must have the following interface:

```
real(kind=MF_DOUBLE) function fun( x1, x2 )
  real(kind=MF_DOUBLE), intent(in) :: x1, x2
end function
```

See also: `mfFun2`

**mfAbs****absolute value***Calling syntax:*

```
C = mfAbs( A )
```

*Description:*

Returns the absolute value (or the module for complex numbers) of the `mfArray` `A` (dense or sparse). This operation is made element-wise.

*See also:* [mfAngle](#)

**mfAngle****phase angle***Calling syntax:*

```
C = mfAngle( A )
```

*Description:*

Returns the phase angle (element-wise), in radians of the complex `mfArray` `A` (dense or sparse).

For real values, this function returns 0 or  $\pi$ . Moreover, it returns 0 when argument is null (real or complex), so maintains the sparsity of the `mfArray`.

*See also:* [mfAbs](#)

**mfComplex****complex conversion***Calling syntax:*

```
C = mfComplex( A [, B] )
```

*Description:*

Converts a real **mfArray** **A** (dense or sparse) in a complex one.

If the optional argument **mfArray** **B** is present, builds a complex **mfArray** whose real part is **A** and the imaginary part is **B**. In this latter case, **A** and **B** must be both real (dense or sparse).

*See also:* [mfReal](#), [mfImag](#)

**mfConj****complex conjugate***Calling syntax:*

```
C = mfConj( A )
```

*Description:*

Returns the conjugate (element-wise) of the complex `mfArray` `A` (dense or sparse).

`A` may be real, but the returned `mfArray` is complex.

*See also:* [.h.](#)

**mfImag****complex imaginary part***Calling syntax:*
$$C = \text{mfImag}( A )$$
*Description:*

Returns the imaginary part (element-wise) of the complex `mfArray` `A` (dense or sparse).

*See also:* [mfReal](#)

**mfReal****complex real part***Calling syntax:*

```
C = mfReal( A )
```

*Description:*

Returns the real part (element-wise) of the complex `mfArray` `A` (dense or sparse).

*See also:* [mfImag](#)

**mfHypot****hypotenuse***Calling syntax:*

```
C = mfHypot( A, B )
```

*Description:*

Returns the hypotenuse of a right rectangle whose sides (`mfArrays` A and B, in dense format) are provided. This operation is made element-wise.

*Remarks:* the computation is done without overflow or underflow.



**mfRound****round towards nearest integer***Calling syntax:*

```
C = mfRound( A )
```

*Description:*

Rounds towards nearest integer each element of the `mfArray` `A` (dense or sparse). The behavior of this routine is similar to the *anint* Fortran 90 intrinsic function.

*See also:* [mfCeil](#), [mfFix](#), [mfFloor](#)

**mfCeil****round towards plus infinity***Calling syntax:*

```
C = mfCeil( A )
```

*Description:*

Rounds towards plus infinity each element of the `mfArray` A (dense or sparse).

*See also:* [mfFix](#), [mfFloor](#), [mfRound](#)

**mfFix****round towards zero***Calling syntax:*

```
C = mfFix( A )
```

*Description:*

Rounds towards zero each element of the `mfArray` A (dense or sparse).

*See also:* [mfCeil](#), [mfFloor](#), [mfRound](#)

**mfFloor****round towards minus infinity***Calling syntax:*

```
C = mfFloor( A )
```

*Description:*

Rounds towards minus infinity each element of the **mfArray** **A** (dense or sparse).

*See also:* [mfCeil](#), [mfFix](#), [mfRound](#)

**mfMod****modulus after division***Calling syntax:*

```
C = mfMod( A, B )
```

*Description:*

Returns the modulus after division of each element of the `mfArray` A (numerical dense only).

*N.B.:* this is the Fortran 90 modulo function

*See also:* [mfRem](#)

**mfRem****remainder after division***Calling syntax:*

```
C = mfRem( A, B )
```

*Description:*

Returns the modulus after division of each element of the `mfArray` A (numerical dense only).

*N.B.:* this is the Fortran 90 `mod` function

*See also:* [mfMod](#)

**mfSign****signum function***Calling syntax:*

```
C = mfSign( A )
```

*Description:*

Applies the signum function to each element of the **mfArray** **A** (numerical dense only). It returns only 1 or  $-1$ .

*N.B.:* It differs from the Fortran 90 **sign** intrinsic function.

*See also:* [mfCSign](#)

**mfCSign****complex signum function***Calling syntax:*

```
C = mfCSign( A )
```

*Description:*

Applies the complex signum function to each element of the `mfArray` `A` (numerical dense only).

*See also:* [mfSign](#)



## 1.6 Specialized Math Functions

<code>mfErf</code>	Error function
<code>mfErfInv</code>	inverse Error function
<code>mfErfC</code>	Complementary Error function
<code>mfErfCInv</code>	inverse Complementary Error function
<code>mfErfCScaled</code>	Scaled Complementary Error function
<code>mfExpInt</code>	Exponential Integral function
<code>mfGamma</code>	Gamma function
<code>mfGammaLn</code>	Logarithm of the Gamma function
<code>mfBesselJ</code>	Bessel functions of the first kind
<code>mfBesselY</code>	Bessel functions of the second kind
<code>mfBesselI</code>	modified Bessel functions of the first kind
<code>mfBesselK</code>	modified Bessel functions of the second kind
<code>mfAiry</code>	Airy function
<code>msEllipKE</code>	complete elliptic integrals of first and second kinds
<code>mfIsPrime</code>	prime number test
<code>mfFactor</code>	prime numbers factorization
<code>msCleanPrimeNumbers</code>	prime numbers storage cleaning
<code>msRat</code>	rational approximation

*See also:*

[Core Routines](#)

[File Input/Output](#)

[Data Analysis Functions](#)

[Operators](#)

[Elementary Math Functions](#)

[Elementary Matrix Manipulation Functions](#)

[Matrix Functions](#)

[Polynomial Functions](#)

[Optimization and Function Functions](#)

[Sparse Matrices](#)

**mfErf****Error function***Calling syntax:*
$$C = \text{mfErf}( A )$$
*Description:*

Returns the Error function (element-wise) of the mfArray **A** (dense only, real or complex).

*See also:* [mfErfC](#), [mfErfInv](#), [mfErfCInv](#), [mfErfCScaled](#)

**mfErfInv****inverse Error function***Calling syntax:*

```
C = mfErfInv( A )
```

*Description:*

Returns the inverse Error function (element-wise) of the `mfArray` `A` (dense only).

Restriction: `A` must be of type real.

*See also:* [mfErf](#), [mfErfC](#), [mfErfCInv](#), [mfErfCScaled](#)

**mfErfC****Complementary Error function***Calling syntax:*

```
C = mfErfC( A )
```

*Description:*

Returns the Complementary Error function (element-wise) of the `mfArray` A (dense only, real or complex).

*See also:* [mfErf](#), [mfErfInv](#), [mfErfCInv](#), [mfErfCScaled](#)

**mfErfCInv****inverse Complementary Error function***Calling syntax:*

```
C = mfErfCInv( A )
```

*Description:*

Returns the inverse Complementary Error function (element-wise) of the `mfArray` `A` (dense only).

Restriction: `A` must be of type real.

*See also:* [mfErf](#), [mfErfInv](#), [mfErfC](#), [mfErfCScaled](#)

**mfErfCScaled****Scaled Complementary Error function***Calling syntax:*

```
C = mfErfCScaled( A )
```

*Description:*

Returns the Scaled Complementary Error function (element-wise) of the `mfArray` `A` (dense only), defined by `mfErfCScaled(x) = exp(x**2) * mfErfC(x)`

Restriction: `A` must be of type real.

*See also:* [mfErf](#), [mfErfInv](#), [mfErfC](#), [mfErfCInv](#)

`mfExpInt`**Exponential Integral function**

*Calling syntax:*

```
C = mfExpInt( A )
```

*Description:*

Returns the exponential integral function (element-wise) of the `mfArray` `A` (dense only).

This function is mathematically defined as:

$$E_1(x) = \int_x^\infty \frac{\exp(-t)}{t} dt$$

For positive value of  $x$ , it has the following properties:

$$E_1(0) = +\infty, \quad E_1(+\infty) = 0$$

*Restriction:* `A` must be of type real and must have a positive value. On the contrary, a warning is emitted.

**mfGamma****Gamma function***Calling syntax:*

```
C = mfGamma( A )
```

*Description:*

Returns the gamma function (element-wise) of the **mfArray** **A** (dense only).

Restriction: **A** must be of type real.

*See also:* [mfGammaLn](#)



**mfGammaLn****Logarithm of the Gamma function***Calling syntax:*

```
C = mfGammaLn( A )
```

*Description:*

Returns the natural logarithm of the gamma function (element-wise) of the `mfArray` `A` (dense only).

Restriction: `A` must contain positive real values.

*See also:* [mfGamma](#)

`mfBesselJ`**Bessel functions of the first kind***Calling syntax:*

```
C = mfBesselJ( alpha, A )
```

*Description:*

Returns the Bessel functions of the first kind  $J_\alpha(x)$  (element-wise) of the `mfArray` `A` (dense only).

The `real` `alpha` order doesn't need to be an integer: both positive and negative fractional orders are possible.

Restriction: `A` must be of type `real` but, according to the values of  $\alpha$  and  $x$ , a complex `mfArray` may be returned.

*Remark:* Some roots of  $J_0(x)$  and  $J_1(x)$  are stored respectively in the arrays: `MF_BESSEL_J0_ROOTS` and `MF_BESSEL_J1_ROOTS`.

*See also:* `mfBesselY`, `mfBesselI`, `mfBesselK`, `MF_BESSEL_J0_ROOTS`, `MF_BESSEL_J1_ROOTS`

**mfBesselY****Bessel functions of the second kind***Calling syntax:*

```
C = mfBesselY( alpha, A )
```

*Description:*

Returns the Bessel functions of the second kind  $Y_\alpha(x)$  (element-wise) of the `mfArray` `A` (dense only).

The `real` `alpha` order doesn't need to be an integer: both positive and negative fractional orders are possible.

Restriction: `A` must be of type `real` but, according to the values of  $\alpha$  and  $x$ , a complex `mfArray` may be returned.

*See also:* `mfBesselJ`, `mfBesselI`, `mfBesselK`

**mfBesselI****modified Bessel functions of the first kind***Calling syntax:*

```
C = mfBesselI( alpha, A )
```

*Description:*

Returns the modified Bessel functions of the first kind  $I_\alpha(x)$  (element-wise) of the `mfArray` `A` (dense only).

The `real` `alpha` order doesn't need to be an integer: both positive and negative fractional orders are possible.

Restriction: `A` must be of type `real` but, according to the values of  $\alpha$  and  $x$ , a complex `mfArray` may be returned.

*See also:* `mfBesselJ`, `mfBesselY`, `mfBesselK`

**mfBesselK****modified Bessel functions of the second kind***Calling syntax:*

```
C = mfBesselK( alpha, A )
```

*Description:*

Returns the modified Bessel functions of the second kind  $K_\alpha(x)$  (element-wise) of the **mfArray** **A** (dense only).

The **real** **alpha** order doesn't need to be an integer: both positive and negative fractional orders are possible.

Restriction: **A** must be of type real but, according to the values of  $\alpha$  and  $x$ , a complex **mfArray** may be returned.

*See also:* [mfBesselJ](#), [mfBesselY](#), [mfBesselI](#)

**mfAiry****Airy function***Calling syntax:*

```
B = mfAiry( A )
```

*Description:*

Returns the Airy function (element-wise) of the `mfArray` `A` (dense only).

Restriction: `A` must be of type real and a real `mfArray` is returned. Complex function is not yet implemented.

*See also:* [mfBesselJ](#)

## msEllipKE complete elliptic integrals of first and second kinds

*Calling syntax:*

```
call msEllipKE( mfOut(K,E), A )
```

*Description:*

Computes the complete elliptic integrals of first and second kind  $K(m)$  and  $E(m)$  (element-wise) of the `mfArray` `A` (dense only), which are stored in the two `mfArray` `K` and `E`.

Each element of the array `A` is taken to be the parameter  $m = k^2$ , where  $k$  is the modulus.

The parameter  $m$  must be ranged in  $[0, 1]$  else `NaN` values are returned for both integrals.

*See also:* `mfOut`

**mfIsPrime****prime number test***Calling syntax:*

```
B = mfIsPrime( A )
```

*Description:*

Tests if numbers in the `mfArray` `A` are prime numbers. This function returns a boolean `mfArray` of same shape as `A`. The argument `A` may be scalar, vector or matrix, and is supposed to contain only integer numbers.

*Remark:* Integers involved in this routine must be less than 2,147,000,000.

*See also:* [mfFactor](#), [msCleanPrimeNumbers](#)



**mfFactor****prime numbers factorization***Calling syntax:*

```
B = mfFactor( A )
```

*Description:*

Returns the prime factors of the scalar `mfArray` `A`. The argument `A` is supposed to contain an integer number.

*Remark:* Integers involved in this routine must be less than 2,147,000,000.

*See also:* [mfIsPrime](#), [msCleanPrimeNumbers](#)

*Example(s):*

```
x = 2**4 * 3**3 * 5**2 * 7
call msDisplay( x, "x = 2**4 * 3**3 * 5**2 * 7" )
print "(/,A)", "*** test number 109 ***"
call msDisplay( mfFactor(x), "mfFactor(x)" )
```

output:

```
x = 2**4 * 3**3 * 5**2 * 7 =
```

```
75600
```

```
mfFactor(x) =
```

```
2 2 2 2 3 3 3 5 5 7
```

**msCleanPrimeNumbers****prime numbers storage cleaning***Calling syntax:*

```
call msCleanPrimeNumbers( )
```

*Description:*

Cleans the temporary storage of prime numbers, required for **mfIsPrime** and **mfFactor** routines. According to the magnitude of the involved integers, up to 450 MB of memory can be freed.

msRat

rational approximation

*Calling syntax:*

```
call msRat( mfOut(N,D), A [, tol] )
```

*Description:*

Computes the rational approximation (element-wise) of the `mfArray` A (real dense only), and returns the matrix of numerators in the `mfArray` N and the matrix of denominators in the `mfArray` D.

Default relative tolerance for the approximation is  $10^{-6}$ . Tolerance cannot be larger than  $10^{-2}$  and cannot be smaller than  $10^{-12}$ .

For example, with the default tolerance,  $\pi = 355/113$ . Any numerical value has a rational approximation, even `Inf` = 1/0 and `NaN` = 0/0.

See also: `mfOut`

*Example(s):*

```
x = MF_PI
call msDisplay( x, "x = MF_PI" )
call msRat( mfOut(y,z), x )
call msDisplay( y, "numerator", z, "denominator" )
```

output:

```
x = MF_PI =
```

```
3.1416
```

```
numerator =
```

```
355
```

```
denominator =
```

```
113
```

```
x = mfHilb(4)
call msDisplay( x, "x = mfHilb(4)" )
call msRat( mfOut(y,z), x )
call msDisplay( y, "numerator", z, "denominator" )
```

output:

```
x = mfHilb(4)
```

```
1.0000    0.5000    0.3333    0.2500
0.5000    0.3333    0.2500    0.2000
0.3333    0.2500    0.2000    0.1667
0.2500    0.2000    0.1667    0.1429
```

⋯/⋯

numerator =

1	1	1	1
1	1	1	1
1	1	1	1
1	1	1	1

denominator =

1	2	3	4
2	3	4	5
3	4	5	6
4	5	6	7

## 1.7 Elementary Matrix Manipulation Functions

<code>mfEye</code>	identity matrix
<code>mfLinSpace</code>	linear spaced vector
<code>mfLogSpace</code>	log spaced vector
<code>mfMagic</code>	magic square
<code>msMeshGrid</code>	arrays for interpolation and 3-D plots
<code>mfZeros</code>	matrix of zeros
<code>mfOnes</code>	matrix of ones
<code>mfRand</code>	uniformly distributed random numbers
<code>msRand</code>	set the random number generator seed
<code>mfRandN</code>	normally distributed random numbers
<code>mfRandPoiss</code>	Poisson distributed random numbers
<code>mfRepMat</code>	replicate and tile an array
<code>mfMerge</code>	merge of two arrays
<code>mfPack, mfUnpack</code>	packing and unpacking arrays
<code>mfCshift, mfeoshift</code>	array shifting
<code>mf/msDiag</code>	diagonal matrices and diagonals of a matrix
<code>mfBlkDiag</code>	block diagonal concatenation
<code>mf/msFind</code>	find indices of nonzero elements
<code>mfNonZeros</code>	non-zero elements
<code>mf/msReshape</code>	shape modification
<code>mfTriL</code>	lower triangular part
<code>mfTriU</code>	upper triangular part
<code>mfFlipLR</code>	matrix flip Left-Right
<code>mfFlipUD</code>	matrix flip Up-Down
<code>mfRot90</code>	matrix rotation
<code>mfHilb</code>	Hilbert matrix
<code>mfInvHilb</code>	inverse Hilbert matrix
<code>mfVander</code>	Vandermonde matrix
<code>mfCompan</code>	Companion matrix
<code>mfHankel</code>	Hankel matrix
<code>mfToeplitz</code>	Toeplitz matrix
<code>mfPerm</code>	permutation vector creation
<code>mfRandPerm</code>	random permutation vector creation
<code>mfCheckPerm</code>	permutation vector checking
<code>isfinite, mflsFinite</code>	finite test
<code>isinf, mflsInf</code>	infinity test
<code>isnan, mflsNaN</code>	Not-a-Number test
<code>mfIsDiag</code>	diagonal pattern test
<code>mfIsTriL</code>	lower triangular pattern test
<code>mfIsTriU</code>	upper triangular pattern test

*See also:*

[Core Routines](#)

[File Input/Output](#)

[Data Analysis Functions](#)

[Operators](#)

[Elementary Math Functions](#)

[Specialized Math Functions](#)

[Matrix Functions](#)

Polynomial Functions

Optimization and Function Functions

Sparse Matrices

**mfEye****identity matrix***Calling syntax:*

```
A = mfEye( n1 [, n2] )
```

*Description:*

Returns an `mfArray` containing the identity matrix.

If it is called with one integer argument, the identity matrix is square, of shape  $(n1,n1)$ .

If the optional argument `n2` is present, the routine builds an identity matrix of shape  $(n1,n2)$ .

*See also:* [mfOnes](#), [mfZeros](#)

**mfLinSpace** **linear spaced vector, given nb of values***First calling syntax:*

```
A = mfLinSpace( start, end [, nval] )
```

*Description:*

Returns an `mfArray` (row vector) which contains a list of reals equally spaced, from `start` to `end`, with the specified number of values `nval`. `start` and `end` can take any arbitrary finite values, even equal.

By default (*i.e.* when the integer `nval` is not present), the list contains `nval = 100` reals. If `nval` is present, it must be greater than or equal to 2.

*Second calling syntax:*

```
A = mfLinSpace( [ start | end ], nval, step )
```

*Description:*

In this second syntax, only one argument among `start` and `end` can be present. The additional `step` argument specifies the step between two consecutive values; it cannot be equal to zero.

*Remarks:* `start`, `end` and `step` must be of type `real` (single or double precision).

*See also:* [mfColon](#), [mfLogSpace](#)

*Example(s):*

```
call msDisplay( mfLinspace(-MF_PI, MF_PI, 5),           &
                "mfLinspace(-MF_PI, MF_PI, 5)" )
```

output:

```
mfLinspace(-MF_PI, MF_PI, 5) =
-3.1416  -1.5708   0.0000   1.5708   3.1416
```

```
call msDisplay( mfLinSpace(end=1.0d0, nval=5, step=0.1d0), &
                "mfLinSpace(end=1.0d0, nval=5, step=0.1d0)" )
```

output:

```
mfLinSpace(end=1.0d0, nval=5, step=0.1d0) =
0.6000   0.7000   0.8000   0.9000   1.0000
```



**mfLogSpace** **log spaced vector, given nb of values***First calling syntax:*

```
A = mfLogSpace( start, end [, nval] )
```

*Description:*

Returns an mfArray (row vector) which contains a list of reals logarithmic spaced, from  $10^{\text{start}}$  to  $10^{\text{end}}$ , with the specified number of values nval.

By default (*i.e.* when the integer nval is not present), the list contains nval = 20 reals. If nval is present, it must be greater than or equal to 2.

*Second calling syntax:*

```
A = mfLogSpace( [ start | end ], nval, step )
```

*Description:*

In this second syntaxe, only one argument among start and end can be present. The additional step argument specifies the step between the logarithm of two consecutive values; it cannot be equal to zero.

*Remarks:* start, end and step must be of type real (single or double precision).

*See also:* [mfColon](#), [mfLinSpace](#)

*Example(s):*

```
call msDisplay( mfLogspace(0.0d0, 5.0d0, 6),           &
                "mfLogspace(0.0d0, 5.0d0, 6)" )
```

output:

```
mfLogspace(0.0d0, 5.0d0, 6) =
      1      10      100      1000      10000      100000
```

```
call msDisplay( mfLogSpace(start=0.0d0, nval=6, step=0.5d0),           &
                "mfLogSpace(start=0.0d0, nval=6, step=0.5d0)" )
```

output:

```
mfLogSpace(start=0.0d0, nval=6, step=0.5d0) =
  1.0000  3.1623  10.0000  31.6228  100.0000  316.2278
```

**mfMagic****magic square***Calling syntax:*

```
A = mfMagic( n )
```

*Description:*

Returns an `mfArray` containing a magic square, from any positive integer  $n \geq 3$ .

*Example(s):*

```
call msDisplay( mfMagic(3), "mfMagic(3)" )
call msDisplay( mfMagic(4), "mfMagic(4)" )
```

output:

```
mfMagic(3) =
```

```
  8   3   4
  1   5   9
  6   7   2
```

```
mfMagic(4) =
```

```
  1  12   8  13
 15   6  10   3
 14   7  11   2
   4   9   5  16
```

## msMeshGrid

## grid coordinates generation

Calling syntax:

```
call msMeshGrid( mfOut(X,Y), v_x, v_y )
```

Description:

Builds two `mfArrays` containing the  $(x,y)$  coordinates of the nodes of a rectangular, structured grid, generated from the two real vectors `v_x` and `v_y`.

Among the two input vectors (called generator vectors), one must be a row vector, and the other a column vector. Then the row vector is vertically replicated as many times as the size of the other to form one of the coordinate matrices, and conversely for the other.

The coordinate matrices `X` and `Y` are typically used to visualize a data matrix with an orientation different from that used by default. See more explanation in section “*Changing Orientation/Transposition of Matrix Data*” in the *Muesli User Guide*. They can also be used in 2D interpolation (see `mfInterp2`).

*Remark:* Note that most of the time, you don’t need to compute explicitly the coordinate matrices `(X,Y)` since you are able to pass the generator vectors directly to graphic routines (`msPColor`, `msContour`, etc.), and also to the numerical routine `mfGridFun`.

See also: `mfOut`

Example(s):

```
v_x =      mfLinSpace( -1.0d0, 1.0d0, 5 )
v_y = .t. mfLinSpace( -1.5d0, 1.5d0, 7 )
call msMeshgrid( mfOut(X,Y), v_x, v_y )
call msDisplay( X, "X", Y, "Y" )
```

output:

X =

```
-1.0000  -0.5000   0.0000   0.5000   1.0000
-1.0000  -0.5000   0.0000   0.5000   1.0000
-1.0000  -0.5000   0.0000   0.5000   1.0000
-1.0000  -0.5000   0.0000   0.5000   1.0000
-1.0000  -0.5000   0.0000   0.5000   1.0000
-1.0000  -0.5000   0.0000   0.5000   1.0000
-1.0000  -0.5000   0.0000   0.5000   1.0000
```

Y =

```
-1.5000  -1.5000  -1.5000  -1.5000  -1.5000
-1.0000  -1.0000  -1.0000  -1.0000  -1.0000
-0.5000  -0.5000  -0.5000  -0.5000  -0.5000
 0.0000   0.0000   0.0000   0.0000   0.0000
 0.5000   0.5000   0.5000   0.5000   0.5000
 1.0000   1.0000   1.0000   1.0000   1.0000
 1.5000   1.5000   1.5000   1.5000   1.5000
```

**mfZeros****matrix of zeros***Calling syntax:*

```
A = mfZeros( n1 [, n2] )
```

*Description:*

Returns an `mfArray` containing zeros.

If it is called with one integer argument, the output matrix is square, of shape  $(n1,n1)$ .

If the optional argument `n2` is present, the routine builds a matrix of shape  $(n1,n2)$ .

*See also:* [mfEye](#), [mfOnes](#)

**mfOnes****matrix of ones***Calling syntax:*

```
A = mfOnes( n1 [, n2] )
```

*Description:*

Returns an `mfArray` containing ones.

If it is called with one integer argument, the output matrix is square, of shape  $(n1,n1)$ .

If the optional argument `n2` is present, the routine builds a matrix of shape  $(n1,n2)$ .

*See also:* [mfEye](#), [mfZeros](#)

**mfRand****uniformly distributed random numbers***Calling syntax:*

```
A = mfRand( n1 [, n2] )
```

*Description:*

Returns an `mfArray` containing pseudo-random real values, with a uniform distribution in  $[0, 1]$ .

If it is called with one integer argument, the output matrix is square, of shape  $(n1, n1)$ .

If the optional argument `n2` is present, the routine builds a matrix of shape  $(n1, n2)$ .

*Other syntax:*

```
A = mfRand( string )
```

When called with the string `"seed"`, the seed (six long integers stored as double reals) of the random number generator is returned. This value can be later used to reset the seed to a previous state with the `msRand` routine.

*Remark:* Generated numbers doesn't depend on the compiler used, because the `random_number` Fortran 90 intrinsic routine is not use. The `RngStreams` package (included in the MUESLI library) is used instead.

*See also:* `mfRandN`, `mfRandPoiss`

**msRand****set the random number generator seed***Calling syntax:*

```
call msRand( [ seed ] )
```

*Description:*

Set the random number generator seed either from given values, or from the clock.

Without argument, the seed is set from the clock.

If the optional argument **seed** is present, then this argument must be an **mfArray** whose values are used to reset the seed of the **RngStreams** package, included in the MUESLI library. This seed must be an array of six integer numbers (stored as double precision reals) satisfying the following constraints:

- the first three values must be less than 4294967087 (and not all zero);
- the last three values must be less than 4294944443 (and not all zero).

Note that a check is done in the current routine.

*See also:* [mfRand](#), [mfRandN](#), [mfRandPoiss](#)

**mfRandN****normally distributed random numbers***Calling syntax:*

```
A = mfRandN( n1 [, n2] )
```

*Description:*

Returns an `mfArray` containing pseudo-random real values, with a normal distribution (with zero mean and unit variance).

If it is called with one integer argument, the output matrix is square, of shape  $(n1,n1)$ .

If the optional argument `n2` is present, the routine builds a matrix of shape  $(n1,n2)$ .

*See also:* [mfRand](#), [mfRandPoiss](#), [msRand](#)



**mfRandPoiss****Poisson distributed random numbers***Calling syntax:*

```
A = mfRandPoiss( mu, n1 [, n2] )
```

*Description:*

Returns an `mfArray` containing pseudo-random integer values, with a Poisson distribution, with mean (and variance) equal to `mu`.

The argument `mu` is a real number.

If it is called with only one size, the output matrix is square, of shape `(n1,n1)`.

If the optional argument `n2` is present, the routine builds a matrix of shape `(n1,n2)`.

*See also:* [mfRandN](#), [mfRand](#), [msRand](#)

**mfRepMat****replicate and tile an array***Calling syntax:*

```
C = mfRepMat( A, m, n )
```

*Description:*

This routine replicates the tile `mfArray` `A`, to build a bigger `mfArray`. The returned `mfArray` can be viewed as a `m`-by-`n` tiling matrix.

The behavior of this routine is similar to the *spread* Fortran 90 intrinsic function.

*Example(s):*

```
x = reshape( [ (i, i = 1, 6) ], [ 2, 3 ] )  
call msDisplay( x, "x", mfRepmat(x,3,2), "mfRepmat(x,3,2)" )
```

output:

`x =`

```
 1  3  5  
 2  4  6
```

`mfRepmat(x,3,2) =`

```
 1  3  5  1  3  5  
 2  4  6  2  4  6  
 1  3  5  1  3  5  
 2  4  6  2  4  6  
 1  3  5  1  3  5  
 2  4  6  2  4  6
```

## mfMerge

## merge of two arrays

*Calling syntax:*

```
C = mfMerge( A, B, mask )
```

*Description:*

The three arguments are `mfArrays` having the same shape. This function merge the two numeric arrays A and B under the control of the boolean `mask`. Its behavior is like that of the *merge* Fortran 90 intrinsic function.

Sparse arrays are not handled.

*Example(s):*

```
A = 3.0d0*mfOnes(3,2)
B = -1.0d0*mfOnes(3,2)
mask = mfEye(3,2) > 0.5d0
call msDisplay( A,"A", B,"B", mask,"mask" )
call msDisplay( mfMerge(A,B,mask), "mfMerge(A,B,mask)" )
```

output:

A =

```
 3   3
 3   3
 3   3
```

B =

```
-1  -1
-1  -1
-1  -1
```

mask =

```
 T   F
 F   T
 F   F
```

mfMerge(A,B,mask) =

```
 3  -1
-1   3
-1  -1
```

## mfPack

## packing an array

*Calling syntax:*

```
C = mfPack( A, mask )
```

*Description:*

Packs the elements of the numeric `mfArray` `A` in a long column vector, under the control of the boolean `mask`. The behavior of this routine is similar to the *pack* Fortran 90 intrinsic function.

Sparse arrays are not handled.

See also: [mfUnpack](#)

*Example(s):*

```
A = mfMagic(3)
mask = A >= 5.0d0
call msDisplay( A,"A", mask,"mask" )
Ap = mfPack( A, mask )
call msDisplay( Ap, "A packed" )
```

output:

A =

```
  8    3    4
  1    5    9
  6    7    2
```

mask =

```
  T    F    F
  F    T    T
  T    T    F
```

A packed =

```
  8    6    5    7    9
```

```
R = mfOnes(3)*MF_NAN
call msDisplay( mfUnpack(Ap,mask,field=R), "A unpacked" )
```

output:

A unpacked =

```
  8.0000    NaN    NaN
    NaN    5.0000    9.0000
  6.0000    7.0000    NaN
```

## mfUnpack

## unpacking an array

*Calling syntax:*

```
C = mfUnpack( A, mask, field )
```

*Description:*

Unpacks the elements of the numeric vector `mfArray` `A` under the control of the boolean `mask`. The returned `mfArray` is completed from values of `field`. `A` should have been previously processed by the `mfPack` routine.

The behavior of this routine is similar to the *unpack* Fortran 90 intrinsic function.

Sparse arrays are not handled.

See also: `mfPack`

*Example(s):*

```
A = mfMagic(3)
mask = A >= 5.0d0
call msDisplay( A,"A", mask,"mask" )
Ap = mfPack( A, mask )
call msDisplay( Ap, "A packed" )
```

output:

A =

```
  8   3   4
  1   5   9
  6   7   2
```

mask =

```
  T   F   F
  F   T   T
  T   T   F
```

A packed =

```
  8   6   5   7   9
```

```
R = mfOnes(3)*MF_NAN
call msDisplay( mfUnpack(Ap,mask,field=R), "A unpacked" )
```

output:

A unpacked =

```
  8.0000   NaN   NaN
   NaN   5.0000  9.0000
  6.0000   7.0000   NaN
```

**mfCshift****array shifting***Calling syntax:*

```
C = mfCshift( A, shift )
```

*Description:*

Performs a circular shift on the vector `mfArray` `A`. `shift` is an integer. The behavior of this routine is similar to the `cshift` Fortran 90 intrinsic function.

Sparse arrays are not handled.

See also: [mfEoshift](#)

*Example(s):*

```
A = [ 1, 2, 3, 4, 5, 6 ]  
call msDisplay( A, "A" )  
call msDisplay( mfCshift(A,shift=1), "mfCshift(A,shift=1)" )
```

output:

```
A =  
  1   2   3   4   5   6  
  
mfCshift(A,shift=1) =  
  2   3   4   5   6   1
```

**mfEoshift****array shifting***Calling syntax:*

```
C = mfEoshift( A, shift )
```

*Description:*

Performs an end-off shift on the vector `mfArray` `A`. `shift` is an integer. The behavior of this routine is similar to the *eoshift* Fortran 90 intrinsic function.

Sparse arrays are not handled.

See also: [mfCshift](#)

*Example(s):*

```
A = [ 1, 2, 3, 4, 5, 6 ]
call msDisplay( A, "A" )
b = 99
call msDisplay( mfEoshift(A,shift=1,boundary=b),           &
                "mfEoshift(A,shift=1,boundary=b)" )
```

output:

```
A =
  1   2   3   4   5   6
mfEoshift(A,shift=1,boundary=b) =
  2   3   4   5   6   99
```

mf/msDiag

## diagonal matrices and diagonals of a matrix

The first form is:

```
C = mfDiag( A [, d] )
```

If **A** is a matrix-like **mfArray** (dense or sparse), this function extracts the main (or the **d**-) diagonal (the output is dense, whatever the storage type of **A** is).

If **A** is a vector-like **mfArray** (dense only), this function builds a dense square matrix which has **A** as main (or as **d**-) diagonal. For building a sparse matrix, use **mfSpDiags**.

The subroutine form:

```
call msDiag( A, v [, d] )
```

modifies the main (or the **d**-) diagonal of the **mfArray** **A** (dense or sparse) by copying the elements of the vector-like **mfArray** **v**. The data type of **A** may be changed because **A** and **v** can have real or complex values. The vector **v** is not modified.

*Remarks:* When **d** is equal to zero, it points to the main diagonal; when positive, the upper part of the matrix is concerned. If the arg. **d** is not present, the main diagonal is the default.

*See also:* **mfBlkDiag**, **mfEye**, **mfSpDiags**

*Example(s):*

```
v = [ 1, 2, 3 ]
C = mfDiag(v,2)
call msDisplay( C, "C = mfDiag(v,2)" )
```

output:

```
v =
  1   2   3
C = mfDiag(v,2) =
  0   0   1   0   0
  0   0   0   2   0
  0   0   0   0   3
  0   0   0   0   0
  0   0   0   0   0
```

```
v = [ 4, 5, 6 ]
call msDisplay( v, "v" )
call msDiag( C, v, d=-2 )
call msDisplay( C, "C" )
```

output:

```
v =
  4   5   6
C =
  0   0   1   0   0
  0   0   0   2   0
  4   0   0   0   3
  0   5   0   0   0
  0   0   6   0   0
```



## mfBlkDiag

## block diagonal concatenation

The first calling syntax:

```
C = mfBlkDiag( A, B )
```

gives the concatenation of the two (square) blocks diagonal A and B.

The other calling syntax:

```
C = mfBlkDiag( A, n )
```

concatenates  $n$  times ( $n$  being non negative) the square matrix A on the diagonal.

*Remarks:* A (and B, for the first form), may be dense or sparse, and of any type accepted by the `.vc.` or `.hc.` operators.

*See also:* [mf/msDiag](#)

*Example(s):*

```
A = mfRot90(mfEye(3,3))
call msDisplay(A,"A")
call msDisplay( mfBlkDiag(A,3), "blkdiag(A,3)" )
```

output:

A =

```
0  0  1
0  1  0
1  0  0
```

blkdiag(A,3) =

```
0  0  1  0  0  0  0  0  0
0  1  0  0  0  0  0  0  0
1  0  0  0  0  0  0  0  0
0  0  0  0  0  1  0  0  0
0  0  0  0  1  0  0  0  0
0  0  0  1  0  0  0  0  0
0  0  0  0  0  0  0  0  1
0  0  0  0  0  0  0  1  0
0  0  0  0  0  0  1  0  0
```

mf/msFind

find indices of nonzero elements

The first form:

```
C = mfFind( A )
```

finds *non zero* (resp. *TRUE*) elements of the numerical (resp. boolean) **mfArray** *A* and returns a long column of their indices (called also linear indices).

Usually, this routine is applied to a boolean **mfArray**, automatically created in comparison operators; for example, `mfFind( A > 1.0d0 )` returns indices of elements which verify the specified property.

The subroutine form:

```
call msFind( mfOut(i,j[,v]), A )
```

allows the user to retrieve the matrix-indices. The two vectors returned (*i* and *j*) contain the row-index and column-index for non-zero elements.

If the optional argument *v* is present, it contains the values of corresponding non-zero elements.

*Warning:* Contrary to MATLAB, **mf/msFind** always return row index vectors, instead of column vectors.

*See also:* [mfNonZeros](#), [mfOut](#)

*Example(s):*

```
A = mf( [ 9, 0, 0 ] ) .vc.           &
      mf( [ 0, 0, 7 ] ) .vc.       &
      mf( [ 0, 11, 0 ] )
call msDisplay( A, "A" )
call msFind( mfOut(i,j,v), x )
call msDisplay( i,"row indices", j,"col indices", v,"values" )
```

output:

```
A =
  9    0    0
  0    0    7
  0   11    0

row indices =
  1    3    2

col indices =
  1    2    3

values =
  9   11    7
```

**mfNonZeros****non-zero elements***Calling syntax:*

```
C = mfNonZeros( A )
```

*Description:*

Returns all non-zero elements of the `mfArray` `A` in a vector.

Works as `msFind`, except that indices (i,j) are not returned.

*See also:* [ms/mfFind](#)

## mf/msReshape

## shape modification

*Generic interface:*

```
function mfReshape( A, m, n ) result( out )

    integer, intent(in) :: A(:)
or real(kind=MF_DOUBLE), intent(in) :: A(:)
or type(mfArray) :: A

    integer, intent(in) :: m, n

    type(mfArray) :: out
```

*Description:*

This function extends the Fortran intrinsic *reshape*; it can be applied to a dense or sparse `mfArray`.

*Remark:* in the special call: `mfReshape( A, MF_EMPTY, n )` with `A` being an `mfArray` only, the first dimension, if not specified, is deduced from the total number of elements in `A` (the second dimension `n` can also be replaced by `MF_EMPTY`). Same behavior using `MF_NO_ARG` instead of `MF_EMPTY`.

Another possible form is:

```
call msReshape( A, m, n )
```

which does the same job with the `mfArray` `A`, except that the shape modification is made “in place”. Here, `m` or `n` cannot be replaced by `MF_EMPTY` or `MF_NO_ARG`. This second routine is more efficient than the first one, especially for sparse matrices.

See also: [mfRepMat](#)

*Example(s):*

```
x = [ (i, i = 1, 12) ]
call msDisplay( x, "x" )
call msDisplay( mfReshape(x, 4, 3 ), "mfReshape(x, 4, 3 )" )
call msDisplay( mfReshape(x, 2, MF_EMPTY ), "mfReshape(x, 2, MF_EMPTY )" )
```

output:

```
x =
    1    2    3    4    5    6    7    8    9   10   11   12

mfReshape(x, 4, 3 ) =
    1    5    9
    2    6   10
    3    7   11
    4    8   12

mfReshape(x, 2, MF_EMPTY ) =
    1    3    5    7    9   11
    2    4    6    8   10   12
```

**mfTriL****lower triangular part***Calling syntax:*

```
C = mfTriL( A [ , k ] )
```

*Description:*

This function extracts the lower triangular part of an `mfArray`, including the main diagonal.

If `k` is present, it returns the lower part of `A` up to the `k`-th diagonal (included). `k` must be integer; it can be negative.

*See also:* [mfTriU](#)

**mfTriU****upper triangular part***Calling syntax:*

```
C = mfTriL( A [ , k ] )
```

*Description:*

This function extracts the upper triangular part of an `mfArray`, including the main diagonal.

If `k` is present, it returns the upper part of `A` down to the `k`-th diagonal (included). `k` must be integer; it can be negative.

*See also:* [mfTriL](#)

**mfFlipLR****matrix flip Left-Right***Calling syntax:*

```
C = mfFlipLR( A )
```

*Description:*

This function flips the mfArray A in the left-right direction.

See also: [mfFlipUD](#), [mfRot90](#)

*Example(s):*

```
A = reshape( [ (i,i=1,15) ], [3,5] )
call msDisplay( A, "A" )
call msDisplay( mfFlipLR(A), "mfFlipLR(A)" )
```

output:

A =

```
  1   4   7  10  13
  2   5   8  11  14
  3   6   9  12  15
```

mfFlipLR(A) =

```
 13  10   7   4   1
 14  11   8   5   2
 15  12   9   6   3
```

**mfFlipUD****matrix flip Up-Down***Calling syntax:*

```
C = mfFlipUD( A )
```

*Description:*

This function flips the `mfArray` `A` in the up-down direction.

See also: [mfFlipLR](#), [mfRot90](#)

*Example(s):*

```
A = reshape( [ (i,i=1,15) ], [3,5] )
call msDisplay( A, "A" )
call msDisplay( mfFlipUD(A), "mfFlipUD(A)" )
```

output:

```
A =
```

```
  1   4   7  10  13
  2   5   8  11  14
  3   6   9  12  15
```

```
mfFlipUD(A) =
```

```
  3   6   9  12  15
  2   5   8  11  14
  1   4   7  10  13
```



mfRot90

matrix rotation

*Calling syntax:*

```
C = mfRot90( A [, k] )
```

*Description:*

This function rotates the `mfArray` `A` in the trigonometric direction, by the angle `k*90` in degrees. (*i. e.* for  $90^\circ$ , last column becomes first row).

`k` may be any integer (including zero and negative value). It is an optional argument (default value is 1).

See also: [mfFlipLR](#), [mfFlipUD](#)

*Example(s):*

```
A = reshape( [ (i,i=1,6) ], [3,2] )
call msDisplay( A, "A" )
call msDisplay( mfRot90(A,1), "mfRot90(A,1) [90° anticlockwise]" )
call msDisplay( mfRot90(A,-1), "mfRot90(A,-1) [90° clockwise]" )
```

output:

A =

```
 1  4
 2  5
 3  6
```

mfRot90(A,1) [90° anticlockwise] =

```
 4  5  6
 1  2  3
```

mfRot90(A,-1) [90° clockwise] =

```
 3  2  1
 6  5  4
```

**mfHilb****Hilbert matrix***Calling syntax:*

```
C = mfHilb( n )
```

*Description:*

Builds a square mfArray which contains an Hilbert matrix. It is a well known example of badly conditioned matrix.

*See also:* [mfInvHilb](#), [mfCond](#)

*Example(s):*

```
A = mfHilb(5)
call msDisplay( A, "A = mfHilb(5)" )
call msDisplay( mfCond(A), "cond(A)" )
```

output:

```
A = mfHilb(5) =
  1.0000    0.5000    0.3333    0.2500    0.2000
  0.5000    0.3333    0.2500    0.2000    0.1667
  0.3333    0.2500    0.2000    0.1667    0.1429
  0.2500    0.2000    0.1667    0.1429    0.1250
  0.2000    0.1667    0.1429    0.1250    0.1111
```

```
cond(A) =
```

```
4.7661E+05
```

`mfInvHilb`**inverse Hilbert matrix***Calling syntax:*

```
C = mfInvHilb( n )
```

*Description:*

Returns the inverse of an Hilbert matrix; therefore the matrix product of `mfHilb(n)` by `mfInvHilb(n)` is the identity matrix.

*Remarks:* this inverse is not computed by some linear algebra algorithm but by an exact formula.

*See also:* [mfHilb](#)

*Example(s):*

```
A = mfHilb(5)
B = mfInvHilb(5)
call msDisplay( B, "B = mfInvHilb(5)" )
call msDisplay( mfNorm(mfEye(5) - mfMul(A,B)), "| I - A*B |" )
```

output:

```
B = mfInvHilb(5) =
```

```
      25      -300      1050      -1400      630
     -300      4800     -18900      26880     -12600
      1050     -18900      79380     -117600      56700
     -1400      26880     -117600      179200     -88200
       630     -12600      56700     -88200      44100
```

```
| I - A*B | =
```

```
5.7926E-12
```

## mfVander

## Vandermonde matrix

*Calling syntax:*

```
A = mfVander( v [ , n ] )
```

*Description:*

Returns a Vandermonde matrix. The input vector `mfArray` `v` may be either a row or a column vector.

If the optional argument `n` is present, the returned matrix will have `n` columns, each one constituted by a power of the vector `v`; else the returned matrix will be square, *i. e.* will have as much columns as the size of `v`.

*Example(s):*

```
x = [ 1, 2, 3, 4, 5 ]
call msDisplay( x, "x" )
call msDisplay( mfVander(x,3), "A = mfVander(x,3)" )
```

output:

```
x =
```

```
  1    2    3    4    5
```

```
A = mfVander(x,3) =
```

```
  1    1    1
  4    2    1
  9    3    1
 16    4    1
 25    5    1
```

## mfCompan

## Companion matrix

*Calling syntax:*

```
A = mfCompan( v )
```

*Description:*

Returns the Companion matrix of a polynomial, represented by its coefficients provided in the input vector `mfArray v` (this latter array may be either a row or a column vector).

The eigenvalues of the matrix `A` are the roots of the input polynomial.

See also: [mfRoots](#), [mfEig](#)

*Example(s):*

```
! polynom: (x-1)*(x-2)*(x-3)*(x-4) = x^4 - 10*x^3 + 35*x^2 - 50*x + 24,  
! so the roots are: {1, 2, 3, 4}  
v = [ 1.0d0, -10.0d0, 35.0d0, -50.0d0, 24.0d0 ]  
call msDisplay( v, "v" )  
A = mfCompan(v)  
call msDisplay( A, "A = mfCompan(v)" )  
call msDisplay( mfEig(A), "Eigenvalues of A" )
```

output:

```
v =
```

```
1  -10  35  -50  24
```

```
A = mfCompan(v) =
```

```
10  -35  50  -24  
1   0   0   0  
0   1   0   0  
0   0   1   0
```

```
Eigenvalues of A =
```

```
4.0000 + 0.0000i  
3.0000 + 0.0000i  
2.0000 + 0.0000i  
1.0000 + 0.0000i
```

**mfHankel****mfHankel matrix**

*Calling syntax:*

```
A = mfHankel( C [, R ] )
```

*Description:*

Returns the Hankel matrix of the input vectors `mfArray` C and R (these latter arrays may be either a row or a column vector).

A Hankel matrix has constant anti-diagonal values.

Hankel matrices are real (because only real input vectors are supported) and symmetric (if square).

*See also:* [mfToeplitz](#)

*Example(s):*

```
C = [ 1.0d0, 2.0d0, 3.0d0, 4.0d0 ]
R = [ 4.0d0, 5.0d0, 6.0d0 ]
call msDisplay( C, "C", R, "R" )
call msDisplay( mfHankel(C,R), "mfHankel(C,R)" )
```

output:

C =

```
  1   2   3   4
```

R =

```
  4   5   6
```

mfHankel(C,R) =

```
  1   2   3
  2   3   4
  3   4   5
  4   5   6
```

## mfToeplitz

## Toeplitz matrix

*Calling syntax:*

```
A = mfToeplitz( C [, R ] )
```

*Description:*

Returns the Toeplitz matrix of the input vectors `mfArray` C and R (these latter arrays may be either a row or a column vector).

A Toeplitz matrix has constant diagonal values and is symmetric (if square).

Complex input vectors are supported. In such a case, the complex matrix is hermitian if the first element of R is real.

*See also:* [mfHankel](#)

*Example(s):*

```
C = [ 1.0d0, 2.0d0, 3.0d0, 4.0d0 ]
R = [ 1.0d0, 5.0d0, 6.0d0 ]
call msDisplay( mfToeplitz(C,R), "mfToeplitz(C,R)" )
```

output:

C =

```
  1    2    3    4
```

R =

```
  1    5    6
```

A = mfToeplitz(C,R) =

```
  1    5    6
  2    1    5
  3    2    1
  4    3    2
```

**mfPerm****permutation vector creation***Calling syntax:*

```
p = mfPerm( v )
```

*Description:*

Returns a permutation vector `mfArray` from the vector of indices `v`.

`v` may be either a Fortran 90 integer vector, or a vector-like `mfArray`. In this latter case, the `mfArray` should contains integer values; on the contrary, a warning is emitted by the routine.

*See also:* [mfIsPerm](#), [mfRandPerm](#), [mfCheckPerm](#), [mfColPerm](#), [mfRowPerm](#), [msSaveAscii](#)



**mfRandPerm****random permutation vector creation***Calling syntax:*

```
p = mfRandPerm( n [ , k ] )
```

*Description:*

Returns a random permutation vector `mfArray`. Elements of `p` are unique integers in the range  $[1, n]$ .

If the second argument `k` is present, returns  $k$  unique integers in the range  $[1, n]$ . In this latter case, `p` is not a true permutation vector if  $k \neq n$ .

*See also:* [mfPerm](#), [mfIsPerm](#), [mfCheckPerm](#)

mfCheckPerm

**permutation vector checking***Interface:*

```
function mfCheckPerm( A ) result( bool )  
  
    type(mfArray), intent(in) :: A  
    logical :: bool
```

*Description:*

Returns `.true.` if A is a valid permutation vector, *i. e.* if the integers are consecutive numbers, not necessarily ordered and appearing only once in the list.

*See also:* [mfPerm](#), [mfIsPerm](#)

**isfinite****finite test***Interface:*

```
function isfinite( x ) result( out )  
  
    double precision, intent(in) :: x  
  
    logical :: out
```

*Description:*

This function returns a logical value, according to the value of **x**, which must be only of type **double precision**.

*Remarks:* in the IEEE-754 standard, any real value is either *finite*, *infinite*, or *NaN*.

*See also:* [isinf](#), [isnan](#), [mfIsFinite](#)

**isinf****infinity test***Interface:*

```
function isinf( x ) result( out )  
  
    double precision, intent(in) :: x  
  
    logical :: out
```

*Description:*

This function returns a logical value, according to the value of **x**, which must be only of type **double precision**.

*Remarks:* in the IEEE-754 standard, any real value is either *finite*, *infinite*, or *NaN*.

*See also:* [isfinite](#), [isnan](#), [mfIsInf](#)

**isnan****Not-a-Number test***Interface:*

```
function isnan( x ) result( out )  
  
    double precision, intent(in) :: x  
  
    logical :: out
```

*Description:*

This function returns a logical value, according to the value of **x**, which must be only of type **double precision**.

*Remarks:* in the IEEE-754 standard, any real value is either *finite*, *infinite*, or *NaN*.

*See also:* [isfinite](#), [isinf](#), [mfIsNaN](#)

**mfIsFinite****finite test***Calling syntax:*

```
C = mfIsFinite( A )
```

*Description:*

This elemental function returns a boolean `mfArray`.

*Remarks:* in the IEEE-754 standard, any real value is either *finite*, *infinite*, or *NaN*.

*See also:* [isfinite](#), [mfIsInf](#), [mfIsNaN](#)

**mfIsInf****infinity test***Calling syntax:*

```
C = mfIsInf( A )
```

*Description:*

This elemental function returns a boolean **mfArray**.

*Remarks:* in the IEEE-754 standard, any real value is either *finite*, *infinite*, or *NaN*.

*See also:* [isinf](#), [mfIsFinite](#), [mfIsNaN](#)

**mfIsNaN****Not-a-Number test***Calling syntax:*

```
C = mfIsNaN( A )
```

*Description:*

This elemental function returns a boolean `mfArray`.

*Remarks:* in the IEEE-754 standard, any real value is either *finite*, *infinite*, or *NaN*.

*See also:* [isnan](#), [mfIsFinite](#), [mfIsInf](#)



**mfIsDiag****diagonal pattern test***Calling syntax:*

```
bool = mfIsDiag( A )
```

returns a *TRUE* boolean value if the **mfArray** **A** (sparse or dense) is a diagonal matrix.

*See also:* **mfIsTril**, **mfIsTriu**

**mfIsTril****lower triangular pattern test***Calling syntax:*

```
bool = mfIsTril( A )
```

returns a *TRUE* boolean value if the **mfArray** **A** (sparse or dense) is a lower triangular matrix.

*See also:* [mfIsDiag](#), [mfIsTriu](#)

**mfIsTriu****upper triangular pattern test***Calling syntax:*

```
bool = mfIsTriu( A )
```

returns a *TRUE* boolean value if the **mfArray** **A** (sparse or dense) is a upper triangular matrix.

*See also:* [mfIsDiag](#), [mfIsTril](#)

## 1.8 Matrix Functions

<code>mfDet</code>	determinant
<code>mfTrace</code>	sum of diagonal elements
<code>mfNorm</code>	matrix or vector norm
<code>mfRank</code>	matrix rank
<code>mfCond</code>	matrix condition number
<code>mfRCond</code>	reciprocal condition number estimation
<code>msLU</code>	$LU$ factorization
<code>msLDLT</code>	$LDL^t$ factorization
<code>mf/msChol</code>	Cholesky factorization
<code>msCholSpSymb</code>	Symbolic Cholesky factorization (sparse only)
<code>msCholSpNum</code>	Numerical Cholesky factorization (sparse only)
<code>mf/msBalance</code>	scaling to improve eigenvalue accuracy
<code>mf/msSVD</code>	singular value decomposition
<code>mfInv, .i.</code>	matrix inverse
<code>mfPseudoInv</code>	matrix pseudo-inverse
<code>mfQR, msQR</code>	orthogonal-triangular factorization
<code>mfQleft, mfQright</code>	left or right multiplication by a Q factor (sparse only)
<code>mf/msEig</code>	eigenvalues and eigenvectors
<code>mf/msHess</code>	Hessenberg form
<code>mf/msSchur</code>	Schur decomposition
<code>mfLDiv, .ix.</code>	left matrix divide
<code>mfRDiv, .xi.</code>	right matrix divide
<code>msRref</code>	reduced row echelon form
<code>mfNull</code>	null space
<code>mfOrth</code>	matrix orthogonalization
<code>mfExpm</code>	matrix exponential
<code>mfLogm</code>	matrix logarithm
<code>mfSqrtm</code>	matrix square root
<code>mfPwm</code>	matrix power
<code>mf/msFunm</code>	general matrix function
<code>mf/msEigs</code>	few eigenvalues and eigenvectors
<code>mf/msSVDS</code>	few singular values and vectors
<code>mfNormEst, mfNormEst1</code>	norm estimations
<code>mfCondEst</code>	matrix condition number estimation
<code>mfIsSymm</code>	matrix symmetry inquiry
<code>mfTolForSymm</code>	tolerance for symmetry
<code>mfIsPosDef</code>	definite positiveness inquiry
<code>mfIsDiagDomCol</code>	diagonally dominant by cols inquiry
<code>mfIsStrictDiagDomCol</code>	strictly diagonally dominant by cols inquiry
<code>mfIsFullRank</code>	full rank inquiry
<code>MF_LAPACK_VERSION</code>	LAPACK version
<code>msGetBlasLib</code>	Get BLAS library type
<code>msGetLapackLib</code>	Get LAPACK library type
<code>msGetArpackInfo</code>	Get ARPACK library information
<code>msGetSuiteSparseLib</code>	Get SuiteSparse library version

See also:

Core Routines

File Input/Output

Data Analysis Functions

Operators

Elementary Math Functions

Specialized Math Functions

Elementary Matrix Manipulation Functions

Polynomial Functions

Optimization and Function Functions

Sparse Matrices

**mfDet****determinant***Calling syntax:*

```
C = mfDet( A )
```

*Description:*

Returns the determinant of the **mfArray** **A**.

**A** must be square, and cannot be sparse.

*Remarks:* using the determinant of a matrix to detect whether it is singular is not a good idea: use **mfCond** or **mfRCond** instead.

*See also:* **mfRank**

**mfTrace****sum of diagonal elements***Calling syntax:*

```
C = mfTrace( A )
```

*Description:*

Returns the sum of all diagonal element of the `mfArray` `A` (dense or sparse, real or complex).

*Remarks:* the trace of a square matrix is also the sum of its eigenvalues.

*See also:* [mfEig](#)

**mfNorm****matrix or vector norm**

*Calling syntax:*

```
C = mfNorm( A [, norm | p ] )
```

*Description:*

Returns the norm of the `mfArray` `A`, which can be a vector or a matrix (sparse or dense).

The two optional arguments (`norm` is a character string whereas `p` is an integer) cannot be both present.

- For a matrix, only 1-, 2-, "inf"- or "fro"-norms are supported.

By default, returns the 2-norm (which is also the largest singular value of `A`). If `p` is present, it returns the `p`-norm of `A` (therefore, `p` can take only the values 1 or 2). If `norm` is present, it must be `inf` (infinite-norm) or `fro` (frobenius-norm).

- For a vector, only `p > 0` and "inf"- norms are supported.

By default, returns the 2-norm. If `p` is present, it returns the `p`-norm of `A`. If `norm` is present, it must be `inf` (infinite-norm).

*Note:* For sparse matrices, use `mfNormEst` or `mfNormEst1` instead, which are more efficient.

*See also:* `mfCond`, `mfSVD`



**mfRank****matrix rank***Calling syntax:*

```
C = mfRank( A [ , tol ] )
```

*Description:*

Computes the rank of a matrix, *i. e.* the number of linearly independent rows or columns.

If `tol`, of type `real`, is present then it returns the number of singular values greater or equal to this optional tolerance. Default tolerance is chosen as  $\max(m, n) \|A\|_2 \epsilon$ , where  $m$  and  $n$  are respectively the number of rows and number of columns of the `mfArray` `A`.

*Remarks:*

- it is internally based on the Singular Value Decomposition;
- for sparse matrices, the user is invited to use `mfSVDS`, and examine himself few singular values.

*See also:* [mfSVD](#), [mfSVDS](#), [mfIsFullRank](#)

**mfCond****matrix condition number***Calling syntax:*

```
C = mfCond( A )
```

*Description:*

Returns the condition number of the **mfArray** **A**. It is the ratio of the largest singular value to the smallest one.

*Remarks:* The condition number is always greater than 1. A value equal to infinity (resp. close to the inverse of the  $\epsilon$  machine) indicates that the matrix **A** is singular (resp. nearly singular).

*See also:* [mfCondEst](#), [mFRCond](#), [mfNorm](#), [mfSVD](#), [mfDet](#)

mfRCond

**reciprocal condition number estimation***Calling syntax:*

```
C = mfRCond( A )
```

*Description:*

Returns an estimation of the inverse of the condition number (which is called the reciprocal condition number).

*Remarks:* The reciprocal condition number is always between 0 and 1. A value equal to zero (resp. close to the  $\epsilon$  machine) indicates a singular matrix (resp. nearly singular).

*See also:* [mfCond](#), [mfCondEst](#), [mfNorm](#), [mfSVD](#), [mfDet](#)

msLU

*LU* factorization*Description:*

Computes numerically the *LU* decomposition of an `mfArray`.

*First calling syntax:*

```
call msLU( mfOut( L, U [, p] ), A )
```

For dense `mfArrays`, returns the *L* (lower triangular, with a unit diagonal) and *U* (upper triangular) factors, and, optionally, the row permutation vector *p*, such that:

$$LU = A(p, :)$$

If the optional argument *p* is not present, the routine actually returns a row permuted *L*, such that:

$$LU = A$$

In this latter case, be aware that you will not be able to solve a linear system using only the factors *L* and *U*, because you must know the permutation *p* to be applied to the right hand side vector. See the *Muesli User's Guide* to an example using the *LU* decomposition.

*Second calling syntax:*

```
call msLU ( mfOut( L, U [, p, q, r] ), A )
```

For sparse `mfArrays`, the routine `msLU` behaves in a slightly different manner:

*p* and *q* are respectively row and column permutations vectors while *r* is a vector containing the row scaling of *A*. All these sparse matrices should verify the following (theoretical) relationship:

$$LU = P R A Q$$

where the matrices *P*, *Q*, *R* are associated to the vectors *p*, *q*, *r*. Practically, the RHS of the previous identity should be computed using `mfRowScale`, `mfColPerm` and `mfRowPerm`.

Moreover, the *L* factor contains a pointer to an internal structure containing all the five output matrices, so that a call to the `mfLDiv` routine is simplified.

*Third calling syntax:* In all cases (sparse or dense matrix *A*), the following syntax:

```
call msLU( mfOut(factors), A )
```

provides the possibility to factorize only, without copying factors in explicit `mfArrays`. In this case, the factors (accompanied by the permutations and the scaling) are internally stored (*i.e.* not available for the end-user) and can be referenced only via the `mfMatFactor` `factors`.

The `mfMatFactor` obtained is intended to be used only in `mfLDiv`.

*Remark:* If the matrix *A* is symmetric and positive definite, the current routine may emit a warning: indeed, a Cholesky factorization (via the `mf/msChol` routine) should be more efficient and uses less memory.

See also: `msQR`, `msRref`, `mfOut`

msLDLT

 $LDL^t$  factorization*Calling syntax:*

```
call msLDLT( mfOut(L,D,P), A )
```

*Description:*

Computes numerically the  $LDL^t$  decomposition of a real and symmetric (indefinite) `mfArray` `A`, dense or sparse. Returns a lower triangular `L`, a matrix `D` (block diagonal 1x1 or 2x2) and a permutation matrix `P` such that:  $LDL^t = P^t A P$ .

*Remark:* if `A` is moreover positive definite, then the Cholesky factorization should be more appropriate !

*N.B.:* For sparse matrices:

- the matrix `D` is strictly diagonal;
- be aware that the  $LDL^t$  factorization can fail, especially if the original matrix has some zeros on the main diagonal (the fact that `A` is non-singular is necessary but not sufficient); in this case, use the  $LU$  factorization instead which makes pivoting.

*See also:* [msLU](#), [mf/msChol](#), [mfOut](#)

mf/msChol

## Cholesky factorization

*Description:*

Computes numerically the Cholesky factorization of the `mfArray` `A`, which must be symmetric and positive definite; if this latter property doesn't hold, MUESLI emits an error and returns an empty `mfArray`.

*First calling syntax:*

```
U = mfChol( A )
```

For dense matrices, returns an upper triangular `mfArray` `U`, such that:  $U' U = A$

*Second calling syntax:* For sparse matrices, the calling syntax is slightly different, because a permutation is first applied to the matrix `A` in order to reduce the fill-in:

```
call msChol( mfOut(L,p), A )
```

returns a lower triangular `mfArray` `L` and a permutation `p` such that:  $L L' = P' A P$ . The permutation `p` is always returned as a special `mfArray` (see `mfPerm`), thus the routines `mf/msColPerm` and `mf/msRowPerm` must be used to applied this permutation to the matrix `A`.

*Third calling syntax:* For sparse matrices only, there is also the possibility to factorize only, without copying the factors (`L` and `P`) in explicit `mfArrays`. In this case, the factors are internally stored (*i. e.* not available for the end-user) and can be referenced only via the `mfMatFactor` factors:

```
call msChol( mfOut(factors), A )
```

The `mfMatFactor` obtained is intended to be used only in `mfLDiv`.

See also: `msLU`, `msLDLT`, `mfOut`, `msCholSpSymb`, `msCholSpNum`

**msCholSpSymb****Symbolic Cholesky factorization (sparse only)***Description:*

Computes the symbolic Cholesky factorization of the sparse `mfArray` `A`, which must be symmetric; if this latter property doesn't hold, MUESLI emits an error and returns an empty `mfArray`.

*Interface:*

```
subroutine msCholSpSymb( factor, A )
  type(mfArray),      intent(in)  :: A
  type(mfMatFactor), intent(out)  :: factor
end subroutine
```

After using this routine, the usual step is to call (once or more) the `msCholSpNum` routine, before solving a linear system with `mfLDiv`.

*See also:* [mf/msChol](#)

**msCholSpNum** Numerical Cholesky factorization (sparse only)*Description:*

After having called the symbolic factorisation (via the `msCholSpSymb` routine), computes the numerical Cholesky factorization of the sparse `mfArray` `A`, which must be positive definite; if this latter property doesn't hold, MUESLI emits an error and returns an empty `mfArray`.

*Interface:*

```
subroutine msCholSpNum( factor, A )
  type(mfArray),    intent(in)    :: A
  type(mfMatFactor), intent(in out) :: factor
end subroutine
```

After using this routine, the usual step should be to solve a linear system with `mfLDiv`.

*See also:* [mf/msChol](#)



mf/msBalance

scaling to improve eigenvalue accuracy

The first form:

```
B = mfBalance( A )
```

returns an `mfArray` which is balanced, *i. e.* applies similarity transformations to `A` in order to make the rows and columns as close in norm as possible.

The second form:

```
call msBalance( mfOut(T,B), A )
```

also returns the (non singular) diagonal transformation matrix `T`, such that:  $B = T^{-1}AT$

*Remark:* there is no permutation applied to the matrix `A`. Moreover, the matrix `A` must be square.

*See also:* [mfNorm](#), [mfEig](#), [mfOut](#)

mf/msSVD

singular value decomposition

*Calling syntax:*

```
S = mfSVD( A )
```

The function form returns only the singular values of the **mfArray** **A** (size  $m$  by  $n$ ), in a column vector that is sorted from the greatest to the smallest; the size of this vector is  $\min(m, n)$  and its type is always real, whatever the type of **A**.

The subroutine form allows the user to access to the full decomposition:

```
call msSVD( mfOut(U,S,V), A [, economy_size ] )
```

which returns three **mfArrays** such that  $A = USV'$ . **U** and **V** are both unitary matrices whose columns contain, respectively, the left- and right-singular vectors of **A**. In this case, **S** is returned as a rank-2 array.

If the logical optional argument **economy\_size** is present and equal to *TRUE*, then **U** contains only the  $\min(m, n)$  first columns of the matrix **U**, and **V** contains only the  $\min(m, n)$  first columns of the matrix **V**. **S** is always a square matrix of order  $\min(m, n)$ .

*Remarks:* sparse matrices are not handled; please use **mf/msSVDS** instead.

*See also:* **mfNorm**, **mfRank**, **mfDet**, **mfOut**

`mfInv, .i.`**matrix inverse***Calling syntax:*`C = mfInv( A )`

`.i. A (A-1)` is a shortcut for writing: `mfInv( A )`

*Description:*

Returns the inverse of the square `mfArray` `A`, mathematically noted  $A^{-1}$ .

If `A` is singular (or close to, ought to the machine  $\epsilon$ ), it returns an infinite `mfArray` of same shape.

For singular or non square matrices, the Moore-Penrose pseudo-inverse routine `mfPseudoInv` could also be used.

*Remarks:* sparse matrices are not handled; it is very unusual to have to explicitly compute the inverse of a matrix. If necessary, solving the system  $Ax = e_i$  for each basis vector  $e_i$  gives each column of  $A^{-1}$ ; but be aware that you will obtain a (nearly) dense matrix.

*See also:* `mfPseudoInv`, `mfLDiv`, `mf/msSVD`, `mfRank`

**mfPseudoInv****matrix pseudo-inverse***Calling syntax:*

```
C = mfPseudoInv( A [ , tol ] )
```

*Description:*

Returns the Moore-Penrose pseudo-inverse of the **mfArray** **A**.

**A** may be non square or square singular. **mfPseudoInv** returns a matrix, based on the SVD of **A** and any singular values less than the tolerance **tol** are treated as zero. The default tolerance is  $\max(m, n) \|A\|_2 \epsilon$ , where  $m$  and  $n$  are respectively the number of rows and number of columns of the **mfArray** **A**.

*See also:* [mfInv](#), [mf/msSVD](#), [mfRank](#)

mfQR

## orthogonal-triangular decomposition

*Calling syntax:*
$$R = \text{mfQR}( A )$$

performs a QR factorization of the matrix  $A$  ( $m \times n$ , dense or sparse `mfArray`), but returns only the  $R$  factor (upper triangular matrix of size  $n \times n$ ) verifying  $R' R = A' A$ . This is the  $Q$ -less decomposition.

*Remark for sparse matrices:* The use of this routine should be restricted to small or moderate size sparse matrices because no ordering is applied to prevent the fill-in. For large sparse matrices, use the `msQR` routine instead, which has also more options.

*Note:* The complex type is not yet supported for sparse matrices.

*See also:* `msQR`, `msLU`

msQR

## orthogonal-triangular decomposition

*Calling syntax:*

```
call msQR( mfOut(Q,R[,p,RANK]), A [, tol] )
```

applies the orthogonal-triangular decomposition to the `mfArray` `A`, dense or sparse, of size  $m \times n$ . It returns the two `mfArrays` `Q` and `R` such that  $A = QR$ .

Usually, `Q` is an orthogonal matrix (size  $m \times m$ ) and `R` is a upper-triangular matrix (size  $m \times n$ ).

If  $m > n$ , the economy size is always used: `Q` contains only the  $n$  first columns of the orthogonal full matrix `Q` (therefore of size  $m \times n$ ), and `R` is the square upper part (*i. e.* the non-zero part) of the full `R` (therefore of size  $n \times n$ ). This latter case is used for least-square problems.

Optionally, a column permutation vector `p` may be applied to the matrix `A`, such that  $QR = A(:,p)$ :

- for the dense case, the use of this option leads to a factor `R` having the module of its diagonal terms in decreasing order;
- for the sparse case, the permutation is chosen to obtain a better sparsity for both `Q` and `R` factors.

If the `mfArray` `RANK` is present, it contains on return the numerical rank of the matrix `A`:

- for the dense case, a different method is used in order to compute safely the rank: it is the rank-revealing QR;
- for the sparse case, an estimation of the rank is returned.

If the argument `tol` (real double) is present, it specifies to which accuracy the rank is computed. Default value is the machine precision, `MF_EPS`.

*Other syntax:* for sparse matrices only, the additional syntax can be used:

```
call msQR( mfOut(Qhouse,R[,p,RANK]), A [, tol] )
```

which returns the Householder vectors of the `Q` matrix in the `mfMatFactor` `Qhouse` variable, and the `R` triangular factor in the `mfArray` `R`. Although `Qhouse` doesn't contain explicitly the matrix `Q`, the `Shape` routine applied to it will returned the shape of `Q`, *i. e.*  $(m,m)$ . The shape of `R` is  $(m,n)$ .

This second form should be used for large size matrices, `Qhouse` being much more sparse than `Q`. The user is invited to use one of the routines `mfQleft` or `mfQright` in order to perform the multiplication of `Q` with another vector or matrix.

The other parameters have the same meaning as in the first calling syntax.

*Note:* The complex type is not yet supported for sparse matrices.

*See also:* `mfQR`, `msLU`, `mfOut`

**mfQleft****left multiplication by a sparse Q factor***Calling syntax:*

```
B = mfQleft( Qhouse, A )
```

returns the product  $Q' A$ .

The `mfMatFactor` `Qhouse` holds a sparse  $Q$  factor (obtained from a  $QR$  decomposition of a sparse matrix); the `mfArray` `A` may be a vector (dense) or a matrix (dense or sparse). `B` has the same structure (dense or sparse) than `A`.

By performing the operation: `Q = .t. mfQleft( Qhouse, mfSpEye(m,m) )` the standard form of the  $Q$  factor can be obtained (but be aware that `Qhouse` is often much more sparse than `Q`).

*Note:* The complex case is not yet implemented.

*See also:* [msQR](#), [mfQright](#)

**mfQright****right multiplication by a sparse Q factor***Calling syntax:*

```
B = mfQright( A, Qhouse )
```

returns the product  $AQ$ .

The `mfMatFactor` `Qhouse` holds a sparse  $Q$  factor (obtained from a  $QR$  decomposition of a sparse matrix); the `mfArray` `A` may be a vector (dense) or a matrix (dense or sparse). `B` has the same structure (dense or sparse) than `A`.

By performing the operation: `Q = mfQright( mfSpEye(m,m), Qhouse )` the standard form of the  $Q$  factor can be obtained (but be aware that `Qhouse` is often much more sparse than `Q`).

*Note:* The complex case is not yet implemented.

*See also:* [msQR](#), [mfQleft](#)



**mf/msEig****eigenvalues and eigenvectors**

The first form:

```
E = mfEig( A )
```

returns the eigenvalues of the `mfArray` `A` in the vector `mfArray` `E`.

The subroutine form:

```
call msEig( mfOut(V,D), A )
```

returns two `mfArrays`. `D` is a diagonal matrix containing the eigenvalues and `V` is the matrix whose columns are the corresponding eigenvectors so that:  $AV = VD$  (or, equivalently,  $A = VDV'$ ).

*Remarks:*

- Sparse matrices are not handled; please use `mf/msEigs` instead.
- Eigenvalues are returned in ascending order, according to the magnitude for complex ones.

*See also:* `mf/msEigs`, `mf/msSchur`, `mfOut`

**mf/msHess****Hessenberg form**

The first form:

```
H = mfHess( A )
```

computes the Hessenberg form of the `mfArray` `A`. The returned `mfArray` has the same eigenvalues as `A` but contains zeros below the first subdiagonal.

The subroutine form:

```
call msHess ( mfOut(P,H), A )
```

returns two `mfArrays`. `H` is the Hessenberg form and `P` is a unitary matrix so that:  $A = PHP'$ .

*Remarks:* sparse matrices are not (yet) handled.

*See also:* [mfOut](#)

mf/msSchur

## Schur decomposition

*Calling syntax:*

```
call msSchur ( mfOut(U,T), A [, form ] )
```

produces an upper triangular Schur matrix  $T$  and a unitary matrix  $U$  so that:  $A = UTU'$ .  $A$  must be square.

For a real, dense `mfArray`  $A$  the Schur matrix  $T$  is generally quasi-triangular (real form by default, see below).

The optional character argument `form` may be equal to "real" or "complex".

When processing a complex, dense `mfArray`  $A$ , or when the optional `form` string is equal to "complex", the matrix  $T$  is complex, (strictly) upper triangular.

*Other syntax:*

```
T = mfSchur( A [, form ] )
```

just returns the  $T$  factor.

*Remarks:*

- in the real form, the matrix  $T$  contains 1-by-1 and 2-by-2 diagonal blocks: the 2-by-2 blocks correspond to complex conjugate pairs of eigenvalues of  $A$ .

Each 2-by-2 block is in the form:

$$\begin{pmatrix} a & b \\ c & a \end{pmatrix}$$

where  $bc < 0$ . The eigenvalues of such a block are  $a \pm \sqrt{bc}$ .

- the Schur decomposition is intended to be used for non-symmetric eigenvalue problems; if the `mfArray`  $A$  is symmetric/hermitian, it is preferable to compute eigenvalues/vectors via the `mf/msEig` routines (in such a case,  $V$  and  $D$  `mfArrays` returned by `mf/msEig` correspond exactly to  $U$  and  $T$ ). A warning is therefore emitted if  $A$  is symmetric or hermitian.
- sparse matrices are not (yet) handled.

See also: `mfOut`

mfLDiv, .ix.

left matrix divide

*Calling syntax:*

```
x = mfLDiv( A, b )
```

**A .ix. b** ( $A^{-1}b$ ) is a shortcut for writing: `mfLDiv( A, b )`

*Description:* solves a linear system of the form  $Ax = b$ , *i. e.* returns  $x = A^{-1}b$  without computing  $A^{-1}$ .

The `mfArray` **A** (of size  $m \times n$ ) may be real or complex, sparse or dense, and doesn't need to be square; it can be even rank deficient (tests are made internally to use the most appropriate method):

- if  $m > n$  the mean-square solution is returned;
- if  $m < n$  the minimum 2-norm solution is returned.

This routine automatically detects if **A** is triangular and chooses the appropriate method.

Multiple right hand sides may be simultaneously solved, by concatenating all the RHS vectors in one rank-2 `mfArray` **b**. This feature is not available for sparse matrices *A* (but see below the way of solving simultaneously equations by using intermediate factors).

*Note:* For the sparse complex case, only square matrices *A* are supported.

Using this routine is always more efficient than computing the inverse of the matrix **A** first followed by the product with **b**.

*Remarks:*

- After doing an *LU* factorization of the (dense) matrix **A**, this routine can also be called to solve the linear system  $Ax = PLUx = b$ , by using the following syntax:

```
x = mfLDiv( L, U, P, b[, option="transp" ] )
```

The optional last argument allows the user to solve the system  $A'x = b$  (*transpose* in the real case, *conjugate transpose* in the complex case).

- After doing a Cholesky factorization of the (dense) matrix **A** via `mfChol`, this routine can also be called to solve the linear system  $Ax = U'Ux = b$ , by using the following syntax:

```
x = mfLDiv( U, b, form="cholesky" )
```

- Similarly,

```
x = mfLDiv( L, U, b )
```

is used for a sparse matrix. As noted in the `msLU` page, the `mfArray` **L** factor contains a pointer to an internal structure containing all necessary data concerning the *LU* factorization. Note that the *RHS* **b** cannot have here multiple columns.

⋯/⋯

- For using with an `mfMatFactor` factors (from, *e. g.*, `msLU` or `mf/msChol`), the routine must be called as:

```
x = mfLDiv( factors, b[, option="transp" ] )
```

This latter interface allows the user to simultaneously solve multiple RHS. Moreover, for this case only, the RHS `b` may be dense or sparse. The optional last argument allows the user to solve the system  $A'x = b$ .

- When a (near) singular matrix is encountered, a *Warning* message may be emitted, according to the message level parameter (see `msSetMsgLevel` to change this level).

*See also:* `mFRDiv`

`mFRDiv`, `.xi`. **right matrix divide**

*Calling syntax:*

```
x = mFRDiv( b, A )
```

`b` `.xi`. `A` ( $bA^{-1}$ ) is a shortcut for writing: `mFRDiv( b, A )`

*Description:* solves linear system of the form  $x A = b$ , *i. e.* returns  $x = b A^{-1}$  without computing  $A^{-1}$ .

The `mfArray` `A` (of size  $m \times n$ ) may be real or complex, sparse or dense, and doesn't need to be square; it can be even rank deficient (tests are made internally to use the most appropriate method):

- if  $n > m$  the least-square solution is returned;
- if  $n < m$  the minimum 2-norm solution is returned.

This routine automatically detects if `A` is triangular and chooses the appropriate method.

Multiple right hand sides may be simultaneously solved, by concatenating all the RHS vectors in one rank-2 `mfArray` `b`. This feature is not available for sparse matrices `A` (you should use `mfLDiv` instead, by using transposition).

*Note:* For the sparse complex case, only square matrices `A` are supported.

Using this routine is always more efficient than computing the inverse of the matrix `A` first followed by the product with `b`.

*Remarks:*

- After doing an  $LU$  factorization of the (dense) matrix `A`, this routine can also be called to solve the linear system  $x A = x P L U x = b$ , by using the following syntax:

```
x = mFRDiv( b, L, U, P )
```

- After doing a Cholesky factorization of the (dense) matrix `A` via `mf/msChol`, this routine can also be called to solve the linear system  $x A = x U' U = b$ , by using the following syntax:

```
x = mFRDiv( b, U, form="cholesky" )
```

- Similarly,

```
x = mFRDiv( L, U, b )
```

is used for a sparse matrix. As noted in the `msLU` page, the `mfArray` `L` factor contains a pointer to an internal structure containing all necessary data concerning the  $LU$  factorization. Note that the *RHS* `b` cannot have here multiple columns.

- When a (near) singular matrix is encountered, a *Warning* message may be emitted, according to the message level parameter (see `msSetMsgLevel` to change this level).

*See also:* `mfLDiv`

**msRref****reduced row echelon form***Calling syntax:*

```
call msRref ( mfOut(R,jpiv), A [, tol ] )
```

computes the reduced row echelon form of the `mfArray` `A`.

The optional real `tol` is the tolerance (should be positive) used to compute the rank of the matrix. This tolerance cannot be too small. Minimum is the machine precision. When it is known, use the precision of the elements of the matrix `A`.

Note that the rank provided by this method is only an approximation which may differ from that computed with other methods (*e.g.*, the Singular Value Decomposition `msSVD`). However, this approach is pedagogically interesting.

*See also:* `mfRank`, `mfOrth`, `mfNull`, `msQR`, `mfOut`

**mfNull****null space***Calling syntax:*

```
B = mfNull( A [ , rational, tol ] )
```

returns an orthonormal basis for the null space of the **mfArray** **A**.

The optional logical **rational** argument specifies whether the rational basis is expected or not.

The optional real **tol** argument is the tolerance (should be positive) used to compute the rank of the matrix. As **mfNull** calls **msRref**, **tol** cannot be less than the machine  $\epsilon$ .

*See also:* [mfRank](#), [mfOrth](#), [msRref](#), [msQR](#), [msSVD](#)



**mfOrth****matrix orthogonalization***Calling syntax:*
$$B = \text{mfOrth}( A )$$

returns an orthonormal basis for the range of the `mfArray` `A`.

*See also:* [mfRank](#), [mfNull](#), [msRref](#), [msQR](#), [msSVD](#)

**mfExpn****matrix exponential***Calling syntax:*
$$B = \text{mfExpn}( A )$$

computes the matrix exponential of the **mfArray** **A** (dense only).

*See also:* **mfExp**, **mfLogm**, **mfSqrtm**, **mfPowm**, **mfFunm**

**mfLogm****matrix logarithm***Calling syntax:*
$$B = \text{mfLogm}( A )$$

computes the matrix logarithm of the **mfArray** *A* (dense only).

*See also:* [mfLog](#), [mfExpm](#), [mfSqrtm](#), [mfPowm](#), [mfFunm](#)

**mfSqrtm****matrix square root***Calling syntax:*
$$B = \text{mfSqrtm}( A )$$

computes the matrix square root of the `mfArray` `A` (dense only).

The property  $BB = A$  doesn't always hold, because  $A$  may not have a square root.

*See also:* [mfSqrt](#), [mfExpm](#), [mfLogm](#), [mfPovm](#), [mfFunm](#)

**mfPowm****matrix power***Calling syntax:*
$$B = \text{mfPowm}(A, e)$$

computes the matrix power of the **mfArray** **A**, *i. e.*  $A^e$ .

If **e** is integer, then **A** may have a sparse or a dense structure. Any positive integer is accepted.

If **e** is real, then **A** must have a dense structure. Any real value for **e** is accepted.

*See also:* [mfPow10](#), [mfExpm](#), [mfLogm](#), [mfSqrtm](#), [mfFunm](#)

mf/msFunm

general matrix function

*Calling syntax:*

```
F = mfFunm( A, fun )
```

applies the matrix function `fun` to the `mfArray` `A` (dense only).

`fun` is either a character string giving the name of a usual function (as *sin*, *cos*, *asin*, ...), or the name of a user function. In this latter case, the user function must have the following interface:

```
function fun(z1) result(z2)
  complex(kind=MF_DOUBLE) :: z1, z2
end function
```

The subroutine form, which has the calling syntax:

```
call msFunm( mfOut(F,e), A, fun )
```

returns also an estimation of the error in the scalar `mfArray` `e`. Note that in the case of the exponential function (`fun` set to "exp"), the `mfExpm` is directly called, so that the error estimation will be not available (the `mfArray` `e` will be empty).

*See also:* [mfFun](#), [mfExpm](#), [mfLogm](#), [mfSqrtm](#), [mfPown](#), [mfOut](#)

## mf/msEigs

## few eigenvalues and eigenvectors

The first form:

```
E = mfEigs( A, k [, which|sigma] [, tol, ncv] )
```

returns few eigenvalues of the matrix `A` using ARPACK in the vector `mfArray E`. `A` may be real/complex, sparse/dense.

The number of requested eigenvalues `k` must be ranged in  $[2, n - 2]$ .

`which` is a `character(len=2)` optional argument, can take the values "LM" or "SM", depending on whether the Largest or the Smaller Magnitude eigenvalues/vectors are requested. In addition, `which` can take the following values:

– for real, symmetric matrices:

"LA" = Largest Algebraic, with an algebraic selection;

"SA" = Smallest Algebraic, with an algebraic selection;

"BE" = Both Ends, with an algebraic selection (half from the largest ones and half from the smallest ones).

– for real, unsymmetric matrices:

"LR" = Largest Real part, with an *algebraic* selection;

"SR" = Smallest Real part, with an *algebraic* selection;

"LI" = Largest Imaginary part, with a *magnitude*<sup>1</sup> selection;

"SI" = Smallest Imaginary part, with a *magnitude*<sup>1</sup> selection;

– for complex matrices:

"LR" = Largest Real part, with an *algebraic* selection;

"SR" = Smallest Real part, with an *algebraic* selection;

"LI" = Largest Imaginary part, with a *algebraic* selection;

"SI" = Smallest Imaginary part, with a *algebraic* selection;

Eigenvalues are generally returned in a ascending order, excepted for the "LM" and "LA" cases, for which they are returned in a descending order.

`sigma` is a `complex` optional argument. If present, `mfEigs` tries to find the `k` eigenvalues closest to the complex `sigma`.

If `tol` is present, it indicates the tolerance of the computed eigenvalues. By default, the machine epsilon is taken.

If `ncv` is present, it indicates how many Arnoldi vectors are generated (following the ARPACK documentation, the minimum value for `ncv` is  $2*k+1$  and the maximum value is the order  $n$  of the matrix; a warning is emitted if these conditions are not fulfilled).

If `ncv` is not present, the `mfEigs` routine tries larger and larger values of `ncv`, until (hopefully) the convergence of all requested eigenvalues.

In both cases (`ncv` present or not present), a warning is issued if not all eigenvalues converged. Use the subroutine form, explained below, to obtain a quiet behavior.

⋯/⋯

---

<sup>1</sup>in order to keep adjacent the complex conjugate pairs.

The subroutine form:

```
call msEigs( mfOut(V,E,flag), A, k [, which|sigma] [, tol, ncv] )
```

returns the requested eigenvalues in the vector `mfArray E`, the corresponding eigenvectors in the columns of the `mfArray V`, and the convergence of the iterative process. If the boolean `mfArray flag` is *TRUE* then all the eigenvalues converged; otherwise not all converged. Note that non-converged eigenvalues/eigenvectors are set to NaN.

The remaining arguments are processed as described above.

*See also:* [mf/msEig](#), [mf/msSVDS](#), [mfOut](#)



## mf/msSVDS

## few singular values

The first form:

```
S = mfSVDS( A, k [, which, tol, ncv ] )
```

returns few singular values of the matrix `A` using ARPACK in the vector `mfArray S`. `A` may be real/complex, sparse/dense; it doesn't need to be square.

`k`, the number of required singular values, cannot be larger than  $\min(m, n) - 2$ . If so, `NaN` values are used to fill the vector `S`.

`which` is a `character(len=2)` optional argument, which must be equal to "LM", "SM" or "BE". If present, `mfSVDS` tries to find the `k` singular values of largest magnitude ("LM"), or smallest magnitude ("SM"). Only for real matrices, "BE" allows to compute the both-end singular values. Default value is "LM".

If `tol` is present, it indicates the tolerance of the computed singular values. By default, the machine epsilon is taken.

If `ncv` is present, it indicates how many Arnoldi vectors are generated (following the ARPACK documentation, the minimum value for `ncv` is  $2*k+1$  and the maximum value is  $\min(m, n)$  of the matrix; a warning is emitted if these conditions are not fulfilled).

If `ncv` is not present, the `mfSVDS` routine tries larger and larger values of `ncv`, until (hopefully) the convergence of all requested singular values.

In both cases (`ncv` present or not present), a warning is issued if not all singular values converged. Use the subroutine form, explained below, to obtain a quiet behavior.

The subroutine form:

```
call msSVDS( mfOut(S,flag), A, k [, which, tol, ncv ] )
```

returns the requested singular values in the vector `mfArray S` and the convergence of the iterative process. If the boolean `mfArray flag` is `TRUE` then all the singular values converged; otherwise not all converged. The remaining arguments are processed as described above.

See also: [mf/msSVD](#), [mf/msEigs](#), [mfOut](#)

`mfNormEst, mfNormEst1`**norm estimations***Syntax:*

```
C = mfNormEst( A [ , tol ] )
```

*Description:*

Returns an estimation of the 2-norm of a rank-2 `mfArray` (dense or sparse, real or complex, square or non-square).

The optional argument allows the user to choose the tolerance used in the iterative algorithm. By default, tolerance is  $10^{-6}$ .

*Syntax:*

```
C = mfNormEst1( A )
```

returns an estimation of the 1-norm of a square matrix (sparse or dense).

*See also:* [mfNorm](#)

**mfCondEst****matrix condition number estimation***Calling syntax:*

```
C = mfCondEst( A )
```

*Description:*

Returns an estimation of the condition number of the rank-2 `mfArray` `A`.

*Remarks:* The condition number is always greater than 1. A value equal to infinity (resp. close to the inverse of the  $\epsilon$  machine) indicates that the matrix `A` is singular (resp. nearly singular).

*See also:* [mfCond](#), [mfRCond](#)

**mfIsSymm****matrix symmetry inquiry***Calling syntax:*

```
bool = mfIsSymm( A [ , option="pattern", tol ] )
```

returns a boolean value according to the symmetry property of the `mfArray` `A`. If the matrix is complex, this property means hermitian.

For a sparse `mfArray` `A`, if the optional argument `option` is present and equal to "pattern", then the routine checks only for the symmetry of the sparse structure.

If the optional tolerance `tol` is present, the symmetry test (for the real case) is made according to the rule:

$$\|A - A'\|_1 < 2 \text{tol} \|A\|_1$$

Default tolerance is `MF_EPS`.

*See also:* [mfIsPosDef](#), [mfTolForSymm](#)

**mfTolForSymm****tolerance for symmetry***Calling syntax:*

```
tol = mfTolForSymm( A )
```

returns the tolerance for which the `mfArray` `A` should be symmetric.

*See also:* [mfIsSymm](#)

**mfIsPosDef****definite positiveness inquiry***Calling syntax:*

```
bool = mfIsPosDef( A )
```

returns a boolean value according to the definite positiveness property of the `mfArray` `A`.

*See also:* [mfIsSymm](#)

`mfIsDiagDomCol`**diagonally dominant by cols inquiry***Calling syntax:*

```
bool = mfIsDiagDomCol( A )
```

returns a boolean value according to the “diagonally dominant by cols” property of the `mfArray` `A`.

*See also:* [mfIsStrictDiagDomCol](#)

`mfIsStrictDiagDomCol`                      **strictly diagonally dominant by cols inquiry**

*Calling syntax:*

```
bool = mfIsStrictDiagDomCol( A )
```

returns a boolean value according to the “strictly diagonally dominant by cols” property of the `mfArray` `A`.

*See also:* [mfIsDiagDomCol](#)



**mfIsFullRank****full rank inquiry***Calling syntax:*

```
bool = mfIsFullRank( A [ , tol ] )
```

returns `.true.` if the `mfArray` `A` is full rank, *i. e.* if its rank is equal to the minimum of its dimensions.

If `tol`, of type `real`, is present then this value is used as tolerance in the rank computation. Default tolerance is chosen as  $\max(m, n) \|A\| \epsilon$ .

*See also:* [mfRank](#)

MF\_LAPACK\_VERSION

LAPACK version

*Calling syntax:*

```
string = MF_LAPACK_VERSION()
```

returns the LAPACK version used during the link of the executable.

**Note** the parenthesis used after the name of the variable, because it is implemented as a function.

The returned `string` may be used by the `mfIsVersion` boolean function.

*See also:* `MF_COMPILER_VERSION`, `MF_MUESLI_VERSION`, `msGetBlasLib`, `msGetLapackLib`, `msGetArpackInfo`, `msGetSuiteSparseLib`

**msGetBlasLib****Get BLAS library type***Calling syntax:*

```
call msGetBlasLib( string )
```

returns the BLAS library type used during the link of the executable, that is, either *Reference* for most compilers or a specific package for others (e.g. *MKL* for the INTEL compiler suite; *OpenBLAS* or *ATLAS* for the GNU compiler suite).

**string** is a character string of length at least 128.

The current routine is able to detect the dynamic switch between BLAS implementations like *OpenBLAS* and *ATLAS*.

*See also:* [MF\\_COMPILER\\_VERSION](#), [MF\\_MUESLI\\_VERSION](#), [MF\\_LAPACK\\_VERSION](#), [msGetLapackLib](#), [msGetArpackInfo](#), [msGetSuiteSparseLib](#)

**msGetLapackLib****Get LAPACK library type***Calling syntax:*

```
call msGetLapackLib( string )
```

returns the LAPACK library type used during the link of the executable, that is, either *Reference* for most compilers or a specific package for others (*e.g.* *MKL* for the INTEL compiler suite or *ATLAS* for the GNU compiler suite).

**string** is a character string of length at least 128.

The current routine is able to detect the dynamic switch between BLAS implementations like *Reference* and *ATLAS*.

*See also:* [MF\\_COMPILER\\_VERSION](#), [MF\\_MUESLI\\_VERSION](#), [MF\\_LAPACK\\_VERSION](#), [msGetBlasLib](#), [msGetArpackInfo](#), [msGetSuiteSparseLib](#)

## msGetArpackInfo

## Get ARPACK library information

*Calling syntax:*

```
call msGetArpackInfo( version[, info] )
```

`version` is a character string of length at least 24, containing on return the version of the library. The "NG" letters indicates the *new generation* version, which can be found at: <http://forge.scilab.org/index.php/p/arpack-ng/>.

`info` is an optional character string of length at least 128, containing on return additional information, especially various non official fixes applied to the library.

*See also:* `MF_COMPILER_VERSION`, `MF_MUESLI_VERSION`, `MF_LAPACK_VERSION`, `msGetBlasLib`, `msGetLapackLib`, `msGetSuiteSparseLib`

**msGetSuiteSparseLib****Get SuiteSparse library version***Calling syntax:*

```
call msGetSuiteSparseLib( version )
```

**version** is a character string of length at least 8, containing on return the version of the library.

The returned **string** may be used by the **mfIsVersion** boolean function.

*See also:* [MF\\_COMPILER\\_VERSION](#), [MF\\_MUESLI\\_VERSION](#), [MF\\_LAPACK\\_VERSION](#), [msGetBlasLib](#), [msGetLapackLib](#), [msGetArpackInfo](#)

## 1.9 Polynomial Functions

<a href="#">mfPolyVal</a>	polynomial evaluation
<a href="#">mfPolyFit</a> , <a href="#">msPolyFit</a>	polynomial fitting
<a href="#">mfFunFit</a> , <a href="#">msFunFit</a>	nonlinear function fitting
<a href="#">mfRoots</a>	roots of a polynomial
<a href="#">mfPoly</a>	polynomial with specified roots
<a href="#">mfSpline</a> , <a href="#">msSpline</a>	cubic spline interpolation or smoothing
<a href="#">mfLegendre</a>	Legendre polynomials
<a href="#">mfPPVal</a>	piecewise polynomial evaluation
<a href="#">mfPPDer</a>	piecewise polynomial derivative
<a href="#">mfInterp1</a>	1D interpolation
<a href="#">mfInterp2</a>	regular 2D interpolation
<a href="#">mfPSLG</a>	Planar Straight Line Graph ( <i>derived type</i> )
<a href="#">msPrintPSLG</a>	Planar Straight Line Graph display
<a href="#">mfDelaunay</a>	Delaunay 2D triangulation
<a href="#">mfTriConnect</a>	2D triangular connectivity ( <i>derived type</i> )
<a href="#">msBuildTriConnect</a>	2D triangular connectivity initialization
<a href="#">msUpdateTriConnect</a>	2D triangular connectivity update
<a href="#">msExtractTriConnect</a>	get 2D connectivity from a <a href="#">mfTriConnect</a> structure
<a href="#">msCheckDomainConvexity</a>	Check convexity of a 2D triangulation
<a href="#">msPrintTriConnect</a>	2D triangular connectivity display
<a href="#">msTriNodeNeighbors</a>	2D triangulation node neighbors
<a href="#">mfTriSearch</a> , <a href="#">mfNodeSearch</a>	2D triangulation search
<a href="#">mfGridData</a>	irregular 2D interpolation
<a href="#">mfDelaunay3D</a>	Delaunay 3D tetrahedralization
<a href="#">msEndDelaunay3D</a>	Internal free storage after Delaunay 3D
<a href="#">mfTetraConnect</a>	3D tetrahedral connectivity ( <i>derived type</i> )
<a href="#">msBuildTetraConnect</a>	3D tetrahedral connectivity initialization
<a href="#">msPrintTetraConnect</a>	3D tetrahedral connectivity display
<a href="#">msDel3DNodeNeighbors</a>	3D tetrahedralization node neighbors
<a href="#">mfTetraSearch</a> , <a href="#">mfNodeSearch3D</a>	3D tetrahedralization search
<a href="#">mfGridData3D</a>	irregular 3D interpolation

See also:

[Core Routines](#)

[File Input/Output](#)

[Data Analysis Functions](#)

[Operators](#)

[Elementary Math Functions](#)

[Specialized Math Functions](#)

[Elementary Matrix Manipulation Functions](#)

[Matrix Functions](#)

[Optimization and Function Functions](#)

[Sparse Matrices](#)

mfPolyVal

polynomial evaluation

*Interface:*

```
function mfPolyVal( p, x ) result( out )  
  
    type(mfArray), intent(in) :: p, x  
    type(mfArray) :: out
```

*Description:*

Evaluates polynomial  $p$  at points  $x$ .

The `mfArray`  $p$  is a vector of length  $k+1$  whose elements are the coefficients of the polynomial in descending powers.

$$out = p_1 x^k + p_2 x^{k-1} + \dots + p_k x + p_{k+1}$$

See also: [mfPPVal](#), [mfPolyFit](#)



mfPolyFit

polynomial fitting

*Interface:*

```
function mfPolyFit( x, y, n ) result( out )  
  
    type(mfArray), intent(in) :: x, y  
    integer, intent(in) :: n  
    type(mfArray) :: out
```

*Description:*

Fit polynomial to real data.

The `mfArray` `x` and `y` must be column vectors of same length. They are coordinates of the data. `n` is the degree of the polynomial to be obtained, so  $n + 1$  real coefficients are returned in the vector `out`. These coefficients are sorted for descending powers.

*See also:* [msPolyFit](#), [mfPolyVal](#), [mfFunFit](#)

**msPolyFit****polynomial fitting***Calling syntax:*

```
call msPolyFit( mfOut(p, normr[, r2]), x, y, n )
```

*Description:*

Similar to **mfPolyFit**, but also returns (in **mfArrays**) the norm-2 of the residuals (in **normr**) and optionally the correlation coefficient  $r_{\text{corr}}^2$  (in **r2**).

*Nota:* The correlation coefficient of the approximation is computed as follows:

$$r_{\text{corr}}^2 = 1 - \frac{\text{normr}^2}{M \sigma^2}$$

where  $\sigma^2$  is the standard deviation (as computed by **mfVar**(y)) and  $M$  is the number of data points in **x** and **y**.

*See also:* **mfPolyVal**, **msFunFit**, **mfOut**

mfFunFit

nonlinear function fitting

*Interface:*

```

function mfFunFit( x, y, fun, p0, n, tol ) result( out )

  type(mfArray), intent(in) :: x, y, p0
  interface
    function fun( x, p, n ) result( res )
      import :: MF_DOUBLE
      real(kind=MF_DOUBLE), intent(in) :: x
      real(kind=MF_DOUBLE), intent(in) :: p(n)
      integer, intent(in) :: n
      real(kind=MF_DOUBLE) :: res
    end function fun
  end interface
  integer, intent(in) :: n
  real(kind=MF_DOUBLE), intent(in), optional :: tol

  type(mfArray) :: out

```

*Description:*

Fit arbitrary (nonlinear) function to real data.

Data is stored in the mfArrays *x* and *y*, which must be column vectors of same length. There are *m* couples (*x*, *y*).

*fun* is the real function which tries to model the data. This function is parameterized by *n* variables stored in the mfArray *p*.

At input, *p0* contains an initial guess for the values of the *n* unknown parameters. Final values are stored in the mfArray *out*.

*tol* is the tolerance for the convergence. Its default value is  $10^{-6}$ .

*Remarks:*

- the problem is formulated as a non-linear least-square problem, solved by package *MINPACK*;
- therefore, *m* (the number of couples (*x*, *y*)) must be bigger than the number of parameters *n*.

See also: [msFunFit](#), [mfPolyFit](#), [mfLsqNonLin](#)

**msFunFit****nonlinear function fitting***Calling syntax:*

```
call msFunFit( mfOut(p[, r2]), x, y, fun, p0, n [, tol ] )
```

*Description:*

Similar to **mfFunFit**, but in addition it returns the correlation coefficient  $r_{\text{CORR}}^2$  (in the **mfArray** **r2**).

For this subroutine, the output of the desired **n** variables is stored in the **mfArray** **p**.

*Remark:* Please note that the correlation coefficient  $r_{\text{CORR}}^2$  is ranged in the interval  $[-1, +1]$ . A value close to  $+1$  indicates a perfect correlation while a null value indicates no correlation. A negative value means that the relationship between original data and fitted data is very bad most of time (practically, this should indicate that your function **fun** is not adapted to the data).

*See also:* **mfOut**

**mfRoots****roots of a polynomial***Calling syntax:*

```
r = mfRoots( p )
```

*Description:*

Returns the roots of the polynomial whose coefficients are provided in the **mfArray** **p** (row or column vector).

This polynomial writes:

$$P(x) = p_1 x^{n-1} + p_2 x^{n-2} + \dots + p_{n-1} x + p_n$$

where  $[p_1, p_2, \dots, p_n]$  are the  $n$  components of the input vector **p**.

Even if the roots are real, the returned **mfArray** is complex. The roots are not sorted.

*Remarks:*

- **p** must be of type real.
- The **mfPoly** function is the inverse of the **mfRoots** function.

*See also:* [mfCompan](#), [mfEig](#), [mfFZero](#)

**mfPoly****polynomial with specified roots***Calling syntax:*

```
p = mfPoly( r )
```

*Description:*

Returns the coefficients of the polynomial whose roots are provided in the `mfArray` `r` (row or column vector).

If  $n$  is the size of `p` then the output polynomial reads:

$$P(x) = p_1 x^{n-1} + p_2 x^{n-2} + \dots + p_{n-1} x + p_n$$

*Remarks:*

- The specified roots in `r` may be complex.
- The `mfRoots` function is the inverse of the `mfPoly` function.

*See also:* `mfCompan`, `mfEig`

## mfSpline

## cubic spline interpolation

*Interface:*

```

function mfSpline( x, y,                                     &
                  xi,                                     &
                  BC_type_1, BC_val_1, BC_type_2, BC_val_2, &
                  periodic )                               &

result( y_sec )

type(mfArray),      intent(in)           :: x, y
type(mfArray),      intent(in), optional :: xi
integer,            intent(in), optional :: BC_type_1
real(kind=MF_DOUBLE), intent(in), optional :: BC_val_1
integer,            intent(in), optional :: BC_type_2
real(kind=MF_DOUBLE), intent(in), optional :: BC_val_2
logical,            intent(in), optional :: periodic

type(mfArray) :: y_sec

```

*Description:*

If `xi` is not present, this function returns the coefficients of the spline (piecewise cubic polynomial form) which interpolates the values `y` at the abscissas `x`. The returned coefficients in `y_sec` (second derivative at abscissas) are intended to be used with the `mfPPVal` function.

If `xi` is present, `mfSpline` returns only the interpolated values at the entries contained in the `mfArray` `xi`.

By default, the spline form is natural, which means that the first and the last coefficients are null (*i. e.* curvature is null at both ends). Optionally, boundary conditions of various (and mixed) types may be specified at the ends of the interval:

`BC_type_1 = 1` implies that  $y' = BC\_val\_1$  at first end;

`BC_type_1 = 2` implies that  $y'' = BC\_val\_1$  at first end;

`BC_type_2 = 1` implies that  $y' = BC\_val\_2$  at second end;

`BC_type_2 = 2` implies that  $y'' = BC\_val\_2$  at second end;

If `periodic` is present and equal to `TRUE`, then the value of `y`, along with the first and second derivatives are equal at the two ends of the interval. Default is `FALSE`.

*Remarks:*

- `x` and `y` must be vectors having the same shape, but `xi` may have any shape.
- Abscissas `x` doesn't need to be equally spaced; `x` must contain at least 2 points.
- `x`, `y` and `xi` may be temporary `mfArrays`.
- interpolated values, at abscissas different than the nodes in `x` may be obtained by using the `mfPPVal` function.
- smoothing of data may be obtained by using the `msSpline` routine.

## msSpline

## cubic spline smoothing

*Interface:*

```
call msSpline( mfOut(y_smooth, y_sec), x, y, weights           &
               [, BC_type_1, BC_val_1, BC_type_2, BC_val_2] )
```

*Description:*

Similar to the `mfSpline` function (in particular the last four optional arguments), but apply a smoothing to the data, instead of a strict interpolation. The new (smoothed) values of `y` are stored in the `y_smooth` `mfArray`, and the cubic spline coefficients are stored in the `y_sec` `mfArray`.

*Remarks:*

- The `weights` `mfArray` contains the weight of the smoothing, to be applied to each value of the `y` `mfArray`; it may be a scalar: in such a case, all weights are equal.
- When choosing infinite weights, this routine gives the same results than the `mfSpline` function, *i. e.* a strict interpolation of the data; on the other end, choosing null weights leads to the least-square linear regression of all the data points.
- Typically, the values of the weights vary according to the powers of ten.

See also: `mfOut`



**mfLegendre****Legendre polynomials***Calling syntax:*

```
C = mfLegendre( n, A )
```

*Description:*

Returns the evaluation of the  $n$ -th Legendre polynomial (degree  $n$ ) of each element of the `mfArray` `A`.

Restriction: `A` must be of type real.

mfPPVal

piecewise polynomial evaluation

*Interface:*

```
function mfPPVal( x, y, p, xi, extrapol ) result( yi )  
  
    type(mfArray),          intent(in)          :: p, xi  
    (logical|real(kind=MF_DOUBLE)), intent(in), optional :: extrapol  
    type(mfArray)          :: yi
```

*Description:*

Computes the interpolated values at the entries `xi`.

The way this function treats out-of-range input values in `xi` is similar to that of `mfInterp1` (see the remarks below).

`p` is the vector of Spline coefficients – of the curve  $(x,y)$  – returned by `mfSpline`.

*Remarks:*

- `x`, `y`, `p` and `xi` may be temporary `mfArrays`.
- `xi` `mfArray` may have any shape.
- By default, an element of `yi` is set to `MF_NAN` if the corresponding value in `xi` is outside the range of `x`. The optional argument `extrapol` may be used to override this behaviour: a real value allows the use of a constant for out-of-range inputs. More interestingly, a logical value can be used to compute an extrapolated value by using the interpolation law of the nearest valid interval.

See also: `mfPolyVal`, `mfPPDer`

mfPPDer

piecewise polynomial derivative

*Interface:*

```
function mfPPDer( x, y, p, xi, extrapol ) result( yi )  
  
    type(mfArray),          intent(in)          :: p, xi  
    (logical|real(kind=MF_DOUBLE)), intent(in), optional :: extrapol  
    type(mfArray)          :: yi
```

*Description:*

Similar to [mfPPVal](#) but returns the derivative instead of the function value.

p is the vector of Spline coefficients – of the curve (x,y) – returned by [mfSpline](#).

## mfInterp1

## 1D interpolation

*Interface:*

```

function mfInterp1( x, y, xi, order, extrapol ) result( yi )

    type(mfArray),          intent(in)          :: x, y, xi
    integer,               intent(in), optional :: order
    (logical|real(kind=MF_DOUBLE)), intent(in), optional :: extrapol
    type(mfArray)          :: yi

```

*Description:*

Interpolates data `y`, which are defined along a vector `x`, at the entry(ies) specified by `xi`.

`x` and `y` must be vectors with the same shape; `x` must have strictly monotonous values.

`xi` may be a scalar or a vector; `yi`, which contains interpolated data, will have the same shape as `xi`.

*Remarks:*

- By default a *linear interpolation* (2-point stencil) is used (`order=1`); set the optional argument `order` to 2 (resp. 3) in order to use a *quadratic* (resp. *cubic*) *interpolation* using a 3-point (resp. 4-point) stencil. A *nearest interpolation* (1-point stencil) is also possible: set `order` to 0.
- By default, an element of `yi` is set to `MF_NAN` if the corresponding value in `xi` is outside the range of `x`. The optional argument `extrapol` may be used to override this behaviour: a real value allows the use of a constant for out-of-range inputs. More interestingly, a logical value can be used to compute an extrapolated value by using the interpolation law of the nearest valid interval.

See also: [mfSpline](#), [mfInterp2](#), [mfGridData](#), [msMeshGrid](#)

*Example(s):*

```

x = mfLinspace( 0.0d0, 1.0d0, 5 )
call msDisplay( x, "x" )
print *, "y = x**2"
y = x**2
xi = mfLinspace( 0.05d0, 0.95d0, 4 )
call msDisplay( xi, "xi" )
yi = mfInterp1( x, y, xi, order=2 )
call msDisplay( yi, "interpolated data at many points" )

```

output:

```

x =
    0.0000    0.2500    0.5000    0.7500    1.0000

y = x**2

xi =
    0.0500    0.3500    0.6500    0.9500

interpolated data at many points =
    0.0025    0.1225    0.4225    0.9025

```

⋯/⋯

```
xi = mfLinspace( -0.15d0, 1.15d0, 7 )
call msDisplay( xi, "xi" )
yi = mfInterp1( x, y, xi, order=2 )
call msDisplay( yi, "interpolated data at many points (2 NaNs expected)" )
```

output:

```
xi =
-0.1500   0.0667   0.2833   0.5000   0.7167   0.9333   1.1500
```

```
interpolated data at many points (2 NaNs expected) =
```

```
NaN      0.0044   0.0803   0.2500   0.5136   0.8711   NaN
```

```
yi = mfInterp1( x, y, xi, order=2, extrapol=MF_INF )
call msDisplay( yi, "interpolated data at many points (2 Infs expected)" )
```

output:

```
interpolated data at many points (2 Infs expected) =
```

```
Inf      0.0044   0.0803   0.2500   0.5136   0.8711   Inf
```

```
yi = mfInterp1( x, y, xi, order=2, extrapol=.true. )
call msDisplay( yi, "interpolated data at many points (using extrapolation)" )
```

output:

```
interpolated data at many points (using extrapolation) =
```

```
0.0225   0.0044   0.0803   0.2500   0.5136   0.8711   1.3225
```

mfInterp2

regular 2D interpolation

*Interface:*

```
function mfInterp2( x, y, z, xi, yi, order, extrapol ) result( zi )

    type(mfArray),          intent(in)           :: x, y, z, xi, yi
    integer,               intent(in), optional :: order
    (logical|real(kind=MF_DOUBLE)), intent(in), optional :: extrapol
    type(mfArray)          :: zi
```

*Description:*

Interpolates data  $z$ , which are defined on a rectangular, horizontal grid  $(x,y)$ , at the entry(ies) specified by  $xi$  and  $yi$ .

$x$ ,  $y$  and  $z$  must be matrices with the same shape;  $x$ ,  $y$  must have strictly monotonous values. Usually,  $x$  and  $y$  are built with the routine `msMeshGrid`.

$(xi,yi)$  also must have the same shape (scalars, vectors, or matrices);  $zi$ , which contains interpolated data, will have the same shape as  $xi$  and  $yi$ .

*Remarks:*

- By default a *bilinear interpolation* (4-point stencil) is used (`order=1`); set the optional argument `order` to 2 (resp. 3) in order to use a *biquadratic* (resp. *bicubic*) *interpolation* using a 9-point (resp. 16-point) stencil. A *nearest interpolation* (1-point stencil) is also possible: set `order` to 0.
- Note that the method used is valid only for rectangular, horizontal grid. For a general, irregular grid, see `mfGridData`.
- By default, an element of  $zi$  is set to `MF_NAN` if the corresponding value in  $(xi,yi)$  is outside the range of  $x$  and  $y$ . The optional argument `extrapol` may be used to override this behaviour: a real value allows the use of a constant for out-of-range inputs. More interestingly, a logical value can be used to compute an extrapolated value by using the interpolation law of the nearest valid interval.

See also: `mfInterp1`, `msMeshGrid`

mfPSLG

Planar Straight Line Graph (*derived type*)*Description:*

This derived type encapsulates internal arrays describing a 2D domain definition, using polygonal shapes.

Declaration is made as follows:

```
type(mfPSLG) :: PSLG_domain
```

Contrary to other Muesli derived types, all internal fields are public, letting the user to allocate/deallocate and set the data himself. The complete definition of this kind of object is:

```
type(mfPSLG)
    real(kind=MF_DOUBLE), allocatable :: n_xy(:,,:), holes_xy(:,:)
    integer, allocatable :: edge_n(:,:)
end type
```

`n_xy` contains the coordinates of the nodes; must be of size  $(nn, 2)$ , with  $nn \geq 3$ .

`edge_n` contains the definition of each edge segment, by its two endpoints; ; must be of size  $(ne, 2)$ , with  $ne \geq 0$ .

`holes_xy` contains the definition of holes; they are points having two coordinates; must be of size  $(nh, 2)$ , with  $nh \geq 0$ . A hole should be, ideally, located inside a closed boundary of edges or, alternatively, outside the domain but inside the convex hull (in this later case, its role is to allow concavities). The hole points must not be located exactly on any edge.

*Remarks:*

- This structure can be used directly by `msDelaunay` to triangulate the corresponding domain.
- See examples of PSLG domains in the *Muesli User's Guide*.
- A variable of this type may be freed, at the end of its use, by the `msRelease` routine.

See also: `msPrintPSLG`, `msPlotPSLG`

msPrintPSLG

**Display of a Planar Straight Line Graph***Calling syntax:*

```
call msPrintPSLG( PSLG_domain [, short_info ] )
```

*Description:*

For a small number of nodes (typically less than few dozens), this routine print on the screen the definition of a Planar Straight Line Graph, which is used to represent a domain geometry.

The input argument `PSLG_domain` must be of type `mfPSLG`.

When the boolean optional argument `short_info` is present and equal to `TRUE` then the routine just print the number of items, *i. e.* nodes, edges and holes. Therefore, it is the only way to inspect the structure when it is big.

*See also:* `msPlotPSLG`



## mfDelaunay

## Delaunay 2D triangulation

*First calling syntax:*

```
tri = mfDelaunay( x_in, y_in )
```

*Description:*

Builds a Delaunay 2D triangulation from a list of nodes whose coordinates are given in `x_in` and `y_in` (these two `mfArrays` must be vectors having the same length).

The returned `mfArray` contains indices for the triangles: each row of `tri` provides three integers which describes a triangle (direct orientation, when travelling from first node to the second and the third ones).

*Second calling syntax:*

```
call msDelaunay( mfOut( x, y, tri ), x_in, y_in,           &
                 [ theta_min, area_max ] )
```

*Description:*

Builds a constrained conforming Delaunay 2D triangulation (as previously, from a given list of nodes whose coordinates are stored in `x_in` and `y_in`), giving a quality mesh by adding new nodes where it is required. Two different criteria are used:

- A minimal angle `theta_min`, to avoid triangles with too small angles. This angle, in degree, must be less than 28.6 (otherwise the algorithm may fail to converge – anyway, the routine will emit an error). The recommended value ranges from 20 to 25.
- A maximum area `area_max`, to avoid big triangles.

These two optional arguments are `real`. At least one is required.

*Third calling syntax:*

```
call msDelaunay( mfOut( x, y, tri ), PSLG_domain,       &
                 [ theta_min, area_max ] )
```

*Description:*

Same as the above interface, but take a PSLG domain on input (see `mfPSLG`), instead of a list of nodes. PSLG means *Planar Straight Line Graph* and, very briefly, can be viewed as a polygonal description of the boundaries of a domain; it is intended to store the description of a plane domain to be meshed.

*See also:* `msBuildTriConnect`, `mfNodeSearch`, `mfTriSearch`, `mfDelaunay3D`

**mfTriConnect****2D triangular connectivity (*derived type*)***Description:*

This derived type encapsulates internal arrays describing the connectivity of a 2D triangulation. It must be initialized with the `msBuildTriConnect` routine.

Declaration is made as follows:

```
type(mfTriConnect) :: tri_connect
```

Note that this structure embeds not only the connectivity tables, but also all nodes coordinates.

See `msExtractTriConnect` for more information about the content of this structure.

A variable of this type must be freed, at the end of its use, by the `msRelease` routine.

*See also:* `msPrintTriConnect`, `msTriMesh`

## msBuildTriConnect

## 2D triangular connectivity initialization

*Interface:*

```

subroutine msBuildTriConnect( x, y, tri, tri_connect,           &
                             check_tri_orient,              &
                             tri_renum, equil_face_orient )

  type(mfArray),      intent(in)      :: x, y
  type(mfArray),      intent(in out)  :: tri
  type(mfTriConnect), intent(out)     :: tri_connect
  logical,            intent(in), optional :: check_tri_orient
  logical,            intent(in), optional :: tri_renum, equil_face_orient

```

*Description:*

This routine initializes the internal structures of the 2D triangulation connectivity `tri_connect`. See `mfTriConnect`.

Arguments are `mfArrays` describing (i) the coordinates of all nodes (in `x` and `y`) and (ii) the definition of the triangles in terms of nodes (in `tri`).

The indices in the `mfArray tri` describe the 2D triangulation; they may come from the `mfDelaunay` routine applied to the coordinates `x` and `y`.

The optional logical argument `check_tri_orient` is used to check that all triangles, described in the `mfArray tri`, have a direct orientation; this is required if you plan to apply, later on, the `msCheckDomainConvexity` routine. Default is to apply such a check. As this check is costly, you should omit it only if you are sure on the constraint about triangles' orientation, for example when `tri` results from the use of the `mfDelaunay` routine. When used, this check may change some indices in the `tri mfArray`.

The optional logical argument `tri_renum` is used to apply a renumbering of the triangles, in such a way that they are, wherever possible, geometrically contiguous. In this case, the table of triangles `tri` can be modified (row ordering). Default is to not apply such a renumbering.

The optional logical argument `equil_face_orient` is used to modify the orientation of triangles' faces, in such a way that they are, wherever possible, equilibrated at each node. Default is to not modify the faces' orientation.

*Remarks:*

- After use, the `tri_connect` object should be freed via a call to the routine `msRelease`.
- The nodes coordinates are embedded in the `tri_connect` structure. Therefore, you should NOT change the nodes coordinates after calling the current routine: indeed, while the connectivity remains the same, the convexity (which is a geometrical property embedded in the structure, see `msExtractTriConnect`) may be affected. Otherwise, especially if you DO modify the coordinates of the boundary nodes, you will have to compute again the connectivity.

*See also:* `mfTriSearch`, `mfNodeSearch`, `msPrintTriConnect`

**msUpdateTriConnect****2D triangular connectivity update***Interface:*

```
subroutine msUpdateTriConnect( x, y, tri_connect )  
  
    type(mfArray),           :: x, y  
    type(mfTriConnect), intent(in out) :: tri_connect
```

*Description:*

Update the nodes' position in an **mfTriConnect** structure.

Arguments **x** and **y** are **mfArrays** containing the new  $(x, y)$  position of the nodes in the 2D triangulation.

*See also:* **msBuildTriConnect**

**msExtractTriConnect**      **get 2D connectivity from a mfTriConnect structure***Interface:*

```

subroutine msExtractTriConnect( tri_connect, tri_f, face_n,           &
                              face_tri, convexity )

  type(mfTriConnect),  intent(in)           :: tri_connect
  integer, allocatable, intent(out), optional :: tri_f(:, :), face_n(:, :), &
                              face_tri(:, :)
  integer,              intent(out), optional :: convexity

```

*Description:*

Usually, the 2D mesh connectivity is embedded (with hidden components) in a **mfTriConnect** structure. If the user want to know/use the links between nodes, triangles and faces, he has to extract himself the corresponding connectivity tables.

The input 2D connectivity **tri\_connect** must have been initialized by the **msBuildTriConnect** routine.

According to the optional argument presence, this routine returns the following integer tables, containing positive integers (when nothing else is specified):

- **tri\_f**, of dimension (**nt**, 3), which contains the three faces of a given triangle; **nt** is the total number of triangles.
- **face\_n**, of dimension (**nf**, 2), which contains the two nodes which define a given face; **nf** is the total number of faces.
- **face\_tri**, of dimension (**nf**, 2), which contains the two triangles separated by a given face; **nf** is the total number of faces. In the case where the given face is on the boundary domain, only the first triangle number is valid; the second one is set to a value which is negative or zero (see below)
- **convexity**, an integer variable whose value may be  $-1$  (*UNKNOWN*),  $0$  (*FALSE*) or  $1$  (*TRUE*). It is recommended to ask for its value when interpreting the value of the second column of the **face\_tri** table. When the domain convexity is *UNKNOWN* or *TRUE*, the second element of the **face\_tri** table is always zero for a boundary face. When the domain convexity is *FALSE*, the value zero for a boundary face indicates the convex exterior part, the value  $-1$  indicates the non-convex part of the exterior boundary, whereas other negative values indicates an interior boundary (*i. e.* a hole; add one to this number to obtain the numbering of the hole). Note that the order of the interior boundaries' numbering is determined by the smallest value of the nodes for each of these internal boundaries. Note also that the convexity can be explicitly determined by use of the **msCheckDomainConvexity** routine.

*Remarks:*

- the connectivity doesn't depend on the exact location of the nodes, but the convexity does.
- the number of faces (**nf**) can be retrieve by asking the shape of the **face\_n** array.
- the allocatable arrays **tri\_f**, **face\_n** and **face\_tri** are allocated by the routine itself; in the case where one of them is already allocated, it will be deallocated and reallocated if needed.

See also: **mfTriConnect**, **msBuildTriConnect**

**msCheckDomainConvexity****Check convexity of a 2D triangulation***Calling syntax:*

```
call msCheckDomainConvexity( tri_connect )
```

*Description:*

Computes the convexity of a 2D triangulation, given as argument in the `tri_connect` connectivity.

After use of this routine, the `convexity` component of the connectivity may be only `TRUE` or `FALSE`, not `UNKNOWN` (see `msExtractTriConnect`).

*See also:* `mfTriConnect`, `msBuildTriConnect`, `msPrintTriConnect`

**msPrintTriConnect****Display of a 2D triangular connectivity***Calling syntax:*

```
call msPrintTriConnect( tri_connect [, short_info ] )
```

*Description:*

For a small number of nodes (typically less than few dozens), this routine print on the screen the connectivity tables of a triangular mesh (the connectivity could be computed by the **msBuildTriConnect** routine, or by other ways).

The input argument **tri\_connect** must be of type **mfTriConnect**.

When the boolean optional argument **short\_info** is present and equal to *TRUE* then the routine just print the number of items, *i. e.* nodes, triangles and faces. Therefore, it is a simple way to inspect the structure when it is big. Another way is to extract some components of **tri\_connect** by using the **msExtractTriConnect** routine.

*See also:* **msTriMesh**

## msTriNodeNeighbors

## 2D triangulation node neighbors

*Interface:*

```
subroutine msTriNodeNeighbors( tri_connect [, connected_nodes | connected_faces ] )  
  
  type(mfTriConnect), intent(in)           :: tri_connect  
  type(mf_Int_List),  intent(out), optional :: connected_nodes(:)  
  type(mf_Int_List),  intent(out), optional :: connected_faces(:)
```

*Description:*

This routine computes the list of the neighbors (either nodes, stored in `connected_nodes`, or faces, stored in `connected_faces`) for each node belonging to the triangulation given in `tri_connect`.

The output lists, `connected_nodes` and `connected_faces` are both vectors of type `mf_Int_List`, a special structure which can contain a variable number of elements. Be aware that the allocation is done by the current routine, not by the user. The length of these vectors is, of course, equal to the number of nodes of the triangulation.

The input mesh connectivity `tri_connect` must have been built before via a call to `msBuildTriConnect`.



## mfTriSearch

## 2D triangulation search (for triangle)

*Generic Interface:*

```
function mfTriSearch( tri_connect, x, y, strict ) result( num )  
  
    type(mfTriConnect), intent(in) :: tri_connect  
  
    type(mfArray), intent(in) :: x, y  
    or real(kind=MF_DOUBLE), intent(in) :: x, y  
  
    logical, intent(in), optional :: strict  
  
    integer :: num
```

*Description:*

Searches in a Delaunay triangulation the triangle which encloses the point (x,y).

The input mesh connectivity `tri_connect` must have been built before via a call to `msBuildTriConnect`.

For a *general* search (*i. e.* when the optional argument `strict` is `FALSE`) the routine always returns a valid triangle index which is the enclosing triangle to the targeted point, or the nearest triangle if the targeted point is outside the meshed domain.

On the contrary, for a *strict* search (*i. e.* when the optional argument `strict` is `TRUE`, which is the default), if the search succeeds, then `num` contains the (non zero) index of the triangle; else it contains a negative or null value, which is related to concavities in the meshed domain: 0 means a targeted point outside the domain, whereas  $-k$  means a point located in the hole number  $k$  (a warning is emitted).

*Remark:* The belonging of a point to a triangle is not strict: this means that the same point can belong to several adjacent triangles. In particular, a node of the triangulation belongs to all triangles who share it.

*See also:* `mfNodeSearch`

mfNodeSearch

2D triangulation search (for node)

*Interface:*

```
function mfNodeSearch( tri_connect, x, y, strict ) result( num )

    type(mfTriConnect), intent(in) :: tri_connect

    type(mfArray), intent(in) :: x, y
or real(kind=MF_DOUBLE), intent(in) :: x, y

    logical, intent(in), optional :: strict

    integer :: num
```

*Description:*

Searches in a Delaunay triangulation the nearest node to the point (x,y).

The input mesh connectivity `tri_connect` must have been built before via a call to `msBuildTriConnect`.

For a *general* search (*i. e.* when the optional argument `strict` is `FALSE`) the routine always returns a valid node number which is the nearest node to the targeted point, even if this latter point is outside the meshed domain.

On the contrary, for a *strict* search (*i. e.* when the optional argument `strict` is `TRUE`, which is the default), if the search succeeds, then `num` contains the (non zero) index of the node; else it contains a negative or null value, which is related to concavities in the meshed domain: 0 means a targeted point outside the domain, whereas  $-k$  means a point located in the hole number  $k$  (a warning is emitted).

*See also:* `mfTriSearch`

mfGridData

irregular 2D interpolation

*Interface:*

```
function mfGridData( x, y, f, xi, yi ) result( fi )  
  
    type(mfArray), intent(in) :: x, y, f, xi, yi  
    type(mfArray) :: fi
```

*Description:*

Interpolates data **f**, which are defined on an irregular grid (**x,y**), at the entries specified by **xi** and **yi**. **x**, **y** and **f** must be vectors with the same shape.

(**xi,yi**) also must have the same shape (scalars, vectors, or matrices); **fi**, which contains interpolated data, will have the same shape as them.

**fi** is set to MF\_NAN if (**xi,yi**) is outside the convex hull of **x** and **y**.

*Remarks:* a linear interpolation is used.

*See also:* [mfInterp2](#), [mfGridData3D](#)

mfDelaunay3D

**Delaunay 3D tetrahedralization***Interface:*

```
function mfDelaunay3D( x, y, z ) result( tetra )
```

```
    type(mfArray), intent(in) :: x, y, z
```

```
    type(mfArray) :: tetra
```

or

```
function mfDelaunay3D( coords ) result( tetra )
```

```
    type(mfArray), intent(in) :: coords
```

```
    type(mfArray) :: tetra
```

*Description:*

Builds a Delaunay 3D tetrahedralization from a list of nodes whose coordinates are given in **x**, **y** and **z** (these three **mfArrays** must be vectors having the same length). In the second possible interface, **coords** must have three columns.

The returned **mfArray** contains indices for the tetrahedra: each row of **tetra** provides four integers which describes a tetrahedron.

All tetrahedra have a direct orientation: nodes 1, 2 and 3 is a direct triangle if node 4 is above them.

*See also:* [msBuildTetraConnect](#), [mfDelaunay](#)

**msEndDelaunay3D****Internal free storage after Delaunay 3D***Calling syntax:*

```
call msEndDelaunay3D( )
```

*Description:*

After using the **mfDelaunay3D** routine, it is recommended to call **msEndDelaunay3D** in order to clean the auxiliary memory used to build the tetrahedralization.

**mfTetraConnect** **3D tetrahedral connectivity (*derived type*)***Description:*

This derived type encapsulates internal arrays describing the connectivity of a 3D tetrahedralization. It must be initialized with the `msBuildTetraConnect` routine.

Declaration is made as follows:

```
type(mfTetraConnect) :: tetra_connect
```

A variable of this type must be freed, at the end of its use, by the `msRelease` routine.

*See also:* `mfDeLaunay3D`

msBuildTetraConnect

**3D tetrahedral connectivity initialization***Interface:*

```
subroutine msBuildTetraConnect( x, y, z, tetra, tetra_connect )
```

```
  type(mfArray), intent(in) :: x, y, z, tetra
  type(mfTetraConnect), intent(out) :: tetra_connect
```

or

```
subroutine msBuildTetraConnect( coords, tetra, tetra_connect )
```

```
  type(mfArray), intent(in) :: coords, tetra
  type(mfTetraConnect), intent(out) :: tetra_connect
```

*Description:*

This routine initializes the internal structures of a 3D tetrahedralization connectivity.

The indices in the mfArray `tetra` describe the 3D tetrahedralization; they may come from the `mfDelaunay3D` routine applied to the coordinates `x`, `y` and `z`.

Arguments are mfArrays describing (i) the coordinates of all nodes (in `x`, `y` and `z`) and (ii) the definition of the triangles in terms of nodes (in `tetra`).

The second possible interface allows the user to group all the columns vector coordinates in one matrix having a coherent shape.

After use, the `tetra_connect` object should be freed via a call to the routine `msRelease`.

*See also:* `mfTetraSearch`, `mfNodeSearch3D`

**msPrintTetraConnect****Display of a 3D tetrahedral connectivity***Calling syntax:*

```
call msPrintTetraConnect( tetra_connect )
```

*Description:*

For a few numbers of nodes (typically less than few dozens), this routine print on the screen the connectivity tables computed by the **msBuildTetraConnect** routine.



msDel3DNodeNeighbors

3D tetrahedralization node neighbors

*Interface:*

```
subroutine msDel3DNodeNeighbors( tetra, node_neighbors )
```

```
  type(mfArray),    intent(in)  :: tetra
  type(mf_Int_List), intent(out) :: node_neighbors(:)
```

*Description:*

This routine computes the list of the neighbors of all nodes in the allocatable array `node_neighbors` (of type `mf_Int_List`). Be aware that the allocation is done by the current routine, not by the user.

The indices in the `mfArray tetra` describe the 3D tetrahedralization; they may come from the `mfDelaunay3D` routine applied to the coordinates `x`, `y` and `z`.

*See also:* `msBuildTetraConnect`



mfNodeSearch3D

**3D tetrahedralization search (for node)***Interface:*

```
function mfNodeSearch3D( tetra_connect, x, y, z ) result( num )  
  
    type(mfTetraConnect), intent(in) :: tetra_connect  
  
    type(mfArray), intent(in) :: x, y, z  
or real(kind=MF_DOUBLE), intent(in) :: x, y, z  
  
    integer :: num
```

*Description:*

Searches in a Delaunay tetrahedralization the nearest node to the point (x,y,z).

`tetra_connect` must be built before via a call to `msBuildTetraConnect`.

If the search succeeds, then `num` contains the (non zero) index of the node, else it contains 0. If `num` is 0, this means that the point is outside the convex hull (a Warning is emitted).

*See also:* [mfTetraSearch](#), [msBuildTetraConnect](#)

mfGridData3D

irregular 3D interpolation

*Interface:*

```
function mfGridData3D( x, y, z, f, xi, yi, zi ) result( fi )  
  
    type(mfArray), intent(in) :: x, y, z, f, xi, yi, zi  
    type(mfArray) :: fi
```

*Description:*

Interpolates data **f**, which are defined on an irregular 3D grid (**x,y,z**), at the entries specified by **xi**, **yi** and **zi**.

**x**, **y**, **z** and **f** must be vectors with the same shape.

(**xi,yi,zi**) also must have the same shape (scalars, vectors, or matrices); **fi**, which contains interpolated data, will have the same shape as them.

**fi** is set to MF\_NAN if (**xi,yi,zi**) is outside the convex hull of **x**, **y** and **z**.

*Remarks:* a linear interpolation is used.

*See also:* [mfGridData](#)

## 1.10 Optimization and Function Functions

<a href="#">mf/msFZero</a>	single-variable non-linear zero finding
<a href="#">mf/msFSolve</a>	multiple-variable non-linear zero finding
<a href="#">mf/msLsqNonLin</a>	non-linear least-square minimization
<a href="#">mfTrapz</a>	numerical evaluation of integrals by trapezoidal method
<a href="#">mfSimpson</a>	numerical evaluation of integrals by Simpson method
<a href="#">mfQuad</a> , <a href="#">msQuad</a>	numerical evaluation of integrals (adaptive method)
<a href="#">mfDbIQuad</a> , <a href="#">msDbIQuad</a>	numerical evaluation of double integrals (adaptive method)
<a href="#">mfOdeSolve</a> , <a href="#">msOdeSolve</a>	integrator of ODE (explicit) systems
<a href="#">mfDaeSolve</a> , <a href="#">msDaeSolve</a>	integrator of DAE (implicit) systems
<a href="#">mf_DE_Options</a>	options for differential solvers ( <i>derived type</i> )
<a href="#">mf_NL_Options</a>	options for non-linear solvers ( <i>derived type</i> )

See also:

[Core Routines](#)

[File Input/Output](#)

[Data Analysis Functions](#)

[Operators](#)

[Elementary Math Functions](#)

[Specialized Math Functions](#)

[Elementary Matrix Manipulation Functions](#)

[Matrix Functions](#)

[Polynomial Functions](#)

[Sparse Matrices](#)

mf/msFZero

single-variable non-linear zero finding

*Interface:*

```

function mfFZero( fun, x0, tol ) result( out )

  interface
    real(kind=MF_DOUBLE) function fun( x )
      real(kind=MF_DOUBLE), intent(in) :: x
    end function
  end interface

  type(mfArray), intent(in)      :: x0
  real(kind=MF_DOUBLE), optional :: tol

  type(mfArray) :: out

```

*Description:*

Search for a solution of the non-linear equation  $\text{fun}(x) = 0$ , via the Dekker algorithm (combination of bisection, linear and quadratic interpolation).

`fun` is a user-supplied function which has the prescribed interface above.

`x0` must be a real vector `mfArray` containing exactly two values; it defines the interval for searching  $x$ . These two values must be set such that the sign of  $\text{fun}(x)$  differs.

The optional argument `tol` specifies the relative tolerance for the stopping criterium. It should be a non negative and not too small real value; default value is  $2\epsilon$ .

*Remarks:*

- the convergence is usually fast and the Dekker method theoretically never fail, providing the initial interval given in `x0` is correct;
- `fun` has an imposed list of arguments; the user may use module's data in order to exchange other information between his program and this function. Therefore, except for very simple cases, this user's routine must be located inside a module, `USED` also by the user's program.

The subroutine form:

```
call msFZero( mfOut(x,fval[,status]), fun, x0 [, tol ] )
```

allows the user to access to other information: `fval` is the function value associated to the zero `x`, and a `status` (optional) which has the following values:

status	explanation
0	Normal termination of the algorithm.
-1	Bad initialization: <code>fun</code> , applied to the two elements of <code>x0</code> , must have opposite sign.
-2	Bad argument value: <code>x0</code> has not enough components.

*Remark:* Adding the optional argument `status` allows the user to launch its program in a batch mode: indeed, errors in the current routine will not stop the program (It is the responsibility of the programmer to test the value of the `status` variable before using the result). On the contrary (*i. e.* when the `status` optional argument is not used), an error will stop the program and, in debug mode, a traceback of this error will be displayed.

See also: [mfRoots](#), [mfFSolve](#), [mfOut](#)

mfFSolve

multiple-variable non-linear zero finding

*Interface:*

```

function mfFSolve( fcn, n, x0, options, jac, sparse ) result( out )

  interface
    subroutine fcn( n, x, fvec, flag )
      integer,          intent(in) :: n
      real(kind=MF_DOUBLE), intent(in) :: x(n)
      real(kind=MF_DOUBLE)          :: fvec(n)
      integer            :: flag
    end subroutine
  end interface

  type(mfArray), intent(in)      :: x0
  type(mf_NL_Options), intent(in), optional :: options
  external,          optional :: jac
  logical,          intent(in), optional :: sparse

  type(mfArray) :: out

```

*Description:*

Search for a solution of  $n$  non-linear equations with  $n$  unknowns:

$$F_i(x_1, x_2, \dots, x_n) = 0, \quad i = 1, \dots, n$$

described in the subroutine `fcn`. This user-supplied subroutine has the interface prescribed above and computes  $fvec(i) = F_i(x_1, x_2, \dots, x_n)$ ,  $i = 1, \dots, n$ .

`flag` is actually an in-out argument of `fcn`: on entry, its value is always zero. The user can stop the iteration process, by setting it to any negative integer.

`x0` is an initial guess for the solution  $x$ .

The `mfArray options%tol` contains the tolerance(s) for the convergence:

- when it is a scalar, both the function tolerance  $FTOL$  and the parameter tolerance  $XTOL$  are set to the corresponding value;
- when it is a vector of two elements, the values are used to set the two tolerances:  $FTOL$  and  $XTOL$ , respectively.

When the `mfArray options%tol` is empty (*i. e.* not set by the user),  $FTOL$  and  $XTOL$  are both set to  $10^{-9}$ .

See `mf_NL_Options` for other options.

Optionally, the user may provide the computation of the jacobian via the subroutine `jac`. Its interface must be as follows:

```

interface
  subroutine jac( n, x, jacobian )
    integer,          intent(in) :: n
    real(kind=MF_DOUBLE), intent(in) :: x(n)
    real(kind=MF_DOUBLE)          :: jacobian(n,n)
  end subroutine jac
end interface

```

⋯/⋯

The jacobian matrix is defined as  $J = \frac{\partial F}{\partial x}$ , therefore, the rank-2 array `jacobian` must be filled as follows:  
`jacobian(i,j) = Ji,j =  $\frac{\partial F_i}{\partial x_j}$` . Only non-zero values of  $J$  need to be defined.

For the sparse case, the optional argument `sparse` must be set to `.true.` and the `jac` routine must be defined as:

```
interface
  subroutine jac( n, x, job, pd, ipd, jpd, nnz )
    integer,          intent(in) :: n, job
    real(kind=MF_DOUBLE), intent(in) :: x(n)
    real(kind=MF_DOUBLE)          :: pd(*)
    integer,          :: ipd(*), jpd(*), nnz
  end subroutine
end interface
```

The `pd`, `ipd`, `jpd` f90 arrays describe the CSC (Compact Sparse Column) representation of the sparse jacobian matrix, as follows:

- `pd(1:nnz)` contains the non-zero matrix entries;
- `ipd(1:nnz)` contains the row indices;
- `jpd(1:ncol+1)` is the pointer to the beginning of the columns, in arrays (`pd`, `ipd`).

`pd`, `ipd` must contain all diagonal terms, even if they are null. Moreover, row indices must be sorted in ascending order. Lastly, this routine must include a mechanism such that only the value of `nnz` is computed when `job=0`. You must also use the convention: `jpd(ncol+1)=nnz+1`.

*Remarks:*

- the problem is solved by the package *MINPACK*;
- the algorithm may fail (it is not unusual to have no solution for the non-linear problem – the returned value will be therefore a vector of *NaNs*); in such a case, using the `msFSolve` subroutine helps in giving some information about the reason of the failure.
- `fcn` and `jac` have imposed lists of arguments; as for `mfLsqNonLin`, `mfOdeSolve` and `mfDaeSolve` the user may use module's data in order to exchange other information between his program and these routines (especially for checking the number of equations). Therefore, except for very simple cases, these two user's routines must be located inside a module, USED also by the user's program.

See also: `mfFZero`, `mfLsqNonLin`



msFSolve

multiple-variable non-linear zero finding

*Calling syntax:*

```
call msFSolve( mfOut( x[, fvec, status ] ), fcn, n, x0 [, options, jac] )
```

*Description:*

Similar to `mfFSolve`, but also returns the vector function (in the `mfArray` `fvec`) and, optionally, a `status` which has the following values:

status	explanation
1	Normal termination of the algorithm. The stopping criterion about <code>xtol</code> has been reached first.
2	Normal termination of the algorithm. The stopping criterion about <code>ftol</code> has been reached first.
-1	Bad initialization for <code>x0</code> (size or type).
-2	Bad argument value: <code>tol</code> is not strictly positive.
-3	Bad termination: number of calls of <code>fcn</code> has reached or exceeded <code>max_iter*(n+1)</code> (if <code>jac</code> is not present) or <code>max_iter</code> (if <code>jac</code> is present).
-4	Bad termination: <code>tol</code> is too small. No further improvement in the approximate solution <code>x</code> is possible.
-5	Bad termination: iteration is not making good progress.
-10	The user has stopped the algorithm via the argument <code>flag</code> of the <code>fcn</code> subroutine.
-14	The user-supplied <code>fcn</code> routine returned invalid entries ( <i>NaN</i> value).

For this subroutine, the solution is stored in the `mfArray` `x`.

If the `status` value is not positive (*i. e.* when algorithm fails), both `x` and `fvec` are vectors of *NaNs*.

*Remark:* Adding the optional argument `status` allows the user to launch his program in a batch mode: indeed, errors in the current routine will not stop the program (It is the responsibility of the programmer to test the value of the `status` variable before using the result). On the contrary (*i. e.* when the `status` optional argument is not used), an error will stop the program and, in debug mode, a traceback of this error will be displayed.

See also: `mfOut`

mfLsqNonLin

nonlinear least-square minimization

*Interface:*

```

function mfLsqNonLin( m, fcn, p0, n, options, jac ) result( out )

    integer,          intent(in)  :: m, n
    type(mfArray),   intent(in)  :: p0

    interface
        subroutine fcn( m, n, p, fvec, flag )
            integer,          intent(in)  :: m, n
            real(kind=MF_DOUBLE), intent(in) :: p(n)
            real(kind=MF_DOUBLE)          :: fvec(m)
            integer           :: flag
        end subroutine fcn
    end interface

    type(mf_NL_Options), optional :: options
    external,            optional :: jac

    type(mfArray) :: out

```

*Description:*

Minimize the sum of the squares of  $m$  nonlinear functions  $F_i$  depending on  $n$  parameters.

`fcn` is the user-supplied subroutine which calculates the functions; it has the interface prescribed above and computes  $fvec(i) = F_i(p)$ ,  $i = 1, \dots, m$ , where  $p$  represents the vector of the  $n$  parameters.

`flag` is actually an in-out argument of `fcn`: on entry, its value is always zero. The user can stop the iteration process, by setting it to any negative integer. See just below for constrained minimization.

Constraints of type *BOX* are possible, for each parameter(see [mf\\_NL\\_Options](#)).

At input, `p0` contains an initial guess for the values of the  $n$  unknown parameters. Final values are stored in the `mfArray out`.

All the following options are stored in the structure `options` (see [mf\\_NL\\_Options](#)).

The `mfArray options%tol` contains the tolerance(s) for the convergence:

- when it is a scalar, both the function tolerance *FTOL* and the parameter tolerance *XTOL* are set to the corresponding value, while the orthogonality tolerance *GTOL* (it measures the orthogonality between the function vector and the columns of the jacobian) is set to zero;
- when it is a vector of three elements, the values are used to set the three tolerances: *FTOL*, *XTOL* and *GTOL*, respectively.

When the `mfArray options%tol` is empty (*i.e.* not set by the user), *FTOL* and *XTOL* are both set to  $10^{-6}$  while *GTOL* is set to zero.

`options%max_iter` is the maximum number of iterations. Its default value is 50.

⋯/⋯

`options%epsfcn` is the approximation error of the functions  $F_i$ . Its default value is zero. It is used only to compute the step for the finite differences computation of the Jacobian; this argument will not be referenced if `jac` is present. In the case of an approximate computation in the `fcn` routine (*e.g.* an integration or whatelse), the value of `epsfcn` may be critical to obtain good convergence; it must be chosen carefully; see [mf\\_NL\\_Options](#) for additional information.

The logical `options%print` can be used to print some information during the iterative process. Default is `FALSE`.

Optionally, the user may provide the computation of the jacobian via the subroutine `jac`. Its interface must be as follows:

```
interface
  subroutine jac( m, n, p, jacobian )
    integer,          intent(in) :: m, n
    real(kind=MF_DOUBLE), intent(in) :: p(n)
    real(kind=MF_DOUBLE)          :: jacobian(m,n)
  end subroutine jac
end interface
```

The jacobian matrix is defined as  $J = \frac{\partial F}{\partial p}$ , and the rank-2 array `jacobian` must be filled as follows:

`jacobian(i,j) = Ji,j =  $\frac{\partial F_i}{\partial p_j}$` . Only non-zero values of  $J$  need to be defined.

The integer `options%check_jac` allows the user to numerically check (via finite differences) the components of the jacobian each time it is called. A quick global check is done by setting this argument to 1 while a complete (but more expensive) check is done by setting it to 2. Default is 0, *i.e.* no check.

Lastly, the integer `print_check_jac` allows the printing (either on the screen if the value is 1, or in files if the value is 2) of the results of the previous jacobian check. Default is 0, *i.e.* no check.

*Remarks:*

- the problem is solved by the LMA method (Levenberg-Marquardt Algorithm) of the *MINPACK* package;
- `m` must be bigger than the number of parameters `n`.
- `fcn` and `jac` have imposed lists of arguments; as for [mfFSolve](#), [mfOdeSolve](#) and [mfDaeSolve](#) the user may use module's data in order to exchange other information between his program and these routines (especially for checking the number of equations). Therefore, except for very simple cases, these two user's routines must be located inside a module, `USED` also by the user's program.
- the initial step bound for the parameters' vector is based on a factor whose default value is 100. Sometimes, we may want to change this factor to a smaller value, especially if you use the `log()` function to ensure the positiveness of your unknowns; in such a case, `factor = log(100)` is more appropriate, by setting `options%init_step_bound_factor` to this value.

See also: [mfFunFit](#), [msLsqNonLin](#)

msLsqNonLin

nonlinear least-square minimization

*Calling syntax:*

```
call msLsqNonLin( mfOut( p, resnorm[, status, res_log, p_log, ident ] ),      &
                 m, fcn, p0, n[, options, jac ] )
```

*Description:*

Similar to `mFLsqNonLin`, but also returns the 2-norm residue (in the `mfArray` `resnorm`) and, optionally, a `status` which has the following values:

status	explanation
1	Normal termination of the algorithm. Both actual and predicted relative reductions in the sum of squares of the functions <code>fvec</code> are at most <code>ftol</code> .
2	Normal termination of the algorithm. Relative error between two consecutive iterates of the parameters' vector is at most <code>xtol</code> .
3	Normal termination of the algorithm. Conditions for <code>status = 1</code> and <code>status = 2</code> both hold.
-1	Improper input parameters.
-4	<code>fvec</code> is orthogonal to the columns of the jacobian. This means that the gradient is approximatively null (with respect to <code>gtol</code> ): it may correspond to a minimum, or a maximum, or a saddle point, so the algorithm cannot continue.
-5	number of calls of <code>fcn</code> has reached <code>max_iter*(n+1)</code> (if <code>jac</code> is not present) or <code>max_iter</code> (if <code>jac</code> is present).
-6	<code>tol</code> is too small. No further reduction in the sum of squares is possible.
-7	<code>tol</code> is too small. No further improvement in the approximate solution <code>p</code> is possible.
-8	<code>fvec</code> is orthogonal to the columns of the jacobian to machine precision. This means that the gradient is approximatively null: it may correspond to a minimum, or a maximum, or a saddle point, so the algorithm cannot continue. Incidentally, <code>gtol</code> is too small.
-9	The algorithm has been stopped because a constraints' interval for one of the unknown parameters is too small, which makes the finite-differences approximation of the jacobian impossible.
-10	The algorithm has been stopped via the argument <code>flag</code> of the <code>fcn</code> subroutine.
-14	The user-supplied <code>fcn</code> routine returned invalid entries ( <code>NaN</code> value).

For this subroutine, the output of the desired `n` variables is stored in the `mfArray` `p`.

`res_log` and `p_log` are `mfArrays` which contain the history of the norm of the residue and the parameters, along the iterations. Each row of these matrices corresponds to an iteration.

`ident` is an `mfArray` which contains the identifiability of each parameter. This vector has values ranged between 0 and 1, and computed internally by the ratio  $|R_i| / |R_1|$ , where  $R_i, i = 1 \dots n$ , are the diagonal values of the  $R$  matrix obtained after a  $QR$  decomposition of the jacobian (sensitivity matrix). The elements of `ident` have been reordered to match the original order of the parameters. A value equal or close to 0 means that the corresponding parameter is not identifiable. Actually, the user should compare the values of `ident` to the numerical precision of the `fvec` functions.

⋯/⋯

*Remark:* Adding the optional argument `status` allows the user to launch his program in a batch mode: indeed, errors in the current routine will not stop the program (It is the responsibility of the programmer to test the value of the `status` variable before using the result). On the contrary (*i. e.* when the `status` optional argument is not used), an error will stop the program and, in debug mode, a traceback of this error will be displayed.

*See also:* `mfOut`

**mfTrapz****integration by trapezoidal method***First calling syntax:*

```
res = mfTrapz( y )
```

*Description:*

Performs the numerical integration of the data `y`, assuming constant unit spacing for the abscissas, using the trapezoidal rule. If the spacing is different from unity, the result `res` must be multiplied by the effective spacing.

*Second calling syntax:*

```
res = mfTrapz( x, y )
```

*Description:*

Performs the numerical integration of the data `y`, spread against the abscissas `x`.

*Remark:* `x` and `y` must be real vector `mfArrays`.

*See also:* [mfSimpson](#), [mfQuad](#)

**mfSimpson****integration by Simpson method***Calling syntax:*

```
res = mfSimpson( y )
```

*Description:*

Performs the numerical integration of the data **y**, assuming constant unit spacing for the abscissas, using the Simpson rule. If the spacing is different from unity, the result **res** must be multiplied by the effective spacing.

*Second calling syntax:*

```
res = mfSimpson( x, y )
```

*Description:*

Performs the numerical integration of the data **y**, spread against the abscissas **x**.

*Remarks:*

- **x** and **y** must be real vector **mfArrays**.
- the number of points must be odd.

*See also:* [mfTrapz](#), [mfQuad](#)

mfQuad

numerical evaluation of integrals

*Interface:*

```
function mfQuad( fun, a, b, abs_tol, rel_tol, sing ) result( out )

  interface
    real(kind=MF_DOUBLE) function fun( x )
      real(kind=MF_DOUBLE), intent(in) :: x
    end function
  end interface

  real(kind=MF_DOUBLE), intent(in)          :: a, b
  real(kind=MF_DOUBLE), intent(in), optional :: abs_tol, rel_tol
  logical, intent(in), optional            :: sing
  type(mfArray) :: out
```

*Description:*

Performs the numerical computation of the integral of the function  $\text{fun}(x)$  over the interval  $[a, b]$ .

The optional arguments `abs_tol` and `rel_tol` allows the user to give the absolute and/or the relative precision of the result. Default tolerance is  $1 \times 10^{-12}$ .

The second optional argument `sing` should be used when the function  $\text{fun}(x)$  has a singularity at  $x = a$  or/and at  $x = b$ . '`sing=.true.`' leads to use another quadrature method, which usually involves a fewer number of function evaluation.

*Remarks:* `out` is set to `MF_NAN` if required precision cannot be achieved; an error is emitted by the library. Call the subroutine version if you don't want such a behavior.

*See also:* [msQuad](#), [mfTrapz](#), [mfDblQuad](#), [msDblQuad](#)



## msQuad

## numerical evaluation of integrals

Calling syntax:

```
call msQuad( mfOut( q, abserr[, status, neval] ),           &
             fun, a, b [, abs_tol, rel_tol, sing] )
```

Description:

The behavior of this routine is similar to those of [mfQuad](#).

The subroutine call allows to get more information returned by the integrator:

- `q` contains the numerical result
- `abserr` contains an estimation of the absolute error
- `status` (optional) contains the returned error code:
  - `status = 0`: normal and reliable termination of the routine. It is assumed that the requested accuracy has been achieved.
  - `status < 0`: abnormal termination of the routine. The estimates for `q` and `abserr` are less reliable. It is assumed that the requested accuracy has not been achieved. Only a warning is emitted by the library. (Exact meaning of the error can be found [below](#))
- `neval` (optional) contains the effective number of function evaluation

All these variable must be of `type(mfArray)`.

*Remark:* Adding the optional argument `status` allows the user to launch its program in a batch mode: indeed, errors in the current routine will not stop the program (It is the responsibility of the programmer to test the value of the `status` variable before using the result). On the contrary (*i. e.* when the `status` optional argument is not used), an error will stop the program and, in debug mode, a traceback of this error will be displayed.

See also: [mfQuad](#), [mfOut](#), [mfDblQuad](#), [msDblQuad](#)

<code>status</code>	<i>explanation</i>
–1	Maximum number of subdivisions allowed has been achieved.
–2	The occurrence of roundoff errors is detected, which prevents the requested tolerance from being achieved. The error may be under-estimated.
–3	Extremely bad integrand behaviour occurs at some points of the integration interval.
–4	The algorithm does not converge. Roundoff error is detected in the extrapolation table. It is presumed that the requested tolerance cannot be achieved, and that the returned result is the best which can be obtained.
–5	The integral is probably divergent, or slowly convergent. It must be noted that divergence can occur with any other value of <code>status</code> .
–6	Invalid input (this error should have been trapped by the routine <code>msQuad</code> itself).

mfDblQuad

numerical evaluation of double integrals

*Interface:*

```
function mfDblQuad( fun, xa, xb, ya, yb, abs_tol, rel_tol ) result( out )

  interface
    real(kind=MF_DOUBLE) function fun( x, y )
      real(kind=MF_DOUBLE), intent(in) :: x, y
    end function
  end interface

  real(kind=MF_DOUBLE), intent(in)          :: xa, xb, ya, yb
  real(kind=MF_DOUBLE), intent(in), optional :: abs_tol, rel_tol
  type(mfArray) :: out
```

*Other calling syntaxes:*

```
out = mfDblQuad( fun, fun_xa, fun_xb, ya, yb, abs_tol, rel_tol )
```

or

```
out = mfDblQuad( fun, xa, xb, fun_ya, fun_yb, fun_y=.true., abs_tol, rel_tol )
```

where `fun_xa`, `fun_xb`, `fun_ya` and `fun_yb` are all double precision real function of one real argument. By using these latter syntaxes, the user is able to integrate over non rectangular domains. Note that in the second case, the additional argument `fun_y` is mandatory (no other way to disambiguate a unique interface for different routines).

*Description:*

Performs the numerical computation of the double integral of the function  $\text{fun}(x,y)$  over the interval  $[xa, xb] \times [ya, yb]$ .

The optional arguments `abs_tol` and `rel_tol` allows the user to give the absolute and/or the relative precision of the result. Default tolerance is  $1 \times 10^{-12}$ .

*Remarks:* `out` is set to `MF_NAN` if required precision cannot be achieved; an error is emitted by the library. Call the subroutine version if you don't want such a behavior.

*See also:* [mfQuad](#), [msQuad](#)

msDblQuad

numerical evaluation of double integrals

*Calling syntax:*

```
call msDblQuad( mfOut( q, abserr[, status, neval] ),           &
                fun, xa, xb, ya, yb [, abs_tol, rel_tol] )
```

*Description:*

The behavior of this routine is similar to those of `mfDblQuad` (including the fact to do integration on non rectangular domains).

The subroutine call allows to get more information returned by the integrator:

- `q` contains the numerical result
- `abserr` contains an estimation of the absolute error
- `status` (optional) contains the returned error code:
  - `status = 0`: normal and reliable termination of the routine. It is assumed that the requested accuracy has been achieved.
  - `status < 0`: abnormal termination of the routine. The estimates for `q` and `abserr` are less reliable. It is assumed that the requested accuracy has not been achieved. Only a warning is emitted by the library. (Exact meaning of the error can be found [below](#))
- `neval` (optional) contains the effective number of function evaluation

All these variable must be of `type(mfArray)`.

*Remark:* Adding the optional argument `status` allows the user to launch its program in a batch mode: indeed, errors in the current routine will not stop the program (It is the responsibility of the programmer to test the value of the `status` variable before using the result). On the contrary (*i. e.* when the `status` optional argument is not used), an error will stop the program and, in debug mode, a traceback of this error will be displayed.

See also: `mfDblQuad`, `mfOut`

<code>status</code>	<i>explanation</i>
–1	Maximum number of subdivisions allowed has been achieved.
–2	The occurrence of roundoff errors is detected, which prevents the requested tolerance from being achieved. The error may be under-estimated.
–3	Extremely bad integrand behaviour occurs at some points of the integration interval.
–4	The algorithm does not converge. Roundoff error is detected in the extrapolation table. It is presumed that the requested tolerance cannot be achieved, and that the returned result is the best which can be obtained.
–5	The integral is probably divergent, or slowly convergent. It must be noted that divergence can occur with any other value of <code>status</code> .
–6	Invalid input (this error should have been trapped by the routine <code>msDblQuad</code> itself).

## mfOdeSolve

## integrator of ODE (explicit) systems

Main interface:

```
function mfOdeSolve( deriv, t_span, y_0, options, jac, sparse ) result( y )

  interface
    subroutine deriv( t, y, yprime, flag )
      real(kind=MF_DOUBLE), intent(in)      :: t, y(*)
      real(kind=MF_DOUBLE), intent(out)     :: yprime(*)
      integer, intent(in out)              :: flag
    end subroutine
  end interface

  type(mfArray), intent(in)                :: t_span, y_0
  type(mf_DE_Options), intent(in), optional :: options
  external, optional                       :: jac
  logical, intent(in), optional            :: sparse

  type(mfArray) :: y
```

Description:

Performs the numerical integration of a system of (explicit<sup>1</sup>) ordinary differential equations (ODEs) of first order, which is written under the form:

$$y' = F(t, y)$$

described via the subroutine `deriv` (the variables `t`, `y` and `yprime` represent respectively  $t$ ,  $y$  and  $y'$ ). Usually, the integration is done between time  $t_0$  and  $t_{end}$  (extremal values of `t_span`, which is a column vector `mfArray` of at least two components) or, in the continuation mode<sup>2</sup>, up to the new values specified in `t_span` (in this case, `t_span` may contain only one value).

The output of `mfOdeSolve` is the row vector `y` which represents the solution  $y$  at time  $t_{end}$ . If the vector `t_span` contains more than two values (or more than one value in the continuation mode), the routine returns in `y` the intermediate values of  $y$ , as specified by all time values present in `t_span`; in this case, `y` is a rank-2 `mfArray` with as many rows as components in `t_span`.

The integration uses the prescribed initial condition stored in the row vector `y_0`. Note that this `mfArray` is not referenced in the continuation mode.

The last argument `flag` of `deriv` is always set to zero (internally by the solver) on input, and should be altered (inside the routine `deriv`) only in some special situations:

- set `flag` to `-1` for an *Illegal Condition*; the value of  $y'$  at this time may not be available. The routine will try to continue the integration (reducing the time step) as long as possible without getting the illegal condition. [You can put this assignment anywhere in the `deriv` routine.]
- set `flag` to `-2` for an *Emergency Exit*; the value of  $y'$  at this time may not be available. The routine will return control immediately to the calling program. [You can put this assignment anywhere in the `deriv` routine.]
- set `flag` to `3` for an *End Condition*; the value of  $y'$  at this time must be always available. The routine will adapt its time step to finish exactly at the current time given by the argument `t` of `deriv`. [WARNING: you **must put this assignment** at the end of the `deriv` routine, to insure that all the derivatives have been computed.]

⋯ / ⋯

<sup>1</sup>For implicit systems, the `mfDaeSolve` routine should be used instead.

<sup>2</sup>Currently, only the *BDF* integrator has this feature.

The previous three situations are called *stopping conditions*. Note that when a *stopping condition* is found in the user subroutine `resid`, then the vector `t_span` (which contains the value of  $t_{end}$ ) is modified. Note also that the three *stopping conditions* doesn't have the same numerical cost; their cost is mentioned in the following table:

Flag to used in resid	Stopping condition	Numerical cost
-1	<i>Illegal Condition</i>	expensive
-2	<i>Emergency Exit</i>	very cheap
3	<i>End Condition</i>	cheap

All following options are stored in the structure `options` (see `mf_DE.Options`).

The boolean `mfArray options%continuation` allows the user to continue the integration to a new value of  $t_{end}$ , without specify a new  $t_0$ . Thanks to specific calls to `mf/msOdeSolve`, the user is even able to save internal data of the integrator, to stop the program, and to launch again the integrator after the reload of saved data. See the next section *Other calling syntaxes*.

The `mfArray options%tol` allows the user to give the precision of the result, and must contain strictly positive values. Default values are  $10^{-3}$  for the relative tolerance and  $10^{-6}$  for the absolute tolerance; this `mfArray` may be of rank 0, 1 or 2:

- if it is a scalar, it specifies the relative tolerance for all the components of the solution; the absolute tolerance is fixed to  $10^{-6}$ .
- if it is a vector, it must have two elements which specifies the relative and the absolute tolerance, respectively.
- if it is a matrix, it must have two columns (corresponding to the relative and absolute tolerance) and a number of rows equal to the number of equations.

The `mfArray options%y_ind_out` allows the user to get only a subpart of the `mfArray y`; if present, it must contain integer indices of the wanted components of the `y` vector.

The string `options%method` specifies the method to be used. Possible choices are "RKF" (*Runge-Kutta Fehlberg*), "ABM" (*Adams-Bashforth-Moulton*), or "BDF" (*Backward Differentiation Formula*). By default, the *Runge-Kutta Fehlberg* method is selected.

When the "BDF" method is used, the user may provide the `jac` routine to compute the jacobian matrix (otherwise, it will be numerically evaluated by finite differences). Moreover, this jacobian matrix may be defined in dense, band or sparse format. For the first two formats, the interface of the `jac` routine is:

```

interface
    subroutine jac( t, y, jacobian, ldjac )
        real(kind=MF_DOUBLE), intent(in) :: t, y(*)
        real(kind=MF_DOUBLE), intent(out) :: jacobian(ldjac,*)
    end subroutine
end interface

```

The jacobian matrix is defined as  $J = \frac{\partial F}{\partial y}$ , therefore, the rank-2 array `jacobian` must be filled as follows:

$$\text{jacobian}(i,j) = J_{i,j} = \frac{\partial F_i}{\partial y_j}.$$

Please note that, for the dense format, only non-zero values need to be defined.

If the jacobian is symmetric and positive definite (abbreviated as SPD), you should set the `jac_symm_pos_def` option (see `mf_DE.Options`) in order to economize storage and obtain a better performance for its factorization; in such a case, you must give only the upper part of the jacobian.

⋯/⋯

Furthermore, when the jacobian  $J$  is banded, the `mfArray options%band` may be used to economize both memory and CPU time. It must be a vector of exactly two elements:  $ML$  and  $MU$  which are the widths of the lower and upper parts of the band, respectively, with the main diagonal being excluded (*e.g.* for a tridiagonal system, both elements are equal to 1).

In this case, routine `jac` must store the elements  $J_{i,j}$  in the matrix `jacobian` as follows:

```
irow = i - j + ML + MU + 1 jacobian(irow,
```

Actually, `ldjac` is equal to  $2*ML+MU+1$ : indeed, an extra storage is needed for the matrix factorisation. For an SPD matrix, simply take  $ML$  equal to zero in the previous formulae.

For the sparse case, the optional argument `sparse` must be set to `.true.` and the `jac` routine must be defined as:

```
interface
  subroutine jac( t, y, nrow, job, pd, ipd, jpd, nnz )
    real(kind=MF_DOUBLE), intent(in)    :: t, y(*)
    integer,                intent(in)    :: nrow, job
    real(kind=MF_DOUBLE), intent(out)    :: pd(*)
    integer,                intent(out)   :: ipd(*), jpd(*)
    integer,                intent(in out) :: nnz
  end subroutine
end interface
```

The `pd,ipd,jpd` f90 arrays describe the CSC (Compact Sparse Column) representation of the sparse jacobian matrix, as follows:

- `pd(1:nnz)` contains the non-zero matrix entries;
- `ipd(1:nnz)` contains the row indices;
- `jpd(1:ncol+1)` is the pointer to the beginning of the columns, in arrays `(pd,ipd)`.

`pd,ipd` must contain all diagonal terms, even if they are null. Moreover, row indices must be sorted in ascending order. Lastly, this routine must include a mechanism such that only the value of `nnz` is computed when `job=0`. You must also use the convention: `jpd(ncol+1)=nnz+1`.

Be aware that the sparse structure (that is to say, the indices' vectors `ipd` and `jpd`) must remain the same during all the integration process. On the contrary, use the option `spjac_const_struct` of the `mf_DE_Options` derived type. Moreover, you can even force to reuse the same sparse structure if you make many calls to `mf/msOdeSolve` during, *e.g.*, an iterative procedure: see the option `reuse_spjac_struct` of the `mf_DE_Options` derived type.

*Remarks:*

- on output, `y` may contain *NaN* values for some reasons. In such a case, use the `msOdeSolve` routine to further investigate the problem.
- `deriv` and `jac` have imposed lists of arguments; the user may use module's data in order to exchange other information between his program and these routines (especially for checking the number of equations). Therefore, except for very simple cases, these two user's routines must be located inside a module, `USED` also by the user's program.
- for debugging purposes, the user may inspect the values of  $y$  and  $y'$  during the integration process. See explanations about the fields `monitor_y_ind`, `monitor_yp_ind` and `monitor_pause` of the `mf_DE_Options` derived type.
- the *stopping conditions* are not (yet) available for the "ABM" method.

.../...

*Other calling syntaxes*

```
call msOdeSolve( A, "save" [, jac_sparse] )
```

By using this call, the user is able to save all internal data of the integrator in the `mfArray` `A`, and then continue the integration later on. The optional argument `jac_sparse`, which is the name of the routine computing the sparse Jacobian matrix, is required when the Jacobian has a sparse structure.

```
call msOdeSolve( A, "restore" [, jac_sparse] )
```

This call is required to restore all internal data of the integrator, before a new integration sequence. The optional argument `jac_sparse`, which is the name of the routine computing the sparse Jacobian matrix, is required when the Jacobian has a sparse structure.

```
call msOdeSolve( "finalize" )
```

This call is useful to avoid memory leaks at the end of the integration process.

*See also:* [mfDaeSolve](#)

msOdeSolve

integrator of ODE (explicit) systems

*Calling syntax:*

```
call msOdeSolve( mfOut( y, status[, tolout, yp, solve_log, t_log, order_log] ), &
                deriv, t_span, y_0[, options, jac, sparse] )
```

*Description:*

The behavior of this routine is similar to those of `mfOdeSolve`, but it allows to get more information returned by the integrator (via `mfArrays` which must be enclosed to the `mfOut` function):

- `y` contains the numerical result.
- `status` contains a returned error code:
  - `status > 0`: normal and reliable termination of the routine. It is assumed that the requested accuracy has been achieved. (Exact meaning of the status can be found [below](#))
  - `status < 0`: abnormal termination of the routine. The estimates for `y` is less reliable. It is assumed that the requested accuracy has not been achieved. Moreover, in some circumstances, a message is printed; in such cases, the user cannot use numerical values in `y` and `yp` and therefore an appropriate decision must be taken. (Exact meaning of the error can be found [below](#))
- `tolout` is different from `tol` only if `status = -2`: in such a case, it contains an appropriate value for continuing the integration.
- `yp` contains an estimation of the derivative at time  $t_{end}$  (or at all intermediate values defined in `t_span`); moreover, the role of the option `options%y_ind_out` applies also to `yp`.
- `solve_log` contains additional information about the integration process. It is a vector of 4 or 6 elements, according to the method used. These elements are:
  - `nb_step` is the total number of steps used
  - `dt_min` the smallest step used
  - `dt_max` the largest step used
  - `nb_deriv` is the number of calls of the `deriv` routine
  - `nb_jac` is the number of evaluation of the jacobian matrix (only for the "BDF" method)
  - `nb_solve` is the number of times the linear system is solved using the jacobian matrix (only for the "BDF" method)
- `t_log` contains the whole history of the times used during the integration. This can be useful to detect where a critical behavior is located.
- `order_log` contains the whole history of the order used during the integration. The first value, not defined, is set to NaN (Not-a-Number special IEEE floating-point value); as a consequence, this `mfArray` has the same size as `t_log`.

Among these returned variables, only the first two are required, while the others are optional. Moreover, it is forbidden to use the same `mfArray` in place of two or more actual arguments, even empty.

*Remarks:*

- The presence of the argument `status` allows the user to launch its program in a batch mode: indeed, errors in the current routine will not stop the program (it is the responsibility of the programmer to test the value of the `status` variable before using the result). If the `mfOdeSolve` routine was used instead, an error would stop the program and, in debug mode, a traceback of this error would be displayed.

⋯/⋯



- The special calling syntaxes used to save/restore the internal data (in case of continuation in overlay situations), or to finalize the integrator, have been presented at the end of the previous entry.

status	explanation
0	Normal termination of the solver.
4	Normal termination of the solver, but a large amount of work has been expended.
5	Normal termination of the solver, but the <i>RKF</i> integrator has been used very inefficiently because the natural step size has been restricted by too frequent output.
12	Normal termination of the solver, but an <i>End Condition</i> was found ( <code>flag</code> , last argument in <code>deriv</code> , was equal to 3 and the solver has been called to finish at the new current point).
–2	The error tolerances are too stringent.
–3	The local error test cannot be satisfied because you specified a zero value for the absolute error in <code>tol</code> and the corresponding computed solution component is zero. Thus, a pure relative error test is impossible for this component.
–4	The problem appears to be stiff ( <i>RKF</i> and <i>ABM</i> integrators only).
–6	The <i>BDF</i> integrator had repeated convergence test failures on the last attempted step.
–7	The <i>BDF</i> integrator had repeated error test failures on the last attempted step.
–10	Abnormal termination of the solver, due to an <i>Illegal Condition</i> ( <code>flag</code> , last argument in <code>deriv</code> , was equal to –1 and the solver did its best to not obtain –1).
–11	Abnormal termination of the solver, due to an <i>Emergency exit</i> ( <code>flag</code> , last argument in <code>deriv</code> , was equal to –2 and control has been returned to the calling program).
–14	The user-supplied <code>deriv</code> routine returned invalid entries ( <i>NaN</i> value).
–20	Allocation error because the maximum of available memory has been reached. An explanation is printed.
–33	Invalid argument.
–34	Invalid implementation of the user-defined sparse jacobian.
–40	On calling, the number of output argument(s) is incorrect.
–100	The routine wasn't able to start, nor choose an initial timestep ( <code>flag</code> , last argument in <code>deriv</code> , was different from 0).

See also: [mf0deSolve](#), [msDaeSolve](#), [mf0Out](#), [mf\\_DE\\_Options](#)

mfDaeSolve

integrator of DAE (implicit) systems

*Interface:*

```

function mfDaeSolve( resid, t_span, y_0, yp_0, options, jac, sparse ) result( y )

  interface
    subroutine resid( t, y, yprime, delta, flag )
      real(kind=MF_DOUBLE), intent(in)      :: t, y(*), yprime(*)
      real(kind=MF_DOUBLE), intent(out)     :: delta(*)
      integer, intent(in out)              :: flag
    end subroutine
  end interface

  type(mfArray), intent(in out)            :: t_span
  type(mfArray), intent(in)                :: y_0, yp_0
  type(mf_DE_options), intent(in), optional :: options
  external, optional                       :: jac
  logical, intent(in), optional            :: sparse

  type(mfArray) :: y

```

*Description:*

Performs the numerical integration of a system of (fully implicit<sup>3</sup>) differential algebraic equations (DAEs) of first order (and differential index 1 only<sup>4</sup>), which can be written in the general form:

$$R(t, y, y') = 0$$

described via the user subroutine `resid`, which must define the components  $R_i(t, y, y')$  and store the values in the `delta` array (the variables `t`, `y` and `yprime` represent respectively  $t$ ,  $y$  and  $y'$ ). Usually, the integration is done between time  $t_0$  and  $t_{end}$  (extremal values of `t_span`, which is a column vector `mfArray` of at least two components) or, in the continuation mode, up to the new values specified in `t_span` (in this case, `t_span` may contain only one value).

The output of `mfDaeSolve` is the row vector `y` which represents the solution  $y$  at time  $t_{end}$ . If the vector `t_span` contains more than two values, the routine returns in `y` the intermediate values of  $y$ , as specified by all time values present in `t_span`; in this case, `y` is a rank-2 `mfArray` with as many rows as components in `t_span`.

The integration uses the prescribed initial conditions stored in the row vectors `y_0` and `yp_0`. By default, it is assumed that the data `y_0` and `yp_0` are consistent (note that a consistency test is performed; if it fails, an error is returned), *i. e.* verify the equation

$$R(t_0, y_0, y'_0) = 0;$$

otherwise, the user must set the `options%IC_known` argument to `.false.`, so that the initial conditions will be computed by the solver, taking `y_0` and `yp_0` as initial guesses; `yp_0` may be empty but `y_0` must always be allocated and must have its size equal to the number of equations (see `mf_DE_Options` for more details; in particular, the user must indicate which components of these two vectors should be held fixed).

⋯ / ⋯

<sup>3</sup>Not just linearly implicit, which would have a mass matrix. For explicit systems, the `mfOdeSolve` routine should be used instead.

<sup>4</sup>For higher-index problems, the current algorithm may or may not work!

The last argument `flag` of `resid` is always set to zero (internally by the solver) on input, and should be altered (inside the routine `resid`) only in some special situations:

- set `flag` to `-1` for an *Illegal Condition*; the value of  $y'$  at this time may not be available. The routine will try to continue the integration (reducing the time step) as long as possible without getting the illegal condition. [You can put this assignment anywhere in the `resid` routine.]
- set `flag` to `-2` for an *Emergency Exit*; the value of  $y'$  at this time may not be available. The routine will return control immediately to the calling program. [You can put this assignment anywhere in the `resid` routine.]
- set `flag` to `3` for an *End Condition*; the value of  $y'$  at this time must be always available. The routine will adapt its time step to finish exactly at the current time given by the argument `t` of `resid`. [WARNING: you **must put this assignment** at the end of the `resid` routine, to insure that all the residues `delta` have been computed.]

The previous three situations are called *stopping conditions*. Note that when a *stopping condition* is found in the user subroutine `resid`, then the vector `t_span` (which contains the value of  $t_{end}$ ) is modified. Note also that the three *stopping conditions* doesn't have the same numerical cost; their cost is mentioned in the following table:

Flag to used in resid	Stopping condition	Numerical cost
-1	<i>Illegal Condition</i>	expensive
-2	<i>Emergency Exit</i>	very cheap
3	<i>End Condition</i>	cheap

All following options are stored in the structure `options` (see `mf_DE.Options`).

The boolean `mfArray options%continuation` allows the user to continue the integration to a new value of  $t_{end}$ , without specify a new  $t_0$ . Thanks to specific calls to `mf/msDaeSolve`, the user is even able to save internal data of the integrator, to stop the program, and to launch again the integrator after the reload of saved data. See the next section *Other calling syntaxes*.

The `mfArray options%tol` allows the user to give the precision of the result, and must contain non negative values. Default values are  $10^{-3}$  for the relative tolerance and  $10^{-6}$  for the absolute tolerance; this `mfArray` may be of rank 0, 1 or 2:

- if it is a scalar, it specifies the relative tolerance for all the component of the solution; the absolute tolerance is fixed to  $10^{-6}$ .
- if it is a vector, it must have two elements which specifies the relative and the absolute tolerance, respectively.
- if it is a matrix, it must have two columns (corresponding to the relative and absolute tolerance) and a number of rows equal to the number of equations.

The `mfArray options%non_neg` allows the user to apply non-negativity constraints to a subset (or all the set) of the components of the solution  $y$ . It must be a vector describing the indices of such constraints.

The `mfArray options%y_ind_out` allows the user to get only a subpart of the `mfArray`  $y$ ; if present, it must contain integer indices of the wanted components of the  $y$  vector.

The user may provide the `jac` routine to compute the jacobian matrix (otherwise, it will be numerically evaluated by finite differences). This matrix may be defined in dense, band or sparse format. For the first two formats, the interface of the `jac` routine is:

⋯/⋯

```

interface                               subroutine jac( t, y, yprime, jacobian, cj, ldjac )
  real(kind=MF_DOUBLE), intent(in)      :: t, y(*), yprime(*), cj
  integer,                               intent(in)      :: ldjac                real(kind=MF_DOUBLE), intent(out)
end subroutine                             end interface

```

The generalized jacobian<sup>5</sup>  $\tilde{J}$  must be defined as:

$$\tilde{J} = \frac{\partial R}{\partial y} + c_J \frac{\partial R}{\partial y'}$$

where  $c_J$  is a scalar computed by the solver; therefore the numerical values of  $\tilde{J}$  must be stored in the jacobian rank-2 array as follows:  $\text{jacobian}(i,j) = \tilde{J}_{i,j} = \frac{\partial R_i}{\partial y_j} + c_J \frac{\partial R_i}{\partial y'_j}$ .

Please note that, for the dense format, only non-zero values of  $\tilde{J}$  need to be defined.

If the jacobian is symmetric and positive definite (abbreviated as SPD), you should set the `jac_symm_pos_def` option (see [mf\\_DE.Options](#)) in order to economize storage and obtain a better performance for its factorization; in such a case, you must give only the upper part of the jacobian.

Furthermore, the jacobian  $\tilde{J}$  may be banded, in order to economize both memory and CPU time. In such a case, the `mfArray options%band` must be set; it must contain a vector of exactly two elements: *ML* and *MU* which are the widths of the lower and upper parts of the band, respectively, with the main diagonal being excluded (*e.g.* for a tridiagonal system, both elements are equal to 1). In this case, routine `jac` must store the elements  $\tilde{J}_{i,j}$  in the matrix `jacobian` as follows:

```

irow = i - j + ML + MU + 1                jacobian(irow,

```

Actually, `ldjac` is equal to  $2*ML+MU+1$ : indeed, an extra storage is needed for the matrix factorisation. For an SPD matrix, simply take *ML* equal to zero in the previous formulae.

For the sparse case, the optional argument `sparse` must be set to `.true.` and the `jac` routine must be defined as:

```

interface
  subroutine jac( t, y, yprime, cj, nrow, job, pd, ipd, jpd, nnz )
    real(kind=MF_DOUBLE), intent(in)      :: t, y(*), yprime(*), cj
    integer,                               intent(in)      :: nrow, job
    real(kind=MF_DOUBLE), intent(out)     :: pd(*)
    integer,                               intent(out)     :: ipd(*), jpd(*)
    integer,                               intent(in out)  :: nnz
  end subroutine
end interface

```

$c_J$  having the same meaning as before.

⋯/⋯

---

<sup>5</sup>It is so called because it is the linear combination of two jacobian. Actually, it is close to the iteration matrix of the non-linear solver. See also this [remark](#).

The `pd`, `ipd`, `jpd` f90 arrays describe the CSC (Compact Sparse Column) representation of the sparse jacobian matrix, as follows:

- `pd(1:nnz)` contains the non-zero matrix entries;
- `ipd(1:nnz)` contains the row indices;
- `jpd(1:ncol+1)` is the pointer to the beginning of the columns, in arrays `(pd,ipd)` (actually, a jacobian matrix is always square, hence `ncol=nrow`).

Row indices must be sorted in ascending order. Moreover, this routine must include a mechanism such that only the value of `nnz` is computed when `job=0`; therefore the argument `nnz` has generally an `intent(y)` for the first call and an `intent(in)` for subsequent calls.

Be aware that the sparse structure (that is to say, the indices' vectors `ipd` and `jpd`) must remain the same during all the integration process. On the contrary, use the option `spjac_const_struct` of the `mf_DE_Options` derived type. Moreover, you can even force to reuse the same sparse structure if you make many calls to `mf/msOdeSolve` during, *e. g.*, an iterative procedure: see the option `reuse_spjac_struct` of the `mf_DE_Options` derived type.

*Remarks:*

- on output, `y` may contain *NaN* values for some reasons. In such a case, use the `msDaeSolve` routine to further investigate the problem;
- `resid` and `jac` have imposed lists of arguments; the user may use module's data in order to exchange other information between his program and these routines (especially for checking the number of equations). Therefore, except for very simple cases, these two user's routines must be located inside a module, USED also by the user's program.
- for debugging purposes, the user may inspect the values of `y` and `y'` during the integration process. See explanations about the fields `monitor_y_ind`, `monitor_yp_ind` and `monitor_pause` of the `mf_DE_Options` derived type.

*Other calling syntaxes*

```
call msDaeSolve( A, "save" [, jac_sparse] )
```

By using this call, the user is able to save all internal data of the integrator in the `mfArray` `A`, and then continue the integration later on. The optional argument `jac_sparse`, which is the name of the routine computing the sparse Jacobian matrix, is required when the Jacobian has a sparse structure.

```
call msDaeSolve( A, "restore" [, jac_sparse] )
```

This call is required to restore all internal data of the integrator, before a new integration sequence. The optional argument `jac_sparse`, which is the name of the routine computing the sparse Jacobian matrix, is required when the Jacobian has a sparse structure.

```
call msDaeSolve( "finalize" )
```

This call is useful to avoid memory leaks at the end of the integration process.

*See also:* `mfOdeSolve`

msDaeSolve

integrator of DAE (implicit) systems

*Calling syntax:*

```
call msDaeSolve( mfOut( y, status                                &
                   [, tolout, yp, solve_log, init_log, t_log, order_log] ), &
                 resid, t_span, y_0, yp_0[, options, jac, sparse] )
```

*Description:*

The behavior of this routine is similar to those of `mfDaeSolve`, but it allows to get more information returned by the integrator (via `mfArrays` which must be enclosed by the `mfOut` function):

- `y` contains the numerical result
- `status` contains a returned error code:
  - `status > 0`: normal and reliable termination of the routine. It is assumed that the requested accuracy has been achieved. (Exact meaning of the status can be found [below](#))
  - `status < 0`: abnormal termination of the routine. The estimates for `y` is less reliable. It is assumed that the requested accuracy has not been achieved. Moreover, in some circumstances, a message is printed; in such cases, the user cannot use numerical values in `y` and `yp` and therefore an appropriate decision must be taken. (Exact meaning of the error can be found [below](#))
- `tolout` is different from `tol` in some few cases. First, if `status = -2`, it contains an appropriate value for continuing the integration. Second, if `status = -101`, it contains the absolute value of the residual vector  $R(t_0, y_0, y'_0)$  (initial data consistency).
- `yp` contains an estimation of the derivative at time  $t_{end}$  (or at all intermediate values defined in `t_span`); moreover, the role of the optional argument `y_ind_out` applies to `yp`.
- `solve_log` contains additional information about the integration process. It is a vector of 6 elements, which are:
  - `nb_step` is the total number of steps used;
  - `dt_min` the smallest step used;
  - `dt_max` the largest step used;
  - `nb_resid` is the number of calls of the `resid` routine;
  - `nb_jac` is the number of evaluation of the jacobian matrix;
  - `nb_solve` is the number of solving the linear system using the jacobian matrix.
- `init_log` contains specific information about the computation of consistent initial conditions (when this has been required). It is a vector of 4 elements, which are:
  - `nb_resid_0` is the number of calls of the `resid` routine;
  - `nb_jac_0` is the number of evaluation of the jacobian matrix;
  - `nb_solve_0` is the number of solving the linear system using the jacobian matrix;
  - `cpu_time_0` is the CPU time spent in this initialization part.
- `t_log` contains the whole history of the times used during the integration. This can be useful to detect where a critical behavior is located.
- `order_log` contains the whole history of the order used during the integration. The first value, not defined, is set to NaN (Not-a-Number special IEEE floating-point value); as a consequence, this `mfArray` has the same size as `t_log`.

⋯/⋯

Among these returned variables, only the first two are required, while the others are optional. Moreover, it is forbidden to use the same `mfArray` in place of two or more actual arguments, even empty.

*Remark:* The presence of the argument `status` allows the user to launch its program in a batch mode: indeed, errors in the current routine will not stop the program (it is the responsibility of the programmer to test the value of the `status` variable before using the result). If the `mfDaeSolve` routine was used instead, an error would stop the program and, in debug mode, a traceback of this error would be displayed.

<code>status</code>	<i>explanation</i>
0	Normal termination of the solver.
4	Normal termination of the solver, but a large amount of work has been expended.
12	Normal termination of the solver, but an <i>End Condition</i> was found ( <code>flag</code> , last argument in <code>resid</code> , was equal to 3 and the solver has been called to finish at the new current point).
-2	The error tolerances are too stringent.
-3	The local error test cannot be satisfied because you specified a zero value for the absolute error in <code>tol</code> and the corresponding computed solution component is zero. Thus, a pure relative error test is impossible for this component.
-6	The method used had repeated error test failures on the last attempted step.
-7	The corrector could not converge.
-8	The matrix of partial derivatives is singular.
-9	The corrector could not converge: there were repeated error test failures in this step.
-10	Abnormal termination of the solver, due to an <i>Illegal Condition</i> ( <code>flag</code> , last argument in <code>resid</code> , was equal to -1 and the solver did its best to not obtain -1).
-11	Abnormal termination of the solver, due to an <i>Emergency Exit</i> ( <code>flag</code> , last argument in <code>resid</code> , was equal to -2 and control has been returned to the calling program).
-13	Some indices for the non-negativity constraints stored in the <code>non_neg</code> array of the <code>mf_DE_Options</code> are not in the range <code>[1,Neq]</code> (where <code>Neq</code> is the number of equations).
-14	The user-supplied <code>resid</code> routine returned invalid entries ( <i>NaN</i> value).
-15	The user-supplied <code>jac</code> routine (either dense or sparse) returned invalid entries ( <i>NaN</i> value).
-20	Allocation error because the maximum of available memory has been reached. An explanation is printed.
-33	Invalid argument.
-34	Invalid implementation of the user-defined sparse jacobian.
-40	On calling, the number of output argument(s) is incorrect.
-100	The routine wasn't able to start, neither choose an initial timestep, nor check initial conditions for consistency ( <code>flag</code> , last argument in <code>resid</code> , was different from 0).
-101	Initial conditions <code>y_0</code> and <code>yp_0</code> are not consistent.
-102	<code>msDaeSolve</code> failed to compute the initial vector <code>yp_0</code> .

See also: `msOdeSolve`, `mf_DE_Options`

**mf\_NL\_Options** options for non-linear solvers (*derived type*)*Description:*

This derived type gathers options used by the two routines `mfFSolve` and `mfLsqNonLin`, and is defined as follows:

```

type, public :: mf_NL_Options

    type(mfArray)      :: tol
    integer            :: max_iter          = 50
    type(mfArray)      :: epsfcn
    real(kind=MF_DOUBLE) :: init_step_bound_factor = 1.0d2
    logical            :: print              = .false., &
                        print_using_transf   = .false., &
                        reuse_spjac_struct   = .false.
    type(func_ptr), allocatable :: f_inv_transf(:)
    integer            :: check_jac         = 0, &
                        print_check_jac     = 0
    logical            :: box_constrained   = .false.
    type(mfArray)      :: lower_bounds,    &
                        upper_bounds
    real(kind=MF_DOUBLE) :: sing_jac_tol    = epsilon(1.0d0)
    logical            :: print_sing_val    = .false.

end type mf_NL_Options

```

The following fields may be used in both two routines:

- `tol` specifies the tolerance to be used. See the appropriate routine to know the usage of this option.
- `max_iter` specifies the approximated maximum number of iterations.
- `epsfcn` specifies the optimum small increment (in a relative sense) used for computing the derivatives (the elements of the jacobian matrix) by finite differences. Therefore, its value is not used when the jacobian matrix is provided by the user. It may be a scalar or a vector; in the latter case (but only for `LsqNonLin`), each components of `epsfcn` corresponds to an unknown. The value(s) of `epsfcn` must be carefully chosen; there doesn't exist a universal constant because the optimum value depends on the algorithm in the user-supplied `fcn` routine. Its role is basically to equalize the numerical error which comes from the scheme and the roundoff error inherent to the floating-point model. If `fcn` is coded as a mathematical function, it can be set to zero (because internally, the finite-difference routine will choose  $\sqrt{\epsilon}$ , where  $\epsilon$  is the machine precision; this is the default). If `fcn` uses an interpolation over a given interval  $\Delta x$  (*e.g.* from a table lookup) then the `epsfcn` should be related to some power of this  $\Delta x$  value, according the accuracy of the interpolation scheme.
- `init_step_bound_factor` specifies the initial step bound factor. The default value of 100 is recommended in most cases. However it can be changed for another value as low as 0.1. For example, if you use the `log()` function to ensure the positiveness of your unknowns, you should choose `log(100)` instead.
- `print` is used to print on screen the following information during the iterative process: the iteration number, the value of each unknown parameter and the norm of the residue. If some transformation is used between the physical value of the parameters and the actual value in the algorithm, it may be convenient to print the physical value of each parameter; to do that, the user must set the `print_using_transf` field to `.true.` and associate the function pointers stored in the field `f_inv_transf` to appropriate user-defined inverse functions. The last pointer array must be allocated by the user. See the *Muesli User's Guide* for more details.

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- `reuse_spjac_struct` must be set to `.true.` only when you are sure that the sparse structure of the jacobian is not modified during many different calls of the FSolve solver: this can occur inside a loop when using the same set of equations. Be aware that this option can only set to `.true.` after the first call of the solver; on the contrary, an error will arise. Note that this option is used only for the sparse case.
- for debugging purposes (but only when `MF_NUMERICAL_CHECK` is `TRUE`), `check_jac` can be used to make a check of the user jacobian (dense only):
  1. when `check_jac` is set to 1, a global and quick check is done;
  2. when `check_jac` is set to 2, a complete (but more expensive) check is done.

In both cases, a message is displayed according to the errors obtained concerning the accuracy of the jacobian. *Note that this is an estimation because (i) discrepancies found may be strongly affected by both floating-point roundoff errors and badly scaled variables or equations, and (ii) relative errors are based on a sort of norm of the jacobian; when this latter is large, some terms in the error matrix may remain small.*

`print_check_jac` can be used to print the results of the jacobian check:

1. when `print_check_jac` is set to 1, information is displayed on the screen;
2. when `print_check_jac` is set to 2, information is stored in files (one different file for each jacobian call).

In both cases, (i) the given information depends on the level of the check and (ii) the output is done at each call of the `jac` routine, regardless of the severity of the discrepancies. See the *Muesli User's Guide* where a detailed example of use can be found.

- (for `LsqNonLin` only) `box_constrained` can be used to constrain the parameters to be inside a box. Set it to `.true.` and specify the box bounds as follows:
  1. `lower_bounds` is a vector containing the lower bound for each parameter. The length of this `mfArray` vector must be equal to the number of unknown parameters; use `-MF_INF` to release the constraint.
  2. `upper_bounds` is a vector containing the upper bound for each parameter. The length of this `mfArray` vector must be equal to the number of unknown parameters; use `+MF_INF` to release the constraint.

These constraints of type `box` are dynamic, which means that during the iterations, the user can change the value of the bounds (*e.g.* in the `fcn` routine).

- Only when `MF_NUMERICAL_CHECK` is `TRUE`, `sing_jac_tol` allows the user to know whether his system of equations is singular or not. It concerns only the `LsqNonLin` routine. Normally the jacobian is not singular, which means that all the parameters are independant; on the contrary, the routine displays the linear relation between the parameters, by showing the vector of the basis of the nullspace. Note that the nullspace basis is always computed from a local point-of-view (linearized equations); if this basis changes along the iteration, this means that the relationship between the parameters is nonlinear. The default value of this tolerance is the machine  $\epsilon$ . Set `sing_jac_tol` to zero to avoid the computation of the nullspace.
- Only when `MF_NUMERICAL_CHECK` is `TRUE`, `print_sing_val` allows the user to print the singular values of the jacobian matrix. Default is `FALSE`.

All fields of this derived type are `public`, so the user can access each component via the `'%'` Fortran 90 selector.

Lastly, the user can use the `msRelease` routine to free all fields of this structure (and to re-initialize the components between two different calls to any of these integrators).

See also: [mf\\_DE\\_Options](#)

**mf\_DE\_Options** options for differential solvers (*derived type*)*Description:*

This derived type gathers options used by the two integrators `mfOdeSolve` and `mfDaeSolve`, and is defined as follows:

```

type, public :: mf_DE_Options

  logical          :: continuation = .false.
  character(len=3) :: method = ""
  type(mfArray)    :: tol, y_ind_out, band
  type(mfArray)    :: non_neg, y0_ind, yp0_ind
  logical          :: IC_known      = .true.,      &
                    print_progress = .false.,     &
                    disp_times     = .false.,     &
                    jac_symm_pos_def = .false.,   &
                    spjac_const_struct = .true.,   &
                    reuse_spjac_struct = .false.,  &
                    jac_investig     = .false.,   &
                    rational_null_basis = .false., &
                    pseudo_inverse   = .false.
  real(kind=MF_DOUBLE) :: jac_rcond_min = MF_EPS

  logical          :: save_sing_jac      = .false.
  type(mfArray)    :: monitor_y_ind,    &
                    monitor_yp_ind
  logical          :: monitor_pause     = .false.
  integer          :: check_jac         = 0,    &
                    print_check_jac    = 0

  type(mf_DE_Named_Group), allocatable :: named_eqn(:),    &
                                         named_var(:)

end type

```

The following fields may be used in both integrators:

- `continuation` specifies that the integrator is not restarted. Using such a feature to continue the integration leads to much better performance than restarting the integrator.
- `tol` specifies the tolerance in many ways (relative or absolute, as a whole or by component).
- `y_ind_out` allows the user to get only a subpart of the result.
- `band` specifies that the jacobian is stored in a band format.
- `print_progress` specifies that the percentage of work already done is printed in the terminal. This options should not be used when using the main program in a batch mode, redirecting output in a file.
- `disp_times` specifies that time values will also be displayed – wall clock time is used, not CPU time.

(See `msPrepProgress` and `msPrintProgress` for other information concerning the last two options.)

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- `jac_symm_pos_def` must be set to `.true.` only when you are sure that the jacobian is symmetric and positive definite; in such a case, you must only provide the upper part of the jacobian: this will economize some storage. A Cholesky factorization will be used (instead of a general LU one) and, especially for sparse, large matrices, this will be more efficient.
- `spjac_const_struct` must be set to `.false.` only when you are sure that the sparse structure of the jacobian is modified along all the time integration (this is not common!); note that this option is used only for the sparse case.
- `reuse_spjac_struct` must be set to `.true.` only when you are sure that the sparse structure of the jacobian is not modified during many different calls of the DAE or ODE solvers: this can occur during an iterative procedure using the same mesh. Be aware that this option can only set to `.true.` after the first call of the solver; on the contrary, an error will arise. Note that this option is used only for the sparse case.
- for debugging the DAE integration (but only if `jac_investig` is `TRUE`), the user may set a threshold value (not greater than unity) in `jac_rcond_min` in order to detect whether the jacobian is singular or not<sup>6</sup>. When (an estimation of) the reciprocal of condition number is less than or equal to the value of `jac_rcond_min`, then the jacobian is considered as singular: a warning message is then emitted. Moreover, for the dense case only:
  1. additional information is provided to the user, about the null space of the transpose of the jacobian matrix: this may help the user in understanding why the jacobian is singular.
  2. the jacobian and the nullspace of its transpose can be saved on disk according to the value of the boolean `save_sing_jac` (the filenames are respectively `'jacobian.dat'` and `'nullspace.dat'`).

The default value of `jac_rcond_min` is the machine epsilon and, if set by the user, it cannot be smaller than this default value. The nullspace basis may be returned in the form of a rational basis (set `rational_null_basis` to `.true.`) but this should be useful for small problem only (few number of equations) or for pedagogical reasons. The `pseudo_inverse` component is reserved for a future usage.
- for debugging purposes again, the user can tell the appropriate integrator to store all intermediate values (*note*: at the internal time steps!), by specifying a number of indices in `monitor_y_ind`, and/or indices in `monitor_yp_ind`. In such a case, the selected values of the vector  $y$  (resp.  $y'$ ) are copied in the file `'odesolve_y.out'` or `'daesolve_y.out'` (resp. `'odesolve_yp.out'` or `'daesolve_yp.out'`); each line contains the current time (independent variable) in the first column, then the selected values of the dependent variables. The boolean `monitor_pause` allows the user to pause after each successful internal step of the ODE/DAE solver (the default behavior is not to make such an interruption). Moreover, the data files are flushed continuously, so you can use an external graphic tool to plot the data which are monitored.
- recall that the use of `MF_NUMERICAL_CHECK` is recommended, because it allows internal routines to check the validity of the equations or of the jacobian elements, especially non finite values (Infinities, NaNs).

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<sup>6</sup>For the ODE solver, the jacobian provided by the user may be singular, it doesn't matter for the integration process. See the [remark](#) at the end of this entry.

- for debugging purposes (but only when `MF_NUMERICAL_CHECK` is `TRUE`), `check_jac` can be used to make a check of the user jacobian (dense only):
  1. when `check_jac` is set to 1, a global and quick check is done;
  2. when `check_jac` is set to 2, a complete (but more expensive) check is done.

In both cases, a message is displayed according to the errors obtained concerning the accuracy of the jacobian. *Note that this is an estimation because (i) discrepancies found may be strongly affected by both floating-point roundoff errors and badly scaled variables or equations, and (ii) relative errors are based on a sort of norm of the jacobian; when this latter is large, some terms in the error matrix may remain small.*

`print_check_jac` can be used to print the results of the jacobian check:

1. when `print_check_jac` is set to 1, information is displayed on the screen;
2. when `print_check_jac` is set to 2, information is stored in an overwritten file (a unique file along all the integration process). The library makes as many pauses as needed to let the user to inspect this file.

In both cases, (i) the given information depends on the level of the check and (ii) the output is displayed at each call of the `jac` routine, regardless of the severity of the discrepancies. See the *Muesli User's Guide* where a detailed example of use can be found.

- the `named_eqn` and `named_var` fields allow the user to name his equations and variables by grouping them under useful, physical names. The derived type `mf_DE_named_group` is defined as follows:

```
type, public :: mf_DE_Named_Group
  character(len=132) :: name
  integer           :: begin, last
end type
```

The user must allocate himself the arrays `named_eqn(:)` and `named_var(:)`, then correctly initializes the three internal fields: `name` (the name of the group), `begin` and `last` (the indices of equation in `deriv` or `resid` which define the beginning and the end of the each named group). See the *Muesli User's Guide* where an example of use can be found.

The field `method` is specific to the `mfOdeSolve` integrator. It may contains "RKF" (*Runge-Kutta Fehlberg*, which is the default method), "ABM" (*Adams-Bashforth-Moulton*), or "BDF" (*Backward Differentiation Formula*).

The remaining are specific to the `mfDaeSolve` integrator:

- `non_neg` allows the user to constrain some components of the solution to remain non negative.
- `IC_known` indicates whether initial conditions are known (and then supposed to be consistent) or not (see also just below).
- in the case where initial conditions have to be computed (*i. e.* when `IC_known` is equal to `.false.`) and only when the jacobian matrix is provided, the user may indicate which components of the vectors `y_0` and `yp_0` are prescribed in, respectively, `y0_ind` and `yp0_ind` (at most  $N$  components may be prescribed, where  $N$  is the number of the system's equations). If used, these two vectors must have a length equal to  $N$ ; free components are selected by putting a zero at appropriate locations, whereas prescribed components may be selected by putting any non-zero value. The user may also leave the fields empty, which is equivalent to specify that no component at all are prescribed. Values present in the two `mfArrays` `y_0` and `yp_0` are then considered as initial guesses. It is worth mention that initialization may fail in the case where the user prescribed too many components. A very common error is to prescribed the  $N$  components of `y_0` by setting all components of `y0_ind` to one, for a DAE systems which have  $N_a$  algebraic equations; in such a case, all components referencing to the algebraic equations should be left free, and the user can only prescribed the  $N - N_a$  components of `y_0` corresponding to the differential equations.

All fields of this derived type are `public`, so the user can access each component via the ‘%’ Fortran 90 selector.

Lastly, the user can use the `msRelease` routine to free all fields of this structure (and to re-initialize the components between two different calls to any of these integrators).

*Remark:* The `jacobian matrix` of the ODE solver may be singular, because the iteration matrix  $M$  writes:

$$M = I + \Delta t J = I + \Delta t \frac{\partial F}{\partial y}$$

It can be seen easily that for a sufficiently small time-step  $\Delta t$ ,  $M$  is not singular so there is no constraint over  $J$ : it could be even the null matrix! On the contrary, the iteration matrix  $M$  used by the DAE solver is close to the following `generalized jacobian`:

$$M \approx \tilde{J} = \frac{\partial R}{\partial y} + c_J \frac{\partial R}{\partial y'}$$

where  $c_J$  is related to the inverse of the time step  $\Delta t$ . In this latter case,  $\tilde{J}$  cannot be singular. (The two functions  $F(t, y)$  and  $R(t, y, y')$  have been defined respectively at the `mfOdeSolve` and `mfDaeSolve` entries.)

*See also:* `mf_NL_Options`

## 1.11 Sparse Matrices

<code>mfSparse</code>	sparse matrix conversion
<code>mfFull</code>	dense matrix conversion
<code>mfSpAlloc</code> , <code>msSpReAlloc</code>	sparse matrix space allocation
<code>mfNnz</code>	number of nonzero matrix elements
<code>mfNzMax</code>	sparse matrix internal size
<code>mfNcolMax</code>	sparse matrix internal size
<code>mfSpEye</code>	sparse identity matrix
<code>mfSpOnes</code>	replace nonzero elements with ones
<code>mfSpRand</code>	sparse uniformly distributed random matrix
<code>mfSpRandN</code>	sparse normally distributed random matrix
<code>mfSpDiags</code>	sparse matrix formed from diagonals
<code>mfSpCut</code>	cut small elements
<code>mfSpImport</code> , <code>msSpExport</code>	sparse matrix conversion from/to f90 arrays
<code>mfIsRowSorted</code>	row sorted inquiry
<code>msRowSort</code>	sparse matrix row sort
<code>msGetAutoRowSorted</code>	row sorting policy
<code>msSetAutoRowSorted</code>	row sorting policy
<code>mfMatFactor</code>	handle to internal matrix factors ( <i>derived type</i> )
<code>msFreeMatFactor</code>	deallocation of internal matrix factors

See also:

[Core Routines](#)

[File Input/Output](#)

[Data Analysis Functions](#)

[Operators](#)

[Elementary Math Functions](#)

[Specialized Math Functions](#)

[Elementary Matrix Manipulation Functions](#)

[Matrix Functions](#)

[Polynomial Functions](#)

[Optimization and Function Functions](#)

**mfSparse****sparse matrix conversion***Calling syntax:*

```
B = mfSparse( A )
```

converts the `mfArray` `A` (which should be dense) into a sparse `mfArray`.

To create a sparse matrix, use the `mfSpAlloc` routine instead.

*See also:* `mfFull`, `mfSpImport`, `msSpExport`

**mfFull****dense matrix conversion***Calling syntax:*

```
B = mfFull( A )
```

converts the `mfArray` `A` (which should be sparse) into a dense `mfArray`.

*See also:* [mfSparse](#)



mfSpAlloc

sparse matrix space allocation

*Interface:*

```
function mfSpAlloc( m, n, nzmax, ncolmax, kind ) result( out )  
  
    integer,          intent(in)          :: m, n  
    integer,          intent(in), optional :: nzmax, ncolmax  
    character(len=*), intent(in), optional :: kind  
    type(mfArray)    :: out
```

*Description:*

This routine is used to create new space for a sparse `mfArray` of size `m` by `n` (logical dimensions) which will contain at most `nzmax` (if present) non-zero values. If `nzmax` is not present, it is set to zero.

If `ncolmax` is present, it reserves space for a greater number of columns. The value of `ncolmax` cannot be less than `n`; its default value is equal to `n`. This argument is usually employed with the routine `msHorizConcat`.

`kind` may be equal to "real" or "complex"; it defaults to "real".

See also: [msSpReAlloc](#), [msHorizConcat](#)

msSpReAlloc

sparse matrix space re-allocation

*Interface:*

```
subroutine msSpReAlloc( A, nzmax, ncolmax )

    type(mfArray), intent(in out)      :: A
    integer,       intent(in),         optional :: nzmax
    integer,       intent(in),         optional :: ncolmax
```

*Description:*

This routine changes the space for elements in the sparse `mfArray` `A`. At least one argument, among the two optional ones `nzmax` and `ncolmax`, must be present.

The argument `nzmax` corresponds to the maximum number of non zero entries in the sparse structure. It can be increased to any value, but you will get an error if the value of `nzmax` is too small.

The argument `ncolmax` corresponds to the maximum number of the columns. Here again, you will get an error if the value of `ncolmax` is too small. Be careful when changing its value, because the logical size of the matrix is determine by `ncolmax`.

Usually the two arguments are used to *increase* the corresponding value. It may be dangerous to try to *decrease* their value without knowledge about the internal sparse structure. See below to decrease as much as possible the internal size of the structure automatically, without loss of data.

*Other calling syntax:*

To compact an `mfArray` to its minimal room space (both in terms of the maximum number of non zero entries `nzmax`), and maximum number of columns `ncolmax`), use the following special calling sequence:

```
call msSpReAlloc( A, "minimal" )
```

Note that this will remove also any (unwanted) zeros actually stored.

See also: [mfSpAlloc](#)

**mfNnz****number of nonzero matrix elements***Interface:*

```
function mfNnz( A ) result( out )  
  
    type(mfArray), intent(in) :: A  
    integer :: out
```

*Description:*

Returns the number of non-zero element of the sparse mfArray A.

*See also:* [mfNzMax](#)

**mfNzMax****sparse matrix internal size***Interface:*

```
function mfNzMax( A ) result( out )  
  
    type(mfArray), intent(in) :: A  
    integer :: out
```

*Description:*

Returns the maximum number of non-zero element of the sparse mfArray A.

*See also:* [mfNnz](#), [mfNcolMax](#)

**mfNcolMax****sparse matrix internal size***Interface:*

```
function mfNcolMax( A ) result( out )  
  
    type(mfArray), intent(in) :: A  
    integer :: out
```

*Description:*

Returns the maximum number of columns of the sparse `mfArray` `A`.

*See also:* [mfNnz](#), [mfNzMax](#)

**mfSpEye****sparse identity matrix***Interface:*

```
function mfSpEye( m, n, kind ) result( out )  
  
    integer,          intent(in)          :: m  
    integer,          intent(in), optional :: n  
    character(len=*), intent(in), optional :: kind  
    type(mfArray)    :: out
```

*Description:*

This routine creates a sparse `mfArray` of size `m` by `n`.

The optional argument `kind` allows the user to choose a complex array (if `kind` is equal to "complex"); by default, a real matrix is returned.

*See also:* [mfSpDiags](#), [mfSpOnes](#)

**mfSpOnes****replace nonzero elements with ones***Calling syntax:*

```
B = mfSpOnes( A )
```

*Description:*

This routine creates a sparse matrix by replacing all non-zero values of the `mfArray` `A` by one.

*See also:* [mfSpEye](#)

**mfSpRand****sparse uniformly distributed random matrix***First calling syntax:*

```
B = mfSpRand( A )
```

*Description:*

This routine creates a sparse matrix by replacing all non-zero values of the `mfArray` `A` (which may be dense or sparse) by a uniformly distributed random value. Therefore, the `mfArray` `B` has the same sparsity than `A`.

*Second calling syntax:*

```
B = mfSpRand( m, n, density )
```

*Description:*

creates a random, `m`-by-`n`, sparse matrix with approximately `density*m*n` uniformly distributed nonzero entries (the real `density` must be in  $[0,1]$ ).

*See also:* [mfSpEye](#), [mfSpOnes](#), [mfSpRandN](#)



**mfSpRandN****sparse normally distributed random matrix***First calling syntax:*

```
B = mfSpRandN( A )
```

*Description:*

This routine creates a sparse matrix by replacing all non-zero values of the `mfArray` `A` (which may be dense or sparse) by a normally distributed random value. Therefore, the `mfArray` `B` has the same sparsity than `A`.

*Second calling syntax:*

```
B = mfSpRandN( m, n, density )
```

*Description:*

creates a random, `m`-by-`n`, sparse matrix with approximately `density*m*n` normally distributed nonzero entries (the real `density` must be in  $[0,1]$ ).

*See also:* [mfSpEye](#), [mfSpOnes](#), [mfSpRand](#)

**mfSpDiags****sparse matrix formed from diagonals***Interface:*

```
function mfSpDiags( m, n, v, d ) result( out )

    integer, intent(in) :: m, n
    type(mfArray) :: v
    integer, intent(in), optional :: d

    type(mfArray) :: out
```

*Description:*

Creates a sparse matrix (of size  $m$  by  $n$ ) whose the  $d$ -diagonal is the input vector  $v$  (dense).

The vector  $v$  may have a length greater than those of the  $d$ -diagonal (in such a case, subsequent elements will not be referenced); it can be also a scalar (in such a case, the scalar value is spread over the diagonal).

*Remarks:* When  $d$  is equal to zero, it points to the main diagonal; when positive, the upper part of the matrix is concerned. If the arg.  $d$  is not present, the main diagonal is the default.

*Other interface:*

```
function mfSpDiags( m, n, A, d ) result( out )

    integer, intent(in) :: m, n
    type(mfArray) :: A
    integer, intent(in) :: d(:)

    type(mfArray) :: out
```

*Description:*

In this second interface the input `mfArray`  $A$  may be a rank-2 array. So, each column of  $A$  is used to fill a diagonal of the returned sparse matrix, whose index is specified in the vector  $d$ .

If  $A$  is a row vector then each constructed diagonal will have the same elements.

*See also:* [mfSpEye](#), [mf/msDiag](#)

**mfSpCut****cut small elements***Calling syntax:*

```
B = mfSpCut( A, threshold )
```

*Description:*

This routine removes all elements of the **mfArray** **A** (sparse, real or complex) whose magnitude is less or equal than the prescribed **threshold** (positive real arg.).

**mfSpImport****sparse matrix conversion from f90 arrays**

*Calling syntax:*

```
A = mfSpImport( i, j, d[, m, n, nzmax, format, duplicated_entries ] )
```

creates the sparse **mfArray** **A** from a sparse structure stored in classical f90 arrays; **i** and **j** are integer f90 vectors whereas **d** is a real or a complex f90 vector.

The vector **d** may have a null size, in which case the allocation of data space is made by this routine but filled with *NaN* value (initialization may occur later on).

If present, the character string **format** specifies the sparse format; it may be equal to "COO" (*COOrdinates*), "CSC" (*Compact Sparse Columns*) or "CSR" (*Compact Sparse Rows*). By default, **format**="COO" is assumed.

If present, **m** and **n** define the (logical) shape of the sparse **mfArray**; these shape must be large enough to contain all the input indices specified in **i** and **j**. By default, the logical shape is deduced as follows:

- if the format is "COO", then the matrix shape is deduced from the maximum value of arrays **i** and **j**. It follows than all these arrays are inspected.
- if the format is "CSC" (resp. "CSR"), the number of columns (resp. rows) comes from the size of the **j** array (resp. of the **i** array). Then the other dimension is deduced by inspected the appropriate part of the other array; this is because the long index array may be overdimensioned.

If present, **nzmax** allows to reserve more place than the actual size.

After importing f90 arrays:

- eventual duplicated entries are treated according to the optional character argument **duplicated\_entries**. When this argument is present and equal to "ignored", duplicated entries are ignored; when it is equal to "added" (default value), duplicated entries are added; when it is equal to "replaced", last entries found overwrite previous ones.
- entries containing a null value are removed.

*See also:* [msSpExport](#), [mfSparse](#), [mfLoadSparse](#), [msSaveSparse](#)

**msSpExport****sparse matrix conversion to f90 arrays**

*Calling syntax:*

```
call msSpExport( A, i, j, d [, format ] )
```

copies the sparse mfArray A to a sparse structure using classical f90 arrays.

i and j are integer f90 vectors. d is a real or a complex f90 vector.

If present, the character string `format` specifies the sparse format; it may be equal to "COO" (*COOrdinates*), "CSC" (*Compact Sparse Columns*) or "CSR" (*Compact Sparse Rows*). By default, `format="COO"` is assumed.

*See also:* [mfSpImport](#), [mfSparse](#), [mfLoadSparse](#), [msSaveSparse](#)

**mfIsRowSorted****row sorted inquiry***Interface:*

```
function mfIsRowSorted( A ) result( bool )  
  
    type(mfArray), intent(in out) :: A  
    logical :: bool
```

*Description:*

Returns `.true.` if the columns of the sparse `mfArray` `A` are “row sorted” and contain no duplicated entries.

*See also:* [msRowSort](#), [msGetAutoRowSorted](#), [msSetAutoRowSorted](#)

**msRowSort****sparse matrix row sort***Calling syntax:*

```
call msRowSort( A [, struct_only ] )
```

*Description:*

Sorts all columns of the sparse `mfArray` `A` in increasing order, and remove all duplicated entries.

If the logical optional argument `struct_only` is present and equal to `‘.true.’` then the data array is discarded.

*See also:* [mfIsRowSorted](#), [msGetAutoRowSorted](#), [msSetAutoRowSorted](#)

`msGetAutoRowSorted`

row sorting policy

*Interface:*

```
subroutine msGetAutoRowSorted( auto_row_sorted )  
  
    logical, intent(out) :: auto_row_sorted
```

*Description:*

If the returned logical `auto_row_sorted` is *TRUE*, then all sparse matrices are row sorted when needed.

*See also:* [msRowSort](#), [mfIsRowSorted](#), [msSetAutoRowSorted](#)



**msSetAutoRowSorted****row sorting policy***Interface:*

```
subroutine msSetAutoRowSorted( auto_row_sorted )  
  
    logical, intent(in) :: auto_row_sorted
```

*Description:*

Only if `auto_row_sorted` is *TRUE*, then all sparse matrices will be row sorted when needed. Therefore, this routine can change this row sorting policy.

By default, `auto_row_sorted` is *TRUE*.

*See also:* [msRowSort](#), [mfIsRowSorted](#), [msGetAutoRowSorted](#)

`mfMatFactor` **handle to internal matrix factors (*derived type*)**

*Description:*

This derived type is a handle to (sparse or dense) factors computed by some factorization routine (*e. g.* `msLU`, `msQR` or `msChol`). Declaration is made as follows:

```
type(mfMatFactor) :: factor
```

The user cannot manipulate the contents of this derived type: it is indeed intended to be used only by other MUESLI routines.

The user may release this structure by use of the `msFreeMatFactor` routine (but use of `msRelease` is equivalent).

**msFreeMatFactor****deallocation of internal matrix factors***Calling syntax:*

```
call msFreeMatFactor( factor )
```

*Description:*Deallocate the **mfMatFactor** factor.*Remark:* The routine **msRelease** may also be used in an equivalent way.

## 2 FGL: Graphical Library

FGL contains all routines to make figures and plots (only in 2D).

Routines beginning with ‘ms’ are subroutines, whereas those beginning with ‘mf’ are functions. Usually, the two forms of the same routine do the same job, but the latter returns an identification (actually, a handle to the graphic object).

The available routines have been grouped into sub-parts:

- Global graphic settings

- Window’s and figure’s management

- Figure properties

- Figure annotation – Low level graphic object’s manipulation

- High level plotting routines

- Interactive routines

## 2.1 Global graphic settings

<code>msSetBackgroundColor</code>	background color setting
<code>msSetColorOverflowPolicy</code>	set color overflow policy
<code>mfGetColorOverflowPolicy</code>	get color overflow policy
<code>msExitFgl</code>	FGL closing
<code>mfGetX11Device, msSetX11Device</code>	X11 device status
<code>mfGetX11ColorDepth</code>	get X11 screen color depth
<code>mfGetDefaultCapStyle, msSetDefaultCapStyle</code>	default cap style for lines
<code>mfGetDefaultJoinStyle, msSetDefaultJoinStyle</code>	default join style for lines
<code>mfGetCharEncoding, msSetCharEncoding</code>	character encoding

*See also:*

[Window's and figure's management](#)

[Figure properties](#)

[Figure annotation – Low level graphic object's manipulation](#)

[High level plotting routines](#)

[Interactive routines](#)

`msSetBackgroundColor`**background color setting***Interface:*

```
subroutine msSetBackgroundColor( color_string )  
  
character(len=*), intent(in) :: color_string
```

*Description:*

Set the background color. The only two possibilities are "white" (the default) and "black".

This routine must be used at the beginning of the graphic part. The background color must be the same for all the opened windows; it cannot be changed during the execution, until *FGL* graphic part is closed (`msExitFgl`) and automatically reinitialized by opening any figure.

*Remark:* When the background has been selected as black, printing leads to different behavior for EPS and PDF formats (see `msPrint`).

**mfGetColorOverflowPolicy****get color overflow policy***Interface:*

```
function mfGetColorOverflowPolicy() result( policy )  
  
    character(len=10) :: policy(2)
```

*Description:*

Returns two strings. The first one (resp. second one) refers to color overflow in the low part (resp. high part) of the colormap.

The color overflow policy may be "signaled" or "truncated". When it is "signaled", a contrasted color is used to signal the colormap overflow. When it is "truncated", the lowest color (or highest color) is used, giving a smooth aspect to the colors.

Default behavior is "signaled" for both ends.

*See also:* [msSetColorOverflowPolicy](#)

**msSetColorOverflowPolicy****set color overflow policy***Interface:*

```
subroutine msSetColorOverflowPolicy( low, high )  
  
character(len=*), optional :: low, high
```

*Description:*

This routine is used to monitor the colormap overflow. `low` and `high` are two strings which must contain "signaled" or "truncated".

When it is "signaled", a contrasted color is used to signal the colormap overflow. When it is "truncated", the lowest color (or highest color) is used, giving a smooth aspect to the colors.

Default behavior is "signaled" for both ends.

*Remark:* if none of the two arguments is present, then nothing is changed.

*See also:* [mfGetColorOverflowPolicy](#)



**mfGetX11Device****Get X11 device status***Interface:*

```
status = mfGetX11Device( )
```

*Description:*

Returns the status of the X11 device, which can be "on" (the default) or "off".

*See also:* [msSetX11Device](#)

**msSetX11Device****Set X11 device status***Interface:*

```
subroutine msSetX11Device( flag )  
  
    character(len=*), intent(in) :: flag
```

*Description:*

During execution, as MUESLI is able to produce printed images (EPS or PDF) in an independant way, the X11 device can be de-activated, by setting the `flag` parameter to "off". It can be useful for batch executions.

*Remarks:*

- the X11 device is "on" by default;
- it can be enabled/disabled by the `MFPLOT_X11_DEVICE` environment variable, which can take the value 0 or 1.

*See also:* [mfGetX11Device](#)

`mfGetX11ColorDepth``get color depth`

*Interface:*

```
function mfGetX11ColorDepth() result( depth )  
  
    integer :: depth
```

*Description:*

Returns the color depth currently used by the X11 server. A figure must have been previously opened.

*See also:* [mf/msColormapSize](#), [mf/msColormap](#), [msColorbar](#)

**msExitFgl****FGL closing**

*Calling syntax:*

```
call msExitFgl()
```

This routine is intended to be used at the end of your graphical program. It leaves a prompt to the user and waits for an answer ('y' or 'Y'), after warning the user by a text like:

```
***  
End of MUESLI plotting:  
- all figures are going to be closed.  
- graphic memory will be properly cleaned.  
Do you really close graphics ? [y|Y]
```

It is a useful command to avoid that all graphic windows disappear; as mentioned, it also cleans the FGL internal memory (all graphic objects); moreover, X11 windows position and size are saved in a small database.

*Remarks:* If you want that your program terminates without a user action, you can redirect the standard input (via '<' in a shell command) and read a file containing the 'y' symbol. Another possibility is to use the 'yes' unix command which outputs repeatedly the character 'y' to your program via a unix pipe, *e.g.*:

```
$ yes | a.out
```

*See also:* [msRelease](#)

**mfGetDefaultCapStyle****Get default cap style for lines***Calling syntax:*

```
cap_style = mfGetDefaultCapStyle( )
```

*Description:*

Returns the current default cap style, which may be 0 ("CapButt"), 1 ("CapRound") or 2 ("CapProjecting").

The signification of these three attributes may be found easily on the web.

*See also:* [msSetGrObj](#), [msSetDefaultCapStyle](#), [msSetDefaultJoinStyle](#)

**msSetDefaultCapStyle****Set default cap style for lines***Interface:*

```
subroutine msSetDefaultCapStyle( cap_style )  
  
character(len=*), intent(in) :: cap_style
```

*Description:*

Change the global value for the default cap style. The argument `cap_style` may be set to "CapButt", "CapRound" or "CapProjecting".

The signification of these three attributes may be found easily on the web.

Note also that this graphic attribute may be change for a particular object, via the `msSetGrObj` routine.

*See also:* `mfGetDefaultCapStyle`, `mfGetDefaultJoinStyle`

**mfGetDefaultJoinStyle****Get default join style for lines***Calling syntax:*

```
join_style = mfGetDefaultJoinStyle( )
```

*Description:*

Returns the current default join style, which may be 0 ("JoinMiter"), 1 ("JoinRound") or 2 ("JoinBevel").

The signification of these three attributes may be found easily on the web.

*See also:* [msSetGrObj](#), [msSetDefaultJoinStyle](#), [msSetDefaultCapStyle](#)

**msSetDefaultJoinStyle****Set default join style for lines***Interface:*

```
subroutine msSetDefaultJoinStyle( join_style )  
  
character(len=*), intent(in) :: join_style
```

*Description:*

Change the global value for the default join style. The argument `join_style` may be set to "JoinMiter", "JoinRound" or "JoinBevel".

The signification of these three attributes may be found easily on the web.

Note also that this graphic attribute may be change for a particular object, via the `msSetGrObj` routine.

*See also:* [mfGetDefaultJoinStyle](#), [mfGetDefaultCapStyle](#)



**mfGetCharEncoding****Get character encoding***Interface:*

```
encoding = mfGetCharEncoding( )
```

*Description:*

Returns the current character encoding, which is "Latin" (the default) or "UTF-8".

This is used in the following graphic routines, which display character strings in a figure: [mf/msText](#), [msTitle](#), [msXLabel](#), [msYLabel](#), [mf/msFigure](#) and [msLegend](#).

*See also:* [msSetCharEncoding](#)

**msSetCharEncoding****Set character encoding***Interface:*

```
subroutine msSetCharEncoding( encoding )  
  
    character(len=*), intent(in) :: encoding
```

*Description:*

When processing character's strings (*e.g.* in the **msTitle** routine), MUESLI accepts two different character encodings. The charset may be "Latin" (default one) or "UTF-8".

So, the **encoding** argument can take only the following values:

- "Latin" (or "ISO-8859-1" which is an alias)
- "UTF-8"

*Warning:* Not all the characters defined in the "UTF-8" encoding are valid. Actually, only a subpart of the 256 first characters (*i.e.* mostly of the "Latin" encoded characters, but not all) are correctly processed.

*See also:* [mfGetCharEncoding](#)

## 2.2 Window's and figure's management

<code>mf/msFigure</code>	figure creation
<code>msResizeWindow</code>	window resizing
<code>mfGetWinId</code>	current figure identification
<code>msClose</code>	figure deletion
<code>mfGetColorScheme, msSetColorScheme</code>	color scheme
<code>msPrint</code>	file printing (EPS and PDF)
<code>msSetPdfOC</code>	PDF Optional Contents management

*See also:*

[Global graphic settings](#)

[Figure properties](#)

[Figure annotation – Low level graphic object's manipulation](#)

[High level plotting routines](#)

[Interactive routines](#)

mf/msFigure

figure creation

*Calling syntax:*

```
call msFigure( [win_id] [, position] [, size] [, title] )
```

where arguments are all optional.

This routine opens a new window or selects (and therefore makes active) a previously opened one.

The `win_id` argument (integer) indicates the identification of the window; if not present, a sequential integer from 1 is used.

The `position` argument is used to impose the position of the window on the screen. It must be a Fortran array of two integer values specifying the position of the newly created window; the position in pixels of the top-left corner of the window is taken from the top-left corner of the whole screen (virtual screen in case of many monitors), counting positively downward for the  $y$  value. Default position is approximately (0,0) for the first window, and shifted both in  $x$ - and  $y$ -position, in order to be not completely overlapped (for the windows below others, only their title is visible).

The `size` argument is used to impose the size of the window on the screen. It must be a Fortran array of two integer values specifying the size of the newly created window; the two values indicates the width and height in pixels of the window. Default size is 800 by 600.

The `title` argument (character string, of maximum length 80) specifies the title of the figure. This title is visible in the X11 window title; it applies also for the printed EPS and PDF files.

*Remarks:*

- the default size of X11 windows can be modified via the environment variables `MF_PLOT_X11_WIDTH` and `MF_PLOT_X11_HEIGHT`.
- the window title always contains `win_id` and the name of the executable program.
- ordinarily, if you have no figure opened, most of graphical routines automatically open a new one.
- maximum number of concurrent figures is 64. However, `win_id` values don't need to be contiguous, and may be even greater than 64.

The other form:

```
win_id = mfFigure()
```

creates a new figure and returns its (integer) window identification.

*Remarks:* use `mfGetWinId` to get the window identification of the current active figure.

*See also:* `msClose`, `msClf`

**msResizeWindow****window resizing***Calling syntax:*

```
call msResizeWindow( [width, height] )
```

*Description:*

If the optional arguments `width` and `height` are both present, then the window is resized by the library.

On the contrary, *i. e.* when the optional arguments are not present, this routine becomes interactive, prints a prompt on the terminal, and wait the resizing of the window by the mouse.

*See also:* [msFigure](#), [msClf](#)

**mfGetWinId****current figure handle***Calling syntax:*

```
win_id = mfGetWinId( )
```

*Description:*

Returns the window identification (integer) of the current active figure.

*See also:* [msFigure](#)

**msClose****figure deletion***Calling syntax:*

```
call msClose( [win_id] )
```

*Description:*

Closes the specified window, or the current window if the optional argument `win_id` is not present.

Note that after closing a window, the current selected window is undefined, even if other figures yet exist. It is required to select another existing window if you wish to plot inside, else a new figure will be automatically created.

*See also:* [msFigure](#), [msClf](#)

**mfGetColorScheme****Get color scheme***Interface:*

```
color_scheme = mfGetColorScheme( )
```

*Description:*

Returns the color scheme attached to the selected window, which is an integer ranged in [1-4]. Default is 3.

There are four different color schemes, used for recycling colors when you plot several lines on the same figure. They are described in the *Muesli User's Guide* (cf. § 5.2 Color management).

*See also:* [msSetColorScheme](#)



**msSetColorScheme****Set color scheme***Interface:*

```
subroutine msSetColorScheme( color_scheme )  
  
integer, intent(in) :: color_scheme
```

*Description:*

Set the color scheme for the selected window, via an integer argument ranged in [1-4].

There are four different color schemes, used for recycling colors when you plot several lines on the same figure. They are described in the *Muesli User's Guide* (cf. § 5.2 Color management).

The default color scheme is the third one, *i. e.* the new colors in Matlab (from release R2014b).

*See also:* [mfGetColorScheme](#)

**msPrint****file printing**

*Calling syntax:*

```
call msPrint( filename [, file_format ] )
```

*Description:*

Prints the current figure in a file named `filename`.

Currently, `file_format` may be only "EPS" or "PDF". If this optional argument is not present, MUESLI tries to deduce the device type from the extension of the provided `filename`. By default, an EPS file is created.

For EPS (resp. PDF) files, and for debugging purpose, comments can be inserted in the generated file by setting the environment variable `MFPLOTT_EPS_COMMENTS` (resp. `MFPLOTT_PDF_COMMENTS`) to 1 (default is no comments). Be aware that this will increase the size of the file.

Note, if you have selected a black background (see [msSetBackgroundColor](#)), that the EPS only will have also a black background. For the PDF files have always a white background.

*Remarks:*

- EPS and PDF files intensively make use of language-based shading. This means that all coloured gradients (from [msPatch](#) or [msPColor](#) for example) are treated by using appropriate PostScript or PDF commands, and leads to smaller files.
- Of course, printed files may be generated without any X11 capability. This is useful under Windows (where there is no X11 access) or for batch processes.
- For PDF files only, optional contents (also known as layers) may be inserted. See [msSetPdfOC](#).

## msSetPdfOC

## PDF Optional Contents management

The first interface is:

```

subroutine msSetPdfOC( handle,                                &
                      name, mutex, persistent, super_group )

integer,              intent(in)                :: handle
character(len=*),    intent(in), optional      :: name, mutex, super_group
logical,              intent(in), optional      :: persistent

```

It is used to tag a graphic object of the current window as *Optional Content* in the PDF. Doing so, and once the *Layers* of your PDF viewer is opened, you should be able to choose to display or not this graphic object (which appears under the `name`) on the screen.

The graphic object, referenced by its `handle`, may be visible or not. The initial state of visibility in the PDF layers will be consistent with the visibility in the X11 window at the time of printing, except when the `persistent` argument is used: in such a case, only the graphic object tagged as *persistent* will be initially visible in the *mutex* group.

If `name` is not present, then it will be assigned the corresponding graphic object number (as “*handle i*”).

The `mutex` optional argument (*MUTually EXclusive*) is used to group some optional contents in a *Radio-Button group*: at most one of these optional contents may be visible in the PDF (but that does not prevent the existence of a state where none of these are visible — see below the section concerning `persistent` if you want that exactly one content must be visible at a time). The `mutex` name is the name which will appear in the “layers” panel of the PDF viewer, which enclosed all different names. Same thing for the `super_group` optional argument, except that the groups inside are not in mutually exclusion.

When using the `mutex` feature, replacing ‘`name=name`’ by ‘`persistent=.true.`’ allows that one object is always visible, and it is the concerned object by default. A typical application is to group text annotations in the figure in mutually exclusive groups, one for a language; each group may have its own `name`, for example, equal to *Français*, *Deutsch*, etc. The `mutex` name could be then, *Other languages* (*default: English*). See the `Labels_and_Languages_test.f90` program under `src/test/fgl`.

The other interface:

```

subroutine msSetPdfOC( handle,                                &
                      merge, name, mutex, persistent, super_group )

integer,              intent(in)                :: handle(:)
logical,              intent(in), optional      :: merge, persistent
character(len=*),    intent(in), optional      :: name, mutex, super_group

```

concerns a vector of `handle`, and can be used to the following aims:

- when the two arguments `merge` and `name` are *both present*, it merges a group of graphic objects under the same `name` as optional contents; as an example of use, see the `PlotCubicBezier_test` program under `src/test/fgl`.
- when the two arguments `merge` and `name` are *both not present*, it gets a different name for each graphic objects of the group, from the legend of the figure. Of course, such a legend should exist; on the contrary, a generic name (as “*handle i*”) will be used instead. As an example of use, see the figure 4 of the `Legend_test` program under `src/test/fgl`.

The `mutex` optional argument has the same meaning as in the first interface. Its use implies the merge of all optional contents specified by the array of `handles`. Same thing for `super_group`.

⋯/⋯

*Constraints about the presence of optional arguments:*

- `mutex` and `super_group` arguments cannot be both present.
- `persistent` and `name` arguments cannot be both present.
- in a given group of optional contents, the `persistent` argument can be used only one time.
- currently (but this may change in a future version), there are only one Radio-Button group and only one Super-group for each figure.

*Remarks:*

- this routine must be called before creating the PDF file via `msPrint`.
- you are allowed to first call the second interface, using an array of handle, getting the names from the legend and then, call the first interface to modify the name of one specific graphic object.
- the PDF Optional Contents will be ignored if you print in the EPS format.

## 2.3 Figure properties

<code>mf/msAxis</code>	figure axes setting
<code>msAxisFontSize</code>	axis font size setting
<code>msAxisLineWidth</code>	axis line width setting
<code>msCharInPixels</code>	character size policy
<code>mf/msCAxis</code>	get or set color axis
<code>msClf</code>	clear current figure
<code>msColorbar</code>	color bar setting
<code>mf/msColormap</code>	get or set colormap
<code>mf/msColormapSize</code>	get or set colormap size
<code>msDrawBox</code>	redraw the box in current figure
<code>msDrawGrid</code>	if needed, redraw the grid in current figure
<code>msRedrawFigure</code>	redraw the current figure
<code>msGetX11Pixmap</code>	X11 pixmap saving
<code>msGrid</code>	grid setting
<code>msHold</code>	plot command superposition
<code>msRemoveClipBox</code>	remove a clipping box inside axes
<code>msSetClipBox</code>	define a clipping box inside axes
<code>msShading</code>	color shading mode
<code>mf/msTitle</code>	title setting
<code>msTitleFontSize</code>	title font size setting
<code>mf/msXLabel</code>	x-label setting
<code>mf/msYLabel</code>	y-label setting
<code>msLabelFontSize</code>	descriptive labels font size setting
<code>msAxisLabelFormat</code>	kind of labelling for Axis
<code>msSetWinProp</code>	window properties setting
<code>msLegend</code>	add legends to curves, in one frame
<code>mfLegend</code>	add legends to curves, possibly in many frames

*See also:*

[Global graphic settings](#)

[Window's and figure's management](#)

[Figure annotation – Low level graphic object's manipulation](#)

[High level plotting routines](#)

[Interactive routines](#)

## mf/msAxis

## figure axes setting

The *function form*

```
function mfAxis( [ axis ] ) result( mf_range )

    type(mfArray)           :: mf_range
    character(len=*) , optional :: axis
```

returns the current axis values of the selected figure, always in the order: *left, right, bottom, top*, whatever the mode ("xy" or "ij" – see below) is. This array is a vector of length 4 or 2, containing extremal values of the *x*- and/or *y*-axis, according to the presence of the optional argument `axis` which must be equal to the single character "x" or "y".

The *subroutine form* has the following calling syntax:

```
call msAxis( mode | dp_range | mf_range [, axis ] )
```

If the character string `mode` is present, it may have the following values:

- "on" / "off": axes are drawn (default) or hidden (and so for X label, Y label and Figure title).
- "auto": axes' ranges are computed from the actual numerical values of data to be plotted, giving *smart* extremal values; this is the default. Note that graphic data involved do not include arrows or texts, which are considered as annotations.
- "tight": axes' ranges are computed from actual values of data (see just above what is considered as "data"), strictly keeping their extremal values.
- "manual": axes' ranges are not automatic; the current axis values are frozen, whatever the following plots. This mode is also set when a range is explicitly used (see below). Only another call using the "auto" or "tight" argument can unlock it.
- "equal": *x*- and *y*- axis are drawn with the same scale; the default behaviour is "unequal". Note that the *equal* mode is possible only when axes have the same scaling (both linear or both logarithmic).
- "xy" / "ij": the origin of the *x*- and *y*-axis is at the bottom left corner of the figure (default location for most plotting commands) or at the top left corner (when the data is interpreted as a matrix, which is the case for `msSpy`, `msImage` and `msPColor` in the absence of (X,Y) coordinates). In the "xy" mode, the *x*-axis labels are written at the bottom side of the box, whereas they are written at the top one in the other mode.
- "inverted": in this case, the second optional argument `axis` must be present and equal to "x" or "y". Corresponding extremal values of this axis are then swapped together. This doesn't imply that the axis becomes "manual". There is no "normal" state, *i. e.* two successive calls with the "inverted" argument is equivalent to do nothing; in other words, "inverted" is not a property but an action to realize.
- "linlin" / "loglog": *x*- and *y*-axis are both linear (default) or logarithmic (base 10).
- "loglin" / "linlog": as specified, one of the two axes is linear whereas the other is logarithmic (base 10); Note that if the *equal* mode is set, it will be disabled.

If the `real dp_range`, or `mfArray mf_range`, is present (containing 4 values), it is used to initialize the axes' range; the *manual* mode is automatically set. The additional optional argument `axis` can be used to set only the *x*- or the *y*-axis: in this case, the length of the range vector must be equal to 2, instead of 4, and the `axis` argument set to the single character "x" or "y".

The `axis` optional argument can also be used when the following modes are set: *auto*, *tight* and *manual*.

Axes may be inverted (*e. g.*, for the *x*-axis, the maximum value on the left and the minimum value on the right); to do this, simply give a range in decreasing order.

See also: `msAxisFontSize`, `msAxisLineWidth`, `msLabelFontSize`, `msGrid`

**msAxisFontSize****axis font size setting***Interface:*

```
subroutine msAxisFontSize( size_factor )  
  
    real(kind=MF_DOUBLE), intent(in) :: size_factor
```

*Description:*

This routine is used to change the font size of the axis numbering.

`size_factor` must be ranged in [0.4, 2.5]. Default size factor is unity. Actual font size also depends on the `char_height_pixel` mode (see the `msCharInPixels` routine).

*See also:* `msAxis`, `msTitleFontSize`, `msLabelFontSize`, `msAxisLineWidth`

**msAxisLineWidth****axis line width setting***Interface:*

```
subroutine msAxisLineWidth( width )  
  
    real(kind=MF_DOUBLE), intent(in) :: width
```

*Description:*

This routine is used to change the line width of the axis and the associated numbering.

Default width is unity.

*Remark:* If you increase the value of `width`, you will remark that the effective line width in pixels is approximately half of this latter value. Actually, the pixel width is a discontinuous function of `width`, especially at small values. The corresponding behaviour is however continuous for the drawing generated in EPS and PDF files.

*See also:* [msAxis](#), [msAxisFontSize](#), [msLabelFontSize](#)



**msCharInPixels****character size policy***Interface:*

```
subroutine msCharInPixels( mode )  
  
    character(len=*), intent(in) :: mode
```

*Description:*

If `mode` is equal to "off", the character size is proportional to the window size (default behavior).

If `mode` is equal to "on", the character size is absolute. Unity is about 12 pixels.

*See also:* [msAxisFontSize](#), [msText](#)

mf/msCAxis

get or set color axis

The first form:

```
function mfCAxis() result ( out )  
  
    type(mfArray) :: out
```

returns the color axis of the current figure. It is a 2-value vector which contains the min and max values used in the colorbar. The default value (if not set by the user) is the range [0,1].

The subroutine form:

```
call msCAxis( col_range | mf_range | string )
```

is used to set the color axis. One argument is required, it is either a **real** 2-value vector, an **mfArray** or a character string.

When the argument contains numerical values, it specifies the color range. Be aware that the two values must not be too close together: in such a case, the routine enlarges slightly the given interval and emits a warning. Once the color axis has been defined, it will remain the same until the next call.

When the argument is a string, it must be equal to **"reset"**: the color axis takes the initial [0,1] range, whereas it becomes extensible again, when used repeatedly (by successive calls of **msContour**, for example).

*Remark:* The two input numerical values defining the color axis must be ordered: first is the minimum, second is the maximum.

*See also:* **msColorbar**, **msColormap**, **msColormapSize**, **msPColor**, **msContour**, **msPatch**

**msClf****clear current figure***Calling syntax:*

```
call msClf()
```

*Description:*

Clears the current figure, but don't close the corresponding window.

*See also:* [msFigure](#), [msClose](#), [msCla](#)

**msColorbar****color bar setting**

*Calling syntax:*

```
call msColorbar( mode [, position ] [, label ] )
```

*Description:*

If `mode` is equal to "on", adds a colorbar to the current figure.

Its position can be specified by an optional argument, `position`, which can be "vert" (*i. e.* right side) or "horiz" (*i. e.* bottom side); by default the position is automatically chosen.

The optional argument `label` can be used for the labelling of the color bar.

The three arguments are of type `character(len=*)`.

*Remarks:*

- In some situations, in particular when axis scaling are equal (see [msAxis](#)) and one figure side is much smaller than the other, it is recommended to left the routine choose itself the position; otherwise the colorbar may have a too short length.
- It is recommended to call this routine after drawing all objects.

*See also:* [msCAxis](#), [msColormap](#), [msColormapSize](#)

## mf/msColormap

## get or set colormap

The function form:

```
colormap = mfColormap()
```

returns the current colormap in an `mfArray` (rank-2 array of 3 columns) which contains the Red-Green-Blue components of each color. These components are reals, ranged from 0.0 to 1.0.

The other function form:

```
bool = mfColormap( "init_status" )
```

returns a logical value according to the initialization status of the colormap.

The subroutine form:

```
call msColormap( name [, "inverted"] )
```

or

```
call msColormap( colormap [, int_max] )
```

is used to set the colormap.

The user can choose a predefined colormap, via the `character name` argument: "rainbow" (or its alias "jet"), "parula", "hot", "bluered", "fusion", "flag" or "grey" (a grey scale). Number of colors is 256, but it can be changed via `msColormapSize`. You can see their color representation in the *Muesli User's Guide*. If the optional argument "inverted" is added, then the colormap is inverted.

User-defined colormap can also be registered, via the `mfArray colormap`. This array must have 3 columns and a number of rows up to 4096.

By default, `colormap` contains real color components, ranged from 0.0 to 1.0. If the optional argument `int_max` is present, it indicates that entries are integers whose max value is provided (*e.g.* 255 for 256 values for each R,G,B component, giving a subset among 16 millions of colors. Integer color components always start from 0).

*Remarks:*

- Before using this routine, a window must be opened via `msFigure`.
- There is no default colormap. The user must select one of them before using colors.

*See also:* `msCAxis`, `msColorbar`

`mf/msColormapSize`**get or set colormap size**

The function form:

```
size = mfColormapSize()
```

returns the size (integer) of the current colormap.

The subroutine forms:

```
call msColormapSize( size )
```

is used to set the size of the colormap. A maximum of 4096 colors is allowed; note however that in most of case, 256 colors are sufficient to eliminate color artifacts on the screen.

```
call msColormapSize( "auto" )
```

sets the size of the colormap to its default size, *i. e.* 256.

*See also:* [mf/msColormap](#), [msColorbar](#)

**msDrawBox****redraw the box in the current figure***Calling syntax:*

```
call msDrawBox()
```

Redraws the framed box in the current figure.

This routine is useful after drawing some plots which partially erase the ticks and marks of the box. It doesn't redraw the numerical label neither the optional grid (which should remain in the background).

*See also:* [msRedrawFigure](#), [msDrawGrid](#)

`msDrawGrid` **if needed, redraw the grid in the current figure**

*Calling syntax:*

```
call msDrawGrid()
```

Redraws the grid in the current figure, if needed.

This routine is useful during animation: if the grid has been set with the `msGrid` routine, the current routine must be called in the iteration loop, before any plotting with FGL.

See the *Muesli User's Guide* about a typical sequence of Muesli routines to include in an animation loop.

*See also:* `msRedrawFigure`, `msDrawBox`



**msRedrawFigure****redraw the current figure***Calling syntax:*

```
call msRedrawFigure( )
```

redraws the current figure.

Typically, this routine should be used after any graphic object change, modified by the routine **msSetGrObj**, in order to make visible the modification on the screen.

*See also:* **msDrawBox**, **msDrawGrid**, **msResizeFigure**

**msGetX11Pixmap****X11 pixmap saving***Calling syntax:*

```
call msGetX11Pixmap( A1, A2, A3 )
```

*Description:*

This routine returns in three **mfArrays**, the color components of the X11 pixmap drawn on the screen.

If the background color is black, then it gets the R,G,B planes.

If the background color is white, then it gets the C,M,Y planes.

*Remark:* the **mfArray** arguments should not be pointed by another ordinary Fortran pointer (see **msPointer**); on the contrary, a Warning is emitted.

*See also:* **msSetBackgroundColor**

**msGrid****grid setting**

*Calling syntax:*

```
call msGrid( mode [ , minor ] )
```

The string `mode` may have the following values:

- "on": a background grey dashed grid is drawn for major axis ticks; (default)
- "off": grid is hidden;

The boolean optional `minor` can be set to `.true.` to get minor lines (aligned on minor ticks). By default, these minor dotted lines are not drawn.

*See also:* [msAxis](#)

**msHold****plot command superposition***Calling syntax:*

```
call msHold( "on" | "off" )
```

*Description:*

Usually, each new plot command erase the previous one. If you want to keep the previous graphic objects drawn in the figure, you must call this routine with "on".

Use "off" to come back to the default behavior.

*Remark:* to avoid unwanted behavior, place this command after the first plot (`msPlot` or whatever).

**msRemoveClipBox****remove a clipping box inside axes***Interface:*

```
subroutine msRemoveClipBox( )
```

*Description:*

Remove the clipping box set by the `msSetClipBox` routine.

*See also:* `msSetClipBox`

**msSetClipBox****define a clipping box inside axes***Interface:*

```
subroutine msSetClipBox( dp_range )  
  
    real(kind=MF_DOUBLE), intent(in) :: dp_range(:)
```

*Description:*

Define a clipping box (inside current axes) for subsequent plotting commands.

*See also:* [msRemoveClipBox](#)

**msShading****color shading mode**

*Calling syntax:*

```
call msShading( mode )
```

where `mode` is a character string which can be "flat" or "interp".

*Description:*

Sets the shading mode used when drawing patches:

- "flat" implies that only one color is used;
- "interp" leads to interpolated colors between the vertices of the polygonal shape.

"flat" is the default mode.

Note that the "interp" mode doesn't lead to bigger files when printing in PDF. Only for EPS, the use of transparency leads to the inclusion of bitmap images.

The shading has no effect on the display of the colorbar. Indeed, the colormap may have sharp gradients or even jumps in colors, or may use of a very small number of colors (*e.g.* 8 or 16): that must appear clearly in the colorbar.

*See also:* [mf/msPatch](#), [mf/msPColor](#), [msColorbar](#)

mf/msTitle

title setting

*Interface:*

```
subroutine msTitle( title )  
  
    character(len=*), intent(in) :: title
```

*Description:*

Adds a title to the current figure. Not drawn if *axis* is *off*.

Maximum length of the title is 128 characters.

This routine should be called after the other data plotting routines.

Escaped sequences may be use in the string (see [msText](#)) to change the font, the style, the position (sub- or superscript), etc. Note also that the global character size may be changed by using [msTitleFontSize](#).

*Remark:* the function [mfTitle](#) has the same argument list; it returns the (integer) handle of the created graphic objet; this is useful to create many strings in different languages, and set them as optional content for PDF creation (see [msSetPdfOC](#)).

*See also:* [msXLabel](#), [msYLabel](#), [msAxis](#)



**msTitleFontSize****title font size setting***Interface:*

```
subroutine msTitleFontSize( size_factor )  
  
    real(kind=MF_DOUBLE), intent(in) :: size_factor
```

*Description:*

This routine is used to change the font size of the title.

`size_factor` must be ranged in [1.0, 3.5]. Default size factor is 2. Actual font size also depends on the `char_height_pixel` mode (see the [msCharInPixels](#) routine).

*See also:* [msAxis](#), [msAxisFontSize](#), [msTitle](#), [msLabelFontSize](#)

mf/msXLabel

x-label setting

*Interface:*

```
subroutine msXLabel( xlabel )  
  
    character(len=*), intent(in) :: xlabel
```

*Description:*

Adds a label to the x-axis of the current figure. Not drawn if *axis* is *off*.

Maximum length of this label is 96 characters.

This routine should be called after the other data plotting routines.

Escaped sequences may be use in the string (see [msText](#)) to change the font, the style, the position (sub- or superscript), etc. Note also that the global character size may be changed by using [msLabelFontSize](#).

*Remark:* the function [mfXLabel](#) has the same argument list; it returns the (integer) handle of the created graphic objet; this is useful to create many strings in different languages, and set them as optional content for PDF creation (see [msSetPdfOC](#)).

*See also:* [msTitle](#), [msYLabel](#), [msAxis](#)

mf/msYLabel

y-label setting

*Interface:*

```
subroutine msYLabel( ylabel )  
  
    character(len=*), intent(in) :: ylabel
```

*Description:*

Adds a label to the y-axis of the current figure. Not drawn if *axis* is *off*.

Maximum length of this label is 96 characters.

This routine should be called after the other data plotting routines.

Escaped sequences may be use in the string (see [msText](#)) to change the font, the style, the position (sub- or superscript), etc. Note also that the global character size may be changed by using [msLabelFontSize](#).

*Remark:* the function [mfYLabel](#) has the same argument list; it returns the (integer) handle of the created graphic objet; this is useful to create many strings in different languages, and set them as optional content for PDF creation (see [msSetPdfOC](#)).

*See also:* [msTitle](#), [msXLabel](#), [msAxis](#)

**msLabelFontSize****descriptive labels font size setting***Interface:*

```
subroutine msLabelFontSize( size_factor )  
  
    real(kind=MF_DOUBLE), intent(in) :: size_factor
```

*Description:*

This routine is used to change the font size of the axis labels.

`size_factor` must be ranged in [0.4, 2.5]. Default size factor is unity. Actual font size also depends on the `char_height_pixel` mode (see the `msCharInPixels` routine).

*See also:* `msAxis`, `msAxisFontSize`, `msTitleFontSize`, `msXLabel`, `msYLabel`

**msAxisLabelFormat****kind of labelling for Axis***Interface:*

```
subroutine msAxisLabelFormat( x_axis_mode, y_axis_mode )  
  
    character(len=*), intent(in), optional :: x_axis_mode, y_axis_mode
```

*Description:*

This routine is used to set the format of labelling axis.

Default mode is "std", *i. e.* numeric numbers without unit. If set to "time" then numbers are supposed to be seconds and are written under the format (DD) HH MM SS.S.

*See also:* [msAxisFontSize](#)

**msSetWinProp****window properties setting***Interface:*

```
call msSetWinProp( property, data )
```

*Description:* Used to modify a specified property of the current window.

property may take the following values:

- "axis\_font\_size", "axis\_line\_width", "label\_font\_size" or "title\_font\_size":  
→ data of type real
- "xlabel", "ylabel" or "title":  
→ data of type character(len=\*)

*Remark:* Contrary to the specific following routines: `msAxisFontSize`, `msAxisLineWidth`, `msLabelFontSize`, `msTitleFontSize`, `msXLabel`, `msYLabel`, `msTitle`, the redraw of the figure is not done; therefore, the user must call the `msRedrawFigure` to see the change effects.

## msLegend

## add legends to curves, in one frame

First interface:

```

subroutine msLegend( legend_1 [, legend_2, legend_3, ... ]           &
                    [, location | position ] )

character(len=*) , intent(in)           :: legend_1
character(len=*) , intent(in), optional :: legend_2, ..., legend_13
character(len=2)  , intent(in), optional :: location
type(mfArray)    , intent(in), optional :: position

```

Second interface:

```

subroutine msLegend( legend_1, handle_1 [, legend_2, handle_2, ... ]   &
                    [, location | position ] )

character(len=*) , intent(in)           :: legend_1
integer          , intent(in)           :: handle_1
character(len=*) , intent(in), optional :: legend_2, ..., legend_13
integer          , intent(in), optional :: handle_2, ..., handle_13
character(len=2) , intent(in), optional :: location
type(mfArray)    , intent(in), optional :: position

```

Description:

Adds legends to the curves plotted in the figure. Up to 13 legends (noted above as `legend_1`, `legend_2`, ...) in one frame are supported, each containing a string of at most 80 characters.

The handles of the curves may be provided (see the second interface), making possible to legend only a subset of the curves. Of course, all handled must be valid and must be integers returned by *Muesli* graphic functions. Note that the two calling syntaxes above cannot be mixed.

Numbered legends and handles must be used in increasing order, otherwise some legends may not appear.

The optional argument `location` (not to be used in conjunction with `position`) can be used to specify in which corner of the figure the legend is displayed. Possible values are "TL" (top-left), "TR" (top-right), "BL" (bottom-left), "BR" (bottom-right) or "outside" (see below). Default is top-left corner.

The optional argument `position` (not to be used in conjunction with `location`) specify the position of the legend's frame, *i.e.* the coordinates of the top-left angle of the frame. The user is even allowed to locate the legend "outside" of the axes, by specifying any value of the coordinates. The legend frame may or may not be entirely visible in the *X11* window, but it should appear in the EPS and PDF files. This is useful in case of a very high legend. A better way, however, is to use `location="outside"`; in such a case, the legend will be drawn in a small, additional window (but the legend will appear in the same EPS or PDF after printing).

Legends are grouped in a unique frame which can be moved inside or outside axes via the `msMoveLegend` routine. See `mfLegend` to create many frames. A legend frame cannot be removed without knowing its handle, *i.e.* via `mfLegend`.

Remarks:

- Usually, the number of string arguments (or pairs of string and associated handle) specifying the legends is equal to the current number of curves. However, it is possible to specify less legends than the actual number of curves: a simple warning will be emitted during the call. Similarly, specifying a number of legends larger than the number of current curves leads to a simple warning, and additional legends will be discarded.

⋯/⋯

- For bar plot, the different items in the legend correspond to the data series plotted; this works only for *grouped* or *stacked bars* (see `mf/msBar`). Currently, the second interface above is not compatible with bar plots.

*Third interface:*

```
subroutine msLegend( legend_array [, handle_array ]           &
                    [, location | position ] )

character(len=*), intent(in)           :: legend_array(:)
integer,          intent(in), optional :: handle_array(:)
character(len=2), intent(in), optional :: location
type(mfArray),   intent(in), optional :: position
```

*Description:*

Allows the user to group all the legends (and, optionally, the associated handles) in one array of character strings.



**mfLegend****add legends to curves, possibly in many frames***Description:*

As opposed to most of graphic routines, the function version of the **Legend** family behaves differently.

It has the same interfaces as **msLegend** and, as usual, returns the (integer) handle of the graphic objet; moreover, it can be called many times for the same figure, making it useful to create legends in different languages, and to set them as optional content for PDF creation (see **msSetPdfOC**).

## 2.4 Figure annotation – Low level graphic object’s manipulation

<code>mf/msArrow</code>	arrow drawing
<code>mf/msText</code>	text display
<code>mfGetAllGrObj</code>	get all graphic objects
<code>mfGetTypeGrObj</code>	get the type of a graphic object
<code>mfSelectTypeGrObj</code>	select graphic objects by type
<code>msSetGrObj</code>	graphic object setting
<code>msRemoveGrObj</code>	graphic object deletion

*See also:*

[Global graphic settings](#)

[Window’s and figure’s management](#)

[Figure properties](#)

[High level plotting routines](#)

[Interactive routines](#)

**mf/msArrow****arrow drawing**

The first form:

```
call msArrow( x_start, y_start, x_end, y_end           &
              [, color] [, linewidth] [, headsize] [, clipping ] )
```

draws an arrow from the position (`x_start`, `y_start`) to the position (`x_end`, `y_end`). These coordinates must be of type `real`.

The optional argument `color` have the same meaning as in the routine `mf/msPlot`.

Optional arguments `linewidth` and `headsize` (real numbers) can be used to specify the line width and the head size of the arrow. Default values are unity.

If the optional boolean argument `clipping` is set to `FALSE`, then the arrow can be displayed out of the viewport (default is `TRUE`, *i.e.* the arrow is clipped at the viewport; this default behavior is recommended when it is an annotation at some location inside the viewport and you might want to pan or zoom inside the axes).

The second form:

```
call msArrow( x, y, angle                             &
              [, color] [, headsize] )
```

draws only an arrow head, given a position ( $x, y$ ) and an angle in radian (all are real variables).

The remaining arguments have the same meanings as above.

*Remarks:*

- the function `mfArrow` has the same argument list; it returns the (integer) handle of the created graphic object.
- in future, the four first arguments will be able to take also the type `mfArray`, in order to display many arrow at a time.

*See also:* `mf/msText`

mf/msText

text display

*Interface:*

```

call msText( x, y, text                                     &
             [, angle] [, just] [, just_vert] [, pix_voffset] &
             [, color] [, bg] [, height] [, clipping] [, xbox, ybox] )

```

*Description:*

Writes the string `text` at the position  $(x, y)$ . These coordinates may be of type `real` or `mfArray`. Many escape codes allow the use of different kinds of fonts, the use of subscript or superscript, greek letters, *etc.* See the *Muesli User's Guide* at section 5.5 for more information.

If the real argument `angle` is present then text is written with this angle (in degrees).

The real argument `just` specifies the justification of the string in comparison with the position ( $-1$  for left (default),  $0$  for centered,  $+1$  for right — other real values ranged from  $-1$  to  $+1$  are permitted, giving intermediate justifications). Similarly, the real `just_vert` argument concerns the vertical justification (default is  $-1$ , *i.e.* the baseline of the glyph located at `y` coordinate, and  $0$  to obtain the topline of the glyph at `y`; use  $-0.5$  for a vertically centered glyph). Concerning only the vertical justification, the optional boolean argument `pix_voffset` can be used (under X11) to move vertically the string box by a 2 pixel shift — this is especially useful when the bottom or the top of the string box is against a drawn line (default is `pix_voffset=.false.`).

If the optional argument `color` is present, it specifies the color of the text displayed (see `msSetGrObj`). Default color is black when the figure background is white (see `msSetBackgroundColor`).

If the optional argument `bg` is present, it specifies the color of the background (see `msSetGrObj`). Default is transparent.

The optional real argument `height` specifies the height of the characters drawn (default is 1). This height may be relative (the default, character size is proportional to the window size) or absolute (character height is in pixels, unity is about 12 pixels), according to the mode defined in the routine `msCharInPixels`.

If the optional boolean argument `clipping` is set to `FALSE`, then `text` can be displayed out of the viewport (default is `TRUE`, *i.e.* the text is clipped at the viewport; this default behavior is recommended when `text` is an annotation at some location inside the viewport and you might want to pan or zoom inside the axes).

The optional output arguments `xbox` and `ybox` allows the user to retrieve the value of the rectangle frame of the string displayed (4 values for both `x` and `y`, because the string may be inclined). These arguments must be real arrays of length 4.

*Remarks:*

- usually, the current routine is used to annotate a graphic, so it should be employed after any use of `mf/msPlot`; on the contrary, the `msHold` routine must be added before the plot command, else all texts from `mf/msText` will be erased.
- the function `mfText` has the same argument list; it returns the (integer) handle of the created graphic object.

See also: `mf/msArrow`, `msSetCharEncoding`

`mfGetAllGrObj`

**get all graphic objects**

*Calling syntaxe:*

```
hdle_vec = mfGetAllGrObj( )
```

*Description:* Returns a vector of handle for all graphic objects in the current window.

The `hdle_vec` variable, declared by the user, must be an integer vector. For an easy programming use, it should be allocatable: due to a feature of modern Fortran, it will be allocate with the appropriate size during the assignment; moreover, there is no need to deallocate it between calls.

*See also:* [mfGetTypeGrObj](#), [msSetGrObj](#)

`mfGetTypeGrObj`

get the type of a graphic object

*Calling syntaxe:*`type = mfGetTypeGrObj( handle )`*Description:* Returns the type of a graphic object, identified by its handle, as a character string.

The type may be one of the followings:

- "line", "point" or "line+point", typically created by `mf/msPlot`;
- "image", created by `mf/msImage`;
- "text", created by `mf/msText`;
- "polygon", created by `mf/msPatch`;
- "pcolor", created by `mf/msPColor`;
- "contour", created by `mf/msContour`;
- "quiver", created by `mf/msQuiver`;
- "streamline", created by `mf/msStreamline` or `mf/msTriStreamline`;
- "arrow" or "arrow\_head\_only", created by `mf/msArrow`;
- "quadr\_bezier", created by `mf/msPlotQuadrBezier`;
- "cubic\_bezier", created by `mf/msPlotCubicBezier` or `mf/msPlotCubicSpline`;
- "histogram", created by `mf/msPlotHist`;
- "errorbar\_x\_line", "errorbar\_y\_line", "errorbar\_xy\_line", "errorbar\_x\_pt", "errorbar\_y\_pt", "errorbar\_xy\_pt", "errorbar\_x\_line+pt", "errorbar\_y\_line+pt" or "errorbar\_xy\_line+pt", created by `mf/msErrorBar`;
- "pcolor\_spy", "pcolor\_spy\_sparse", "pcolor\_spy\_sparse\_2", "plot\_spy\_sparse", created by `mf/msSpy`;
- "legend", created by `mf/msLegend`;
- "tri\_fill", created by `mf/msTriFill`;
- "trimesh\_by\_fac", "trimesh\_by\_tri" or "mesh\_boundary\_unstruct", created by `mf/msTriMesh`;
- "tri\_pcolor", created by `mf/msTriPColor`;
- "tri\_quiver", created by `mf/msTriQuiver`;
- "tri\_contour", created by `mf/msTriContour`;
- "xlabel", created by `mf/msXLabel`;
- "ylabel", created by `mf/msYLabel`;
- "title", created by `mf/msTitle`;
- "set\_clip\_box", created by `msSetClipBox`;
- "remove\_clip\_box", created by `msRemoveClipBox`.

*See also:* `mfGetAllGrObj`, `msSetGrObj`

`mfSelectTypeGrObj`

**select graphic objects by type**

*Calling syntaxe:*

```
hdl_e_vec = mfSelectTypeGrObj( handles, grobj_type )
```

*Description:* Returns a vector of handles for the graphic objects which match the type specified as argument, among a list of input handles.

`handles` must be a integer vector, containing a set of valid graphic object handles.

`grobj_type` is a character string, containing the type of the graphic object, as returned by `mfGetTypeGrObj`.

The `hdl_e_vec` variable, declared by the user, must be an integer vector. For an easy programming use, it should be allocatable: due to a feature of modern Fortran, it will be allocate with the appropriate size during the assignment; moreover, there is no need to deallocate it between calls.

*See also:* `mfGetAllGrObj`, `msSetGrObj`

## msSetGrObj

## graphic object setting

*First interface:*

```
call msSetGrObj( handle, property, data )
```

*Description:* Changes one property of the graphic object identified by its **handle**. This handle may be a scalar or vector **integer**, or even a vector of handles stored in an **mfArray**.

The type of **data** depends on the target **property**, as detailed below.

**property** may take the following values:

- **"visible"**: **data** may be any string, but the object will be displayed only if **data** is **"on"**; an exception occurs if the object is tagged as *Optional Content* for the PDF driver (see **msSetPdfOC**).
- **"linestyle"**: **data** must be a string among **"-"**, **"--"**, **"-."** (or **".-"** as an alias) or **":"** (or **".."** as an alias), for continuous, dashed, dashed-dotted, and dotted, respectively.
- **"linewidth"**: **data** must be of type **real**, positive (default value is 1).
- **"cap\_style"**: **data** must be a string among **"CapButt"**, **"CapRound"** or **"CapProjecting"** (but not case sensitive). Signification of these three keywords may be found easily on the web and concerns all devices (*X11*, *EPS* and *PDF*). Default is **"CapRound"**.
- **"join\_style"**: **data** must be a string among **"JoinMiter"**, **"JoinRound"** or **"JoinBevel"** (but not case sensitive). Signification of these three keywords may be found easily on the web and concerns all devices (*X11*, *EPS* and *PDF*). Default is **"JoinRound"**.
- **"marker"**: **data** may be a single character among **"."**, **"+"**, **"\*"**, **"o"**, **"x"**, **"s"**, **"^"** or **"d"** (for Dot, Plus, Asterisk, Circle, X, Square, TriangleUp and Diamond, respectively), or an escaped sequence as **"\M01"** to **"\M26"** for using the complete set of markers, described in Fig. 27 of the *Muesli User's Guide*. Negative codes **"\M-14"** to **"\M-21"** tell Muesli to draw the 8 filled markers with a small white border around them. For a more comprehensive reference, the markers may be also specified by an escaped text sequence, as **"\CircleFilled"** (the character case doesn't matter; it can be adapted for a better reading).
- **"markersize"**: **data** must be of type **real**, positive (default value is 1).
- **"color"**: **data** may be a single character, among **"w"**, **"k"**, **"r"**, **"g"**, **"b"**, **"c"**, **"m"** or **"y"** (for white, black, red, green, blue, cyan, magenta and yellow, respectively), or an escaped sequence of the form **"\Cnn"** (e.g. **"\C01"**, **"\C02"**, ...) for using the corresponding color of the current color scheme (see **msSetColorScheme**).
- **"col\_name"**: **data** may be any string which represents a valid colorname from the [X11 RGB database](#).
- **"col\_rgb"**: **data** must be a vector of type **real** and size 3.
- **"text"**: **data** may be any string.
- **"position"**: **data** must be a string among **"first"**, **"last"**, **"up"** or **"down"**. This affects the position in the stack, *i. e.* the drawing order.
- **"opacity"**: **data** must be of type **real**, ranged from 0.0 (full transparency) to 1.0 (full opacity).
- **"coordinates"**: (for text string) **data** must be of type **real** and size 2.
- **"relat.coords"**: (for a legend frame created by **mfLegend**) **data** must be of type **real** and size 2, and is understood as relative coordinates (left and bottom sides correspond to 0, right and top sides correspond to 1).

⋯/⋯



Changing the coordinates of the points in a polyline needs to change both  $x$  and  $y$  coordinates together by using the *Other interface*:

```
call msSetGrObj( handle, "x", x, "y", y )
```

*Remarks:*

- the user must call the `msRedrawFigure` to see the change effects.
- properties are not all editable for a given graphic object. The following table describes what can be modified for all types of graphic objects.

*See also:* `msSetWinProp`, `msRemoveGrObj`

`msRemoveGrObj`

**graphic object deletion**

*Calling syntax:*

```
call msRemoveGrObj( handle [ , redraw ] )
```

*Description:*

Removes the graphic object in the current figure, specified by its handle.

`handle` may be a scalar integer or a vector of handle; in this latter case, `handle` must be an `mfArray`.

For performance reason, the figure is not redrawn after the removing, except if you specify the value *TRUE* for the optional argument `redraw` (default value is *FALSE*). Therefore, there is no need to make yourself a redraw of the figure (routine `msRedrawFigure`), since it is sufficient to specify `redraw = TRUE` on the last call.

*Remark:* After the `grobj` removing, the handle is set to zero. In the case of an `mfArray`, all elements are set to zero but the `mfArray` itself is not released.

*See also:* `msSetWinProp`, `msSetGrObj`

## 2.5 High level plotting routines - 2D

<a href="#">mf/msPlot</a>	data plot (using straight segments)
<a href="#">mf/msErrorBar</a>	data plot with error bars
<a href="#">mf/msPlotQuadrBezier</a>	data plot (using quadratic curved segments)
<a href="#">mf/msPlotCubicBezier</a>	data plot (using cubic curved segments)
<a href="#">mf/msPlotCubicSpline</a>	data plot (using cubic curved segments)
<a href="#">mf/msBar</a>	bar data plot
<a href="#">mf/msPColor</a>	pseudo-color plot
<a href="#">mf/msContour</a>	data contouring
<a href="#">mf/msContourF</a>	data contouring with filled regions
<a href="#">mf/msQuiver</a>	vector field plot
<a href="#">mf/msStreamline</a>	vector field streamline
<a href="#">mf/msPatch</a>	graphic patch
<a href="#">mf/msPlotHist</a>	data histogram
<a href="#">msCumulHist</a>	cumulative data histogram
<a href="#">msImRead, msImWrite</a>	image read and write
<a href="#">mf/msImage</a>	image display
<a href="#">mf/msPlotPSLG</a>	plot a PSLG domain
<a href="#">mf/msTriMesh</a>	plot a triangulation
<a href="#">mf/msTriPColor</a>	pseudo-color on a triangulation
<a href="#">mf/msTriFill</a>	coloring on a triangulation
<a href="#">mf/msTriContour</a>	data contouring on triangles
<a href="#">mf/msTriContourF</a>	data contouring on triangles with filled regions
<a href="#">mf/msTriQuiver</a>	vector field plot on a triangulation
<a href="#">mf/msTriStreamline</a>	vector field streamline on a triangulation
<a href="#">mf/msSpy</a>	sparsity pattern visualization

*See also:*

[Global graphic settings](#)

[Window's and figure's management](#)

[Figure properties](#)

[Figure annotation – Low level graphic object's manipulation](#)

[Interactive routines](#)

mf/msPlot

data plot (using straight segments)

*Calling syntax:*

```

call msPlot( x [, y]                                     &
             [, linespec] [, color] [, linewidth] [, markersize] &
             [, dashes_inverted] )

```

*Description:*

Plots the vector `mfArray` `y` versus the vector `mfArray` `x`.

If `y` is not present then `x` is plotted against its integer indices. One exception is when `x` is complex: in such a case, `msPlot(x)` is equivalent to `msPlot(real(x), imag(x))`, so the drawing is done in the complex plane.

The optional argument `linespec` is a string which contains a multiple attribute vector (color, linestyle, marker) as in MATLAB. See `msSetGrObj` for further information.

The optional argument `color` may be a character string (one-letter color code, escaped sequence, color-name from the [RGB database](#)) or a vector of type `real` and length 3 containing the RGB components of a color.

The optional argument `linewidth` must be a positive number of type `real` (default is 1). Under *X11* the unit is pixel, therefore specifying a value less than 1 makes no difference; however, in *EPS* and *PDF*, this will lead to very thin lines.

The optional argument `markersize` must be a positive number of type `real`; it is used only for marker symbols. If this argument is not present, then the marker size is automatically chosen to be coherent with the line width value.

The optional argument `dashes_inverted` must be a boolean; it is used only for dashed lines: it shifts the dashes in such a way that two identical dashed lines using different colors are both visible, when this argument is used for the second curve.

This routine, as most of high level ones, first erase the current plot; in order to plot multiple graphics objects on the figure, the `Hold` property must be set to "on" via the `msHold` routine.

Log representation of the data is made by using the `msAxis` routine.

*Remarks:*

- the drawing is always clipped at the viewport.
- the function `mfPlot` has the same argument list; it returns the (integer) handle of the created graphic object.
- when calling many time this routine in the same figure, without providing any color information, there is an automatic color selection, cycling the colors from the current colortable (for more information about colortables – or color schemes – see the *Muesli User's Guide*).
- by default, the axis range presents its minimum on the left and its maximum on the right. To invert the axis, use the `msAxis` routine.

See also: `mf/msBar`, `mf/msPlotQuadrBezier`, `mf/msPlotCubicBezier`, `mf/msPlotCubicSpline`

## mf/msErrorBar

## data plot with error bars

Calling syntax:

```
call msErrorBar( [ x, ] y [ , x_err ] [ , y_err ]           &
                [ , linespec ] [ , color ] [ , linewidth ] [ , markersize ] )
```

Description:

Plots the `mfArray` `y` versus the `mfArray` `x`, using line specification given in `linespec` and adding error bars at each point.

The argument `x` is optional (the `x`-axis will use a vector of sequential integers from 1). `x` and `y` must be vectors (row or col) of same length, not matrices.

The optional argument `linespec` (character string) has exactly the same meaning as in the `msPlot` routines. In particular, when not specified, colors will be recycled from the current colortable (for more information about colortables – or color schemes – see the *Muesli User's Guide*).

The optional arguments `linewidth`, `color` and `markersize` have exactly the same meaning as in the `msPlot` routines.

This routine, as most of high level ones, first erase the current plot; in order to plot multiple graphics objects on the figure, the `Hold` property must be set to "on" via the `msHold` routine.

Remark:

- the drawing is always clipped at the viewport.
- the function `mfErrorBar` has the same argument list; it returns the (integer) handle of the created graphic object.
- currently, axis must be both linear.
- due to the simple implementation and the number of optional arguments, it is required, most of times, to use the name of each argument as keywords (on the contrary, errors will occur at compilation and even at run-time). The examples below show typical calls.

See also: `mf/msPlot`, `msAxis`

Example(s):

For adding error bars only along the `y`-axis, the first call:

```
call msErrorBar( mf([2.00d0,1.50d0,3.00d0,2.50d0]),           &
                mf([0.10d0,0.15d0,0.20d0,0.25d0]) )
```

will give at run-time:

```
(MUESLI msErrorBar:) ERROR: bad optional arg combinaison (see doc) !
```

because the first actual argument is associated to `x` and the second one to `y`.

The second one:

```
call msErrorBar(      mf([2.00d0,1.50d0,3.00d0,2.50d0]),           &
                  y_err=mf([0.10d0,0.15d0,0.20d0,0.25d0]) )
```

will not compile:

```
Compilation Error: Missing actual argument for argument 'y'
```

Only this third call is correct:

```
call msErrorBar( y=mf([2.00d0,1.50d0,3.00d0,2.50d0]),           &
                  y_err=mf([0.10d0,0.15d0,0.20d0,0.25d0]) )
```

**mf/msPlotQuadrBezier**                      **data plot (using quadratic curved segments)**

*Interface:*

```
call msPlotQuadrBezier( x, y                                &
                        [, linespec] [, color] [, linewidth] &
                        [, dashes_inverted] )
```

*Description:*

Draws a quadratic Bézier curve from the control points whose coordinates are given in the **mfArrays** **x** and **y**. The drawn object is a quadratic piecewise polynomial parametric curve. The curve is continuous (but doesn't have necessarily continuous derivatives); therefore, the total number of points in the **x** and **y** **mfArrays** must be of the form:  $2k + 1$ , where  $k$  is the number of segments.

Optional arguments **linespec**, **color**, **linewidth** and **dashes\_inverted** have the same meaning as in the routine **msPlot**.

This routine, as most of high level ones, first erase the current plot; in order to plot multiple graphics objects on the figure, the **Hold** property must be set to "on" via the **msHold** routine.

*Remarks:*

- the drawing is always clipped at the viewport.
- the marker choice, when specified, is discarded.
- the function **mfPlotQuadrBezier** has the same argument list; it returns the (integer) handle of the created graphic object.
- when not specified, colors will be recycled from the current colortable (for more information about colortables – or color schemes – see the *Muesli User's Guide*).

*See also:* **mf/msPlotCubicBezier**, **mf/msPlotCubicSpline**

mf/msPlotCubicBezier

data plot (using cubic curved segments)

*Interface:*

```
call msPlotCubicBezier( x, y                                &
                        [, linespec] [, color] [, linewidth] &
                        [, dashes_inverted] )
```

*Description:*

Draws a cubic Bézier curve from the control points whose coordinates are given in the `mfArrays` `x` and `y`. The drawn object is a cubic piecewise polynomial parametric curve. The curve is continuous (but doesn't have necessarily continuous derivatives); therefore, the total number of points in the `x` and `y` `mfArrays` must be of the form:  $3k + 1$ , where  $k$  is the number of segments.

Optional arguments `linespec`, `color`, `linewidth` and `dashes_inverted` have the same meaning as in the routine `msPlot`.

This routine, as most of high level ones, first erase the current plot; in order to plot multiple graphics objects on the figure, the `Hold` property must be set to "on" via the `msHold` routine.

*Remarks:*

- the drawing is always clipped at the viewport.
- the marker choice, when specified, is discarded.
- the function `mfPlotCubicBezier` has the same argument list; it returns the (integer) handle of the created graphic object.
- when not specified, colors will be recycled from the current colortable (for more information about colortables – or color schemes – see the *Muesli User's Guide*).

See also: `mf/msPlotQuadrBezier`, `mf/msPlotCubicSpline`

mf/msPlotCubicSpline

data plot (using cubic curved segments)

*Interface:*

```

call msPlotCubicSpline( abs_curv, x, y, wx, wy,                                &
                        [, linespec] [, color] [, linewidth]                &
                        [, dashes_inverted] )

```

*Description:*

Draws a cubic Spline curve from given points whose coordinates are given in the `mfArrays` `x` and `y`. The drawn object is a cubic piecewise polynomial curve parametrized by the vector `abs_curv`. It is  $C^2$  continuous at segment boundaries (*i. e.* both the tangent vector and the curvature are continuous). The two vectors `wx` and `wy` must have been computed before the call by use of the routine `mfSpline`.

Optional arguments `linespec`, `color`, `linewidth` and `dashes_inverted` have the same meaning as in the routine `msPlot`.

This routine, as most of high level ones, first erase the current plot; in order to plot multiple graphics objects on the figure, the `Hold` property must be set to "on" via the `msHold` routine.

*Remarks:*

- the drawing is always clipped at the viewport.
- the marker choice, when specified, is discarded.
- the function `mfPlotCubicSpline` has the same argument list; it returns the (integer) handle of the created graphic object.
- when not specified, colors will be recycled from the current colortable (for more information about colortables – or color schemes – see the *Muesli User's Guide*).

See also: `mf/msPlotQuadrBezier`, `mf/msPlotCubicBezier`



## mf/msBar

## bar data plot

*Calling syntax:*

```
call msBar( [ x, ] y                                     &
            [, color] [, width] [, baseline] [, style] )
```

*Description:*

Plots the `mfArray` `y` versus the `mfArray` `x`, using vertical bars. The argument `x` is optional (the `x`-axis will use a vector of sequential integers from 1). When `y` is a vector (row or col) then `x` must have the same shape as `y`; however, when `y` is a matrix (processed by columns), then `x` must be a column vector of same length as that of `y` columns.

The optional argument `color` specifies the color used to fill the bars; the color convention is the same as in the `msPlot` routine. See also `msSetGrObj` for further information. It may have many types and shapes:

- it may be a single character string, containing a one-letter color code or a color name from the [RGB database](#); it may be also a vector of  $N$  character strings,  $N$  being the number of columns of `y`.
- it may be a vector of type `real` with 3 RGB components (describing one color); or a matrix of dimension  $(3, N)$ ,  $N$  being the number of columns of `y`.

The optional argument `"width"` must be a positive number of type `real` ranged in  $[0, 1]$ . It is the relative width of the bars (default is 0.8).

The optional argument `"baseline"` must be a positive number of type `real`. Its role depends on whether the Y-axis is linear or logarithmic:

- in the case of a linear Y-axis, `baseline` is usually equal to zero, in order to separate positive from negative data values. The routine plots a thin line to visualize the baseline.
- in the case of a logarithmic Y-axis, `baseline` is the minimum value for data (default value is 0.01). Negative values, or those which are less than `baseline` are discarded.

The optional argument `style` works only for matrix data. When it is equal to `"grouped"` (default value), *grouped bars* are used; when it is equal to `"stacked"`, *stacked bars* are used.

This routine, as most of high level ones, first erase the current plot; in order to plot multiple graphics objects on the figure, the `Hold` property must be set to `"on"` via the `msHold` routine.

*Remarks:*

- the function `mfBar` has the same argument list; it returns the (integer) handle of the created graphic object.
- only the Y-axis can be of logarithmic type; in this case, of course, all values in `y` must be positive.
- when not specified, colors will be recycled from the current colortable (for more information about colortables – or color schemes – see the *Muesli User's Guide*).

See also: `mf/msPlot`, `msAxis`

mf/msPColor

graphic pseudo-color

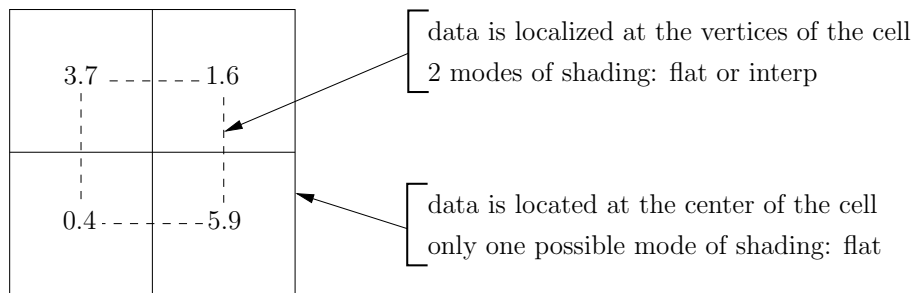
Calling syntax:

```
call msPColor( [ X, Y, ] Z [, data_centering, view] &
               [, grid, grid_color, grid_step] [, lighting] )
```

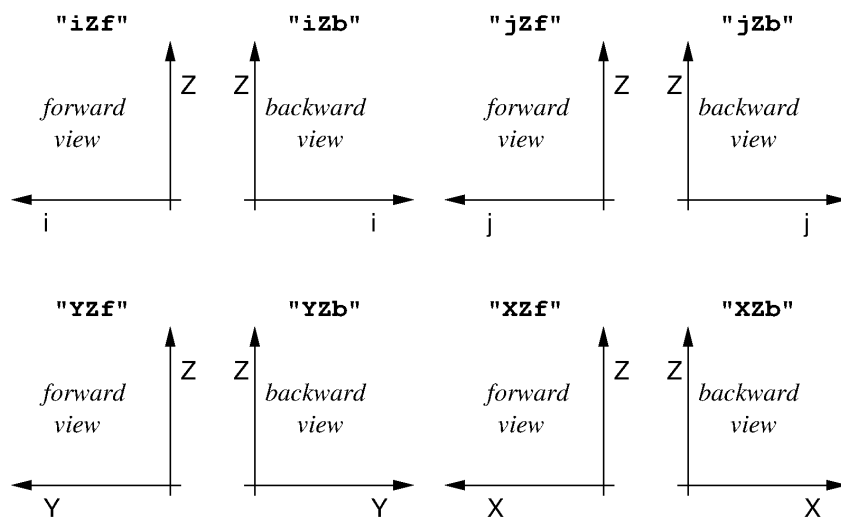
Draws a pseudo color plot of the data contained in the Z mfArray.

The  $(i, j)$  indices are mapped to the axis  $(-Y, X)$ , so data visualisation is coherent with the matrix layout and with other routines working with matrix data ([msContour](#), [msQuiver](#), [msStreamline](#)). If this orientation is not appropriate, use the coordinates (mfArrays X and Y), as described below.

The optional `data_centering` argument specifies how the data stored in the matrix are graphically displayed; it is a string which must be equal to "vertex" (default value —  $(i, j)$  points to the vertex of a cell) or "cell" ( $(i, j)$  points to the center of a cell). In the cell centered model, the shading of the color is only flat, whatever the value specified by the use of [msShading](#). This is summarized in the following figure:



The optional `view` argument is a character string specifying the type of view for displaying the data in the matrix Z: the default view is the usual *top view*, noted "ji" or "XY", according to the presence of the arguments X, Y. When these latter arguments are not present, `view` may be equal to "iZf", "iZb", "jZf" or "jZb", specifying a *side view* as noted by the letters i, j or Z (always the vertical axis); the third letter is a modifier, indicating a *forward* or a *backward* view. In the other case, *i. e.* when the arguments X, Y are presents, the corresponding strings are "YZf", "YZb", "XZf" and "XZb". The different *side views* are summarized below:



Note that, in projection mode, only the default data centering (*i. e.* `data_centering="vertex"`) is accepted.

.../...

A thin line may be drawn to show the boundary of each quadrilateral cell by using the optional argument `grid` equal to `TRUE`. The default is to not show these boundaries. The color of this thin line may be specified in the optional argument `grid_color`, with the same convention as in the `msPlot`, routine; by default, it is the foreground color. The optional argument `grid_step` allows to plot only some lines of the grid, indicating the step to be used along the X or the Y coordinate; it must be a vector of two integers. This is particularly useful when the size of the data is large.

The optional argument `lighting` (boolean variable) changes the use of colors: instead of selecting shades from the Z values, they come from the lighting of the surface. In this case, it is recommended to select the `grey` colormap from the `msColormap` routine. Note also that this option is applicable only when X and Y coordinates are provided.

When arguments X and Y are also provided, then their values are used as coordinates for the data points in Z:

- usually, X and Y are matrices and their shape must be the same as that of the data matrix Z. Use of these coordinates is required when, *e.g.*, you want to swap the indices  $i$  and  $j$ , or apply a transformation (linear or not) between the  $(i, j)$  indices and the  $(x, y)$  coordinates; these coordinate matrices may be created by the `msMeshGrid` routine.
- to economize memory, it is possible to pass only vectors: in this case, X and Y, provided as rank-1 `mfArrays`, must obey to the same constraint as edicted for the generator vectors (see again `msMeshGrid`).

Be aware that X and Y are *not used* to defined the axes of the plot: to do so, you must use the `msAxis` routine with appropriate argument(s).

The color axis may be set explicitly by the user via the `msCAxis` routine; otherwise it will be chosen automatically by the routine itself. In the color axis manual mode, data should be theoretically ranged entirely inside the color axis; on the contrary, the resulting behavior depends on the shading value (cf. `msShading`). When shading is equal to "flat", a quiet behavior is obtained and the colormap overflow can be monitored by use of the `msSetColorOverflowPolicy` routine; when shading is equal to "interp", a warning is emitted by the library because strange colors can be drawn. This latter case should be avoided if possible.

Note that a colormap must have been defined before the call, (via `msColormap`); otherwise, a warning is emitted and strange or unexpected results can occur.

This routine, as most of high level ones, first erase the current plot; in order to plot multiple graphics objects on the figure, the `Hold` property must be set to "on" via the `msHold` routine.

*Remarks:*

- The drawing is always clipped at the viewport.
- The function `mfPColor` has the same argument list; it returns the (integer) handle of the created graphic object.
- For making a pseudo color plot on a triangle (or a triangular patch), use the `msTriPColor` routine.
- NaN values are not (yet) allowed: an error is returned by the routine.

See also: `msPatch`, `msContour`, `msImage`, `msQuiver`

## mf/msContour

## data contouring

Calling syntax:

```
call msContour( [ mfOut(C), X, Y, ] Z                                &
                [, nb_levels, levels, order, linespec, linewidth,   &
                  labels, labelcolor, labelsize ] )
```

Description:

Draws a contour plot of the data contained in the `mfArray` `Z`. The plot is done in the current figure. As opposed as `msPColor` routine, `msContour` accepts only vertex-centered data.

It doesn't fill the regions between the contours with colors; for such a feature, see the `mf/msContourF` routine.

$(i, j)$  indices of `Z` are mapped to the axis  $(-Y, X)$ , so data visualisation is coherent with the matrix layout and with other routines working with matrix data (`msPColor`, `msQuiver`, `msStreamline`). If this orientation is not appropriate, use the coordinates (`mfArrays` `X` and `Y`), as described below.

When arguments `X` and `Y` are also provided, then their values are used as coordinates for the data points in `Z`:

- usually, `X` and `Y` are matrices and their shape must be the same as that of the data matrix `Z`. Use of these coordinates is required when, *e.g.*, you want to swap the indices  $i$  and  $j$ , or apply a transformation (linear or not) between the  $(i, j)$  indices and the  $(x, y)$  coordinates; these coordinate matrices may be created by the `msMeshGrid` routine.
- to economize memory, it is possible to pass only vectors: in this case, `X` and `Y`, provided as rank-1 `mfArrays`, must obey to the same constraint as edicted for the generator vectors (see again `msMeshGrid`).

If the optional `C` `mfArray` is given in front of  $(X, Y)$  coordinate matrices, then it will contain on output a two-row matrix storing the contour lines. Each contiguous drawing segment contains the value of the contour, the number of  $(x, y)$  drawing pairs, and the pairs themselves. The segment are appended end-to-end as

```
C = [ level_1, x_1, x_2, ..., level_2, x_1, x_2, ...;
      pairs_1, y_1, y_2, ..., pairs_2, y_1, y_2, ...]
```

Be aware that these point coordinates must be interpreted in different ways, according the value of `order` (see below).

The optional (integer) argument `nb_levels` specifies the number of contours to be drawned; it cannot be used together with `levels`.

The optional argument `levels`, which must be a rank-1 `mfArray`, is used to specify the level values; it cannot be used together with `nb_levels`.

By default, the number of level curves is equal to 9, and the level values are equally spaced within the *min* and *max* values of the data, or within thoses of the Color Axis if it has been set before (see `msCAxis`); this can be changed by using the optional arguments `nb_levels` and `levels` (see above). A warning is emitted if a level is outside the Color Axis, excepted when the color is prescribed in `linespec`.

By default, the level curves are labelled (use `labels=.false.` to remove the labels) and the contour curves are colored using the current colormap (use a color inside `linespec` to specify the color of all curves). Labels are displayed in the foreground color (*e.g.* black on white) by default; the user may choose another color via the `labelcolor` optional argument. Moreover the label size may be changed by using the optional `labelsize` real argument, which lets the user to specify a percentage of the standard size (default is `labelsize=1.0d0`).

⋯/⋯

The optional argument `order` is an integer (1 or 2) specifying the quality of the approximation of the contour lines. Default is `order = 1`: in this case, segments are straight lines. If `order` is set to 2 then a bilinear interpolation is used inside the cells, and segments are constituted by quadratic Bezier arcs. Note that in all cases, the approximation provides only continuity at the cell boundaries, therefore the tangent lines may appear as broken. Note also that the default case (`order = 1`) is well adapted for most situations; only for situations where you have a small number of cells, or if you want to strongly zoom inside a contour map, you would choose `order = 2`.

Optional arguments `linespec` (character string) and `linewidth` (real value) allow the user to change the appearance of the contour curves. Possible values for these arguments are described in `msSetGrObj`, under the "color", "linestyle" and "linewidth" entries. If a color has been specified, then all contour lines will be drawn with the same color. Be aware, however, that the choice of markers is disabled.

Note that a colormap (see `msColormap`) must have been defined before the call if a specific color is not present in `linespec`; otherwise, a warning is emitted and strange or unexpected results can occur.

This routine, as most of high level ones, first erase the current plot; in order to plot multiple graphics objects on the figure, the `Hold` property must be set to "on" via the `msHold` routine.

*Remarks:*

- The drawing is always clipped at the viewport.
- The function `mfContour` has the same argument list; it returns the (integer) handle of the created graphic object.
- For making contours on a triangle (or a triangular patch), use the `msTriContour` routine.
- NaN values are not (yet) allowed: an error is returned by the routine.

*See also:* `mf/msContourF`, `mf/msImage`, `mf/msQuiver`

mf/msContourF

data contouring with filled regions

*Calling syntax:*

```
call msContourF( [ mfOut(C), X, Y,] Z           &
                 [, nb_levels, levels, linewidth, &
                 labels, labelcolor, labelsize ] )
```

*Description:*

Similar to the `msContour` routine, except that the regions between the contours are filled with appropriate colors.

The whole region whose values are greater than the level is filled with the corresponding color. As a consequence, the region less than all specified levels is left in white. To avoid white regions, it is sufficient to add a level less than or equal the smaller value in the Z array.

Be aware however that some arguments of `msContour` are not available here.

*See also:* `mf/msTriContourF`

mf/msQuiver

vector field plot

*Calling syntax:*

```
call msQuiver( [ X, Y,] u, v                                &
               [, data_centering] [, color] [, arrow_length] [, step]    &
               [, linewidth] [, arrow_head] )
```

Draws the vector field whose 2D components are stored in the `u` and `v` `mfArrays`, located at position `(X,Y)` or whows location is deduced from the layout of `u` and `v` when `X` and `Y` are not present. The plot is done in the current figure.

$(i, j)$  indices are mapped to the axis  $(-Y, X)$ , so data visualisation is coherent with the matrix layout and with other routines working with matrix data (`msContour`, `msPColor`, `msStreamline`). If this orientation is not appropriate, use the coordinates (`mfArrays X` and `Y`), as described below.

When arguments `X` and `Y` are also provided, then their values are used as coordinates for the data points in `u` and `v`:

- usually, `X` and `Y` are matrices and their shape must be the same as those of the data matrices `u` and `v`. Use of these coordinates is required when, *e.g.*, you want to swap the indices  $i$  and  $j$ , or apply a transformation (linear or not) between the  $(i, j)$  indices and the  $(x, y)$  coordinates; these coordinate matrices may be created by the `msMeshGrid` routine.
- to economize memory, it is possible to pass only vectors: in this case, `X` and `Y`, provided as rank-1 `mfArrays`, must obey to the same constraint as edicted for the generator vectors (see again `msMeshGrid`).

Be aware that `X` and `Y` are *not used* to defined the axes of the plot: to do so, you must use the `msAxis` routine with appropriate argument(s).

`u` and `v` must be rank-2 (*i.e.* matrices) `mfArrays` of same shape. They represent respectively the  $X$  and  $Y$  components of the vector field to be drawn. If the orientation or the scaling is not appropriate, use the second form of call described below, by adding coordinates.

The optional `data_centering` argument specifies how the data are stored in the matrix; it is a string which must be equal to `"vertex"` (default value) or `"cell"`.

The optional `color` argument specifies the color used for drawing the arrows: it is a one-letter color symbol or an escaped sequence, as described in the `msSetGrObj` routine.

The optional `arrow_length` argument (real) specifies the maximum length of the arrow field as a multiplicative factor applied to the mesh size; by default its value is 1 so that each arrow is inside the rectangular cell where its center is located. A value much less that 1 is useless, whereas a big value is not recommended.

The optional `step` argument (integer) the step in the loops over the  $(i, j)$  indices to display the arrow; the default value is 1. It is useful to avoid a too big number of arrows for high resolution meshes.

The optional `linewidth` argument (real) specifies the line width, as a relative factor; by default its value is 1. The line width is constant and is the same for all arrows, whatever their length is.

The optional `arrow_head` argument (real) specifies the size of the arrow head, based on the character height; by default its value is 1.

This routine, as most of high level ones, first erase the current plot; in order to plot multiple graphics objects on the figure, the `Hold` property must be set to `"on"` via the `msHold` routine.

.../...

*Remarks:*

- The drawing is always clipped at the viewport.
- An arrow is not drawn if any component of the corresponding vector ( $u$ ,  $v$ ) is equal to  $NaN$ .
- The function `mfQuiver` has the same argument list; it returns the (integer) handle of the created graphic object.
- For drawing a 2D vector field on a triangular mesh, use the `msTriQuiver` routine.
- When specifying a color, the routine `msColormap` should be used before for definition of the colormap.

*See also:* `mf/msContour`, `mf/msPColor`



## mf/msStreamline

## vector field streamline

Calling syntax:

```
call msStreamline( [ X, Y,] u, v, start [, direction, n_arrow]           &
                  [, color] [, linewidth] [, arrow_head] [, npt_max]   &
                  [, curv_tol] )
```

Based on a velocity vector field whose  $x$ - and  $y$ -components are respectively  $u$  and  $v$  (`mfArrays`), draws streamlines in the current figure. There is no restriction about the velocity field: it may have a non-zero divergence, or a non-zero curl.

The streamlines are specified by the 2D-point coordinates stored in the `start` `mfArray`, which may have any number of lines, but exactly two columns. The integration always begins at the starting point, in two possible direction: forward and/or backward (see below the explanation about the `direction` optional argument). Usually, the end-points of a streamline are located at the boundary of the domain, but in some rare cases (velocity field having a non zero divergence) they can end inside the domain, at a stationary point.

$(i, j)$  indices are mapped to the axis  $(-Y, X)$ , so data visualisation is coherent with the matrix layout and with other routines working with matrix data (`msContour`, `msPColor`, `msQuiver`). If this orientation is not appropriate, use the coordinates (`mfArrays`  $X$  and  $Y$ ), as described below.

When arguments  $X$  and  $Y$  are also provided, then their values are used as coordinates for the data points in  $u$  and  $v$ :

- usually,  $X$  and  $Y$  are matrices and their shape must be the same as those of the data matrices  $u$  and  $v$ . Use of these coordinates is required when, *e.g.*, you want to swap the indices  $i$  and  $j$ , or apply a transformation (linear or not) between the  $(i, j)$  indices and the  $(x, y)$  coordinates; these coordinate matrices may be created by the `msMeshGrid` routine.
- to economize memory, it is possible to pass only vectors: in this case,  $X$  and  $Y$ , provided as rank-1 `mfArrays`, must obey to the same constraint as edicted for the generator vectors (see again `msMeshGrid`).

Be aware that  $X$  and  $Y$  are *not used* to defined the axes of the plot: to do so, you must use the `msAxis` routine with appropriate argument(s).

$u$  and  $v$  must be rank-2 (*i.e.* matrices) `mfArrays` of same shape. They represent respectively the  $X$  and  $Y$  components of the vector field to be drawn. If the orientation or the scaling is not appropriate, use the second form of call described below, by adding coordinates.

The optional argument `direction` (character string) specifies whether the integration must be done following the flow direction ("`forward`"), against the flow direction ("`backward`") or in both direction ("`both`"); this latter case is the default.

The optional `n_arrow` argument specifies the number of arrow heads to be drawn at equally curvilinear abscissa along each streamline. It must be an integer greater or equal one (default value is 3).

The optional `color` argument specifies the color used for drawing the streamlines; it has the same meaning as in the routine `msPlot`.

The optional `linewidth` argument (real) specifies the line width, as a relative factor; by default its value is 1.

The optional `arrow_head` argument (real) specifies the size of the arrow head; by default its value is 1.

⋯/⋯

The optional `npt_max` is the maximum number of points for each half-streamline (indeed, you can ask for a forward integration, a backward one or both – see above); its default value is 1000.

The optional `curv_tol` argument concerns the integration process and more specifically the tolerance for high curvature detection; it is relative to the mesh size; its default value is 0.5.

This routine, as most of high level ones, first erase the current plot; in order to plot multiple graphics objects on the figure, the `Hold` property must be set to "on" via the `msHold` routine.

*Remarks:*

- The drawing is always clipped at the viewport.
- The function `mfStreamline` has the same argument list; it returns the vector of the (integer) handles of the created graphic objects. Be aware that even for a single streamline, the returned handle is a vector (of size 1).
- For drawing 2D streamlines on a triangular mesh, use the `msTriStreamline` routine.
- NaN values are not allowed: an error is returned by the routine.

*See also:* `mf/msQuiver`

mf/msPatch

graphic patch

*First interface:*

```
call msPatch( x, y, c [, opacity] [, grid, grid_color] )
```

*Description:*

This routine draws one colored polygonal shape from the `mfArrays` `x`, `y` and `c`. These vectors contain respectively the coordinates of each vertex and the attached color. The polygonal shape doesn't need to be closed, *e.g.* a triangle may be defined only using three points.

The drawing is clipped at the viewport.

Before use, the color axis must be explicitly set by the user via the `msCAxis` routine. Theoretically, data should be ranged entirely inside the color axis; on the contrary, the resulting behavior depends on the shading value (cf. `msShading`). When shading is equal to "flat", a quiet behavior is obtained and the colormap overflow can be monitored by use of the `msSetColorOverflowPolicy` routine; when shading is equal to "interp", a warning is emitted by the library because strange colors can be drawn. This latter case should be avoided if possible.

If the optional argument `opacity` is present, transparency can be used: `opacity` must be a real number between 0 (full transparency, invisible object) and 1 (full opacity).

A thin line may be drawn to show the boundary of the polygonal cell by using the optional argument `grid` equal to `TRUE`. The default is to not show the boundary. The color of this thin line may be specified in the optional argument `grid_color`; by default, it is the foreground color.

A colormap must have been defined before the call, (via `msColormap`); otherwise, a warning is emitted and strange or unexpected results can occur.

*Second interface:*

```
call msPatch( x, y [, color] [, opacity] [, grid, grid_color] [, clipping] )
```

*Description:*

This second form fills the shape with a flat color (if specified), avoiding the use of an array for specifying the color. The `color` argument has the same meaning as in the routine `msPlot`.

`grid` and `grid_color` are described above for the first interface.

The optional argument `clipping` is a boolean (default value is `TRUE`). When set to `FALSE`, it allows the drawing of a polygonal colored shape (only using flat color) outside the viewport. This facility is especially useful when the user wants to update a text string outside the viewport: due to the use of antialiased text drawing, he must erase before the ancient text with a rectangular patch of appropriate color.

*Remarks:*

- the function `mfPatch` has the same argument list; it returns the (integer) handle of the created graphic object.
- this routine, as most of high level ones, first erase the current plot; in order to plot multiple graphics objects of the figure, the `Hold` property must be set to "on" via the `msHold` routine.

See also: `mf/msPColor`

mf/msPlotHist

data histogram

*Calling syntax:*

```
handle = mfPlotHist( x, x_min, x_max, n_bin           &
                    [, color] [, filled] )
```

returns the (integer) handle of the newly created graphic object.

The vector `mfArray` `x` contains the data. The histogram is computed for data ranged from `x_min` to `x_max` using a number of bins equal to `n_bin`.

If present, `color` specifies the color for the bar plot. It may be a character string containing the usual color code (see `msPlot`), a real triplet containing the RGB values or a string containing a color name from the [RGB database](#). If the color is left unspecified, then it is taken from the current colortable (for more information about colortables – or color schemes – see the *Muesli User's Guide*).

If present, the logical argument `filled` specifies that bars are filled with the color used (default is FALSE).

The subroutine form:

```
call msPlotHist( mfOut( num [, x_bin] ), x, x_min, x_max, n_bin   &
                 [, color] [, filled] )
```

allows the user to keep some internal data.

The optional arguments `color` (& Co.) and `filled` have the same meaning as above.

The output `mfArray` `num` is the vector of the bins values.

If present, the `mfArray` `x_bin` is the vector containing the abscissas of the bins.

*Remarks:*

- The drawing is always clipped at the viewport.
- This routine, as most of high level ones, first erase the current plot; in order to plot multiple graphics objects on the figure, the `Hold` property must be set to "on" via the `msHold` routine.
- This routine may be called many times in the same figure with different data: histograms will be superposed one above the other, showing cumulative statistics. When not specified, colors will be recycled from the current colortable. Note that if your data is stored inside a two-dimensional array, then it may be easier to call the `msCumulHist` routine instead.

See also: `msHist`, `mfOut`

**msCumulHist****cumulative data histogram***Interface:*

```
subroutine msCumulHist( X, x_min, x_max, n_bin, x_nb )

    type(mfArray), intent(in) :: X
    real(kind=MF_DOUBLE), intent(in) :: x_min, x_max
    integer, intent(in) :: n_bin
    type(mfArray), optional :: x_nb
```

*Description:*

Cumulative Histogram. Works on columns of the mfArray X.

If X has NCOL columns, draws first an histogram (via `msHist`) from the data of all columns, then draw a second histogram from the data of the NCOL-1 first columns, and so on. Each histogram is drawn in a different color, via the colors of the current colortable (for more information about colortables – or color schemes – see the *Muesli User's Guide*); if NCOL is greater than the maximum, following colors are cycled in the same set.

Columns of X may have been initialized from data which contain different number of element. In such a case, the optional argument `x_nb` is a vector which contains the useful number of elements in each column.

*Remarks:*

- The drawing is always clipped at the viewport.
- This routine, as most of high level ones, first erase the current plot; in order to plot multiple graphics objects on the figure, the `Hold` property must be set to "on" via the `msHold` routine.

*See also:* `msHist`, `mf/msPlotHist`

**msImRead****image read***Interface:*

```
call msImRead( mfOut(A,cmap), filename [, fmt, indexed] )
```

*Description:*

Reads the image file `filename`: the colormap is extracted from the image and stored in the `mfArray` `cmap` and the pixels values are stored in the `mfArray` `A`.

The image can be displayed by using first `msColormap` and then `msImage`.

The optional argument `fmt`, if present, is a string which must contain the image format. Common accepted values for `fmt` are: "TIFF", "JPEG", "PNG", "XPM", ... . Actually, in the current version of MUESLI (but this should change in future), the file `image` is always converted in the XPM format via the 'convert' command of 'ImageMagick'. So, a great number of image formats is supported and, moreover, the argument `fmt` is not yet used for reading.

There are two options to fill the `mfArray` `A`, *i. e.* to give numerical values to pixels (the optional logical argument `indexed` is by default false):

1. **real valued pixels** – each pixel of the array contains a numerical real value (ranged in [0.,1.]), and a linear mapping is used between the whole range of these values and the index range of the colormap. This first way is rather oriented to the numerical processing of the pixels value, and is well adapted to image obtained via the pseudo colors from any numerical matrix. For example, you may apply some filters or compute the gradient of the pixels values and you can visualize the image in different ways by changing the colormap, which is always a continuum of colors.
2. **indexed pixels** – each pixel of the array contains the index of the colormap. This second way is more adapted to digital photos, or to color bitmaps which contain transparency (as for some PNG images – see below). You should not modify the whole colormap, else you may obtain some strange results when you visualize the image. In contrast, you can easily remove or add some colors in the colormap.

*Remarks about transparent pixels:*

If the original image contains transparent pixels ("NONE" color in an XPM file, or transparency in PNG files), then it cannot be opened using the default indexing scheme: the current routine will give an error. You can open it only via the "indexed pixels" scheme. Moreover, these transparent pixels will be colored in medium gray by the `msImage` routine.

*Limitations:*

Currently, these limitations are linked to the XPM format:

- original XPM images having more than two characters per color are not supported (to check yourself, open the XPM file with any text editor: the fourth integer number of the third line must be equal to 1 or 2). Moreover, they must have less than 8281 colors.
- for original XPM images, they must have maximum 12000 pixels in width if colors are stored in one char (*i. e.* when the number of colors is small, less than 91), or 6000 pixels in width if colors are stored in two chars (*i. e.* when the number of colors is greater than 91).
- for images converted in XPM by the 'convert' tool of 'ImageMagick', the number of colors is always less than 256. So, the quality of true-color images is pretty degraded and, at least up to the version 6.9.3 of 'ImageMagick', the picture is darker.

.../...

*Other interface:*

```
call msImRead( mfOut(infos), filename [, fmt], only_infos=.true. )
```

allows the user to obtain some information about the image (currently, only the width and the height in pixels unit), which are returned in the `mfArray` `infos`.

*See also:* [msImWrite](#), [mfOut](#)

**msImWrite****image write***Interface:*

```
call msImWrite( A, cmap, filename [, fmt, indexed] )
```

*Description:*

Writes the `mfArray` `A` to the image file `filename`, using the colormap `cmap`.

The optional argument `fmt`, if present, is a string which must contain the image format. Common accepted values for `fmt` are: "TIFF", "JPEG", "PNG", "XPM", ... . Actually, in the current version of MUESLI (but this should change in future), the file `image` is always converted in the XPM format via the 'convert' command of 'ImageMagick'. So, a great number of image formats is supported.

The optional logical argument `indexed` (its default value is false) has the same meaning as those explained in the `msImRead` routine. It concerns obviously the `mfArray` `A`, not the image stored in the image file `filename`.

*Remarks about transparency:*

- if the `mfArray` `image` contains transparent pixels, consider using an appropriate image format (XPM or PNG) which supports this transparency.
- transparency can be set in your image by two ways:
  1. for the indexed pixels indexing scheme, set a color (in `cmap`) to the triplet (`NaN`, `NaN`, `NaN`).
  2. for the real valued pixels indexing scheme, set an element of the image `mfArray` `A` to `NaN`.

*Limitations:*

- XPM images must have less than 8281 colors in their colormap.
- XPM images must have maximum 12000 pixels in width if colors are stored in one char (*i. e.* when the number of colors is small, less than 91), or 6000 pixels in width if colors are stored in two chars (*i. e.* when the number of colors is greater than 91).

See also: `msImRead`, `mf/msImage`



mf/msImage

image display

*Interface:*

```
call msImage( image [, angle] [, flip] [, indexed] )
```

*Description:*

Displays in the current figure the `mfArray` `image`, associated with the appropriate colormap previously set by `msColormap`.

$(i, j)$  indices of the `image` are mapped to the axis  $(-Y, X)$ , so data visualisation is coherent with `Contour` and `PColor`.

The optional real argument `angle` is used to define the orientation in degrees of the image (default is 0 degree, acceptable values are any multiple of 90: 90, 180, 270, but also negative values such as  $-90$ ).

The optional argument `flip` is a string can take the following values: "NONE", "HORIZ" (or mirror, left/right swap), "VERT" (or upside/downside swap); default value is "NONE".

The optional logical argument `indexed` (its default value is `FALSE`) has the same meaning as those explained in the `msImRead` routine. It tells the current routine that the `image` `mfArray` contains integer indices of colors and not real values.

This routine, as most of high level ones, first erase the current plot; in order to plot multiple graphics objects on the figure, the `Hold` property must be set to "on" via the `msHold` routine.

*Remarks:*

- The drawing is always clipped at the viewport.
- The function `mfImage` has the same argument list; it returns the (integer) handle of the created graphic object.

*See also:* `mf/msContour`, `mf/msPColor`

mf/msPlotPSLG

plot a PSLG domain

*Description:*

This routine plots a PSLG domain and, optionally, shows the numbering of nodes, edges and holes.

*Calling syntax:*

```
call msPlotPSLG( PSLG_domain [, color] [, linewidth]           &  
                [, nod_num] [, edg_num] [, hol_num] )
```

PSLG\_domain, of type **mfPSLG**, represents the 2D domain definition. It must be built by the user.

The optional **color** argument specifies the color used for drawing the cells: it may be a character string or a vector of type **real** and length 3 (see **mf/msPlot** ).

The optional **linewidth** argument (real) specifies the line width, as a relative factor; by default its value is 1.

The three last optional arguments **nod\_num**, **edg\_num** and **hol\_num**, all booleans, are used to display respectively nodes', edges' and holes' numbering of the PSLG. By default, numbering is not displayed.

Be aware that only nodes involved in segments are drawn; unused nodes are therefore ignored. To see all registered nodes, use **msPrintPSLG**.

*Remarks:*

- The drawing is always clipped at the viewport.
- This routine, as most of high level ones, first erase the current plot; in order to plot multiple graphics objects on the figure, the **Hold** property must be set to "on" via the **msHold** routine.
- The function **mfPlotPSLG** has the same argument list; it returns the (integer) handle of the created graphic object.

mf/msTriMesh

plot a triangulation

*Description:*

This routine plots a triangular mesh and, optionally, shows the numbering of triangles, nodes and faces.

*First calling syntax:*

```
call msTriMesh( x, y, tri [, color] [, linewidth] [, height]           &
                [, tri_num] [, nod_num] [, boundary_only] )
```

The `mfArrays` `x` and `y` are vectors of same length which describe the position  $(x, y)$  of the nodes. The `mfArray` `tri` contains the triangulation (*i.e.* the triangles' indices, as returned by, *e.g.*, the routine `mfDelaunay`).

The optional `color` argument specifies the color used for drawing the cells: it has the same meaning as in other plotting routine involving colors (see the `msSetGrObj` routine).

The optional `linewidth` argument (real) specifies the line width, as a relative factor; by default its value is 1.

The optional `height` argument (real) specifies, for the numbering of triangles, nodes and faces, the character height, as a relative factor; by default its value is 1.

The two last optional arguments `tri_num` and `nod_num`, both booleans, are used to display triangles' and nodes' numbering of the triangular mesh. By default, numbering is not displayed.

When the optional boolean argument `boundary_only` is used with the value `TRUE` then only the boundary of the mesh is drawn. In this case, the triangles' numbers are never displayed, whatever the optional argument `tri_num` is.

*Second calling syntax:*

```
call msTriMesh( tri_connect, ... [, fac_num] )
```

The first argument is `tri_connect` of type `mfTriConnect`, the mesh connectivity (see `msBuildTriConnect`); it replaces the three first `mfArrays` in the first calling syntax.

Same optional arguments as in the first calling syntax may be added. Note however that an additional optional argument is possible in this second case: the boolean `fac_num` concerns the numbering of the triangle faces.

This second use of `msTriMesh` uses a fast algorithm to draw the mesh; the printed files (both EPS and PDF) are also smaller in size.

*Remarks:*

- The drawing is always clipped at the viewport.
- This routine, as most of high level ones, first erase the current plot; in order to plot multiple graphics objects on the figure, the `Hold` property must be set to "on" via the `msHold` routine.
- The function `mfTriMesh` has the same argument list; it returns the (integer) handle of the created graphic object.

See also: `msPrintTriConnect`

mf/msTriPColor

pseudo-color on a triangulation

*Calling syntax:*

```
call msTriPColor( x, y, z, tri )
```

*Description:*

This routine is equivalent to the routine `msPColor`, but for data which are spread on a triangulation.

The `mfArrays` `x`, `y` and `z` are vectors of same length which describes position  $(x,y)$  of the vertices and the corresponding function value.

The `mfArray` `tri` contains the triangulation (*i. e.* the triangle's indices, as returned by, *e. g.* the routine `mfDelaunay`).

*Remarks:*

- The drawing is always clipped at the viewport.
- Use `msTriMesh` to show the grid or the boundary of the triangular mesh.
- The function `mfTriPColor` has the same argument list; it returns the (integer) handle of the created graphic object.
- This routine, as most of high level ones, first erase the current plot; in order to plot multiple graphics objects on the figure, the `Hold` property must be set to "on" via the `msHold` routine.
- NaN values are not (yet) allowed: an error is returned by the routine.

*See also:* `mf/msTriContour`, `mf/msTriFill`, `msPatch`

**mf/msTriFill****coloring on a triangulation***Calling syntax:*

```
call msTriFill( x, y, val, tri )
```

*Description:*

This routine is equivalent to the routine **msPatch** (when using flat colors), but for data which are spread on a triangulation.

The **mfArrays** **x** and **y** are vectors of same length which describes position  $(x, y)$  of the nodes.

The value to be colored is stored inside the vector **mfArray** **val**. This latter vector must have a length equal to the number of triangles. The **mfArray** **val** may contain *NaN* values: in such a case the corresponding triangles are not drawn.

The **mfArray** **tri** contains the triangulation (*i.e.* the triangle's indices, as returned by, *e.g.* the routine **mfDelaunay**).

*Remarks:*

- The drawing is always clipped at the viewport.
- Use **msTriMesh** to show the grid or the boundary of the triangular mesh.
- The function **mfTriFill** has the same argument list; it returns the (integer) handle of the created graphic object.
- This routine, as most of high level ones, first erase the current plot; in order to plot multiple graphics objects on the figure, the **Hold** property must be set to "on" via the **msHold** routine.

*See also:* **mf/msTriContour**, **mf/msTriPColor**

## mf/msTriContour

## data contouring on a triangulation

*Description:*

This routine is equivalent to the routine `msContour`, but for data which are spread on a triangular grid. It doesn't fill the regions between the contours with colors; for such a feature, see the `mf/msTriContourF` routine.

*First calling syntax:*

```
call msTriContour( [ mfOut(C),] X, Y, Z, tri           &
                  [, nb_levels, levels, linespec, linewidth, &
                    labels, labelcolor, labelsize ] )
```

The `mfArrays` `X`, `Y` and `Z` are vectors of same length which describes position  $(x, y)$  of the nodes and the corresponding function value  $z$ .

The `mfArray` `tri` is the triangulation (*e.g.* returned by the routine `mfDeLaunay`).

If the optional `C` `mfArray` is given in front of  $(X, Y)$  coordinate matrices, then it will contain on output a two-row matrix storing the contour lines. Each contiguous drawing segment contains the value of the contour, the number of  $(x, y)$  drawing pairs, and the pairs themselves. The segment are appended end-to-end as

```
C = [ level_1, x_1, x_2, ..., level_2, x_1, x_2, ...;
      pairs_1, y_1, y_2, ..., pairs_2, y_1, y_2, ...]
```

By default, the number of level curves is equal to 9, and the level values are equally spaced within the *min* and *max* values of the Color Axis (see `msCAxis`); this can be changed by using the optional arguments `nb_levels` and `levels` (see below).

The optional (integer) argument `nb_levels` specifies the number of contours to be drawned; it cannot be used together with `levels`.

The optional argument `levels`, which must be a rank-1 `mfArray`, is used to specify the level values.

The optional arguments `linespec` (character string) and `linewidth` allow the user to change the appearance of the contour curves. The possible values for these arguments are described in `msSetGrObj`, under the "color", "linestyle" and "linewidth" entries.

By default, the level curves are labelled (use `labels=.false.` to remove the labels) and the contour curves are colored using the current colormap (use a color inside `linespec` to specify the color of all curves). Labels are displayed in the foreground color (*e.g.* black on white) by default; the user may choose another color via the `labelcolor` optional argument. Moreover the label size may be changed by using the optional `labelsize` real argument, which lets the user to specify a percentage of the standard size (default is `labelsize=1.0d0`).

*Second calling syntax:*

```
call msTriContour( [ mfOut(C),] Z, tri_connect, [ ... ] )
```

Here, `tri_connect` (of type `mfTriConnect`) is the mesh connectivity (see `msBuildTriConnect`); it replaces the three `mfArrays` `X`, `Y` and `tri` in the first calling syntax. The other optional arguments are the same.

⋯/⋯

*Remarks:*

- The triangular mesh used doesn't need to be convex, and may also have holes. See `mfPSLG` to create triangulation with holes.
- The drawing is always clipped at the viewport.
- Use `msTriMesh` to show the grid or the boundary of the triangular mesh.
- The function `mfTriContour` has the same argument list; it returns the (integer) handle of the created graphic object.
- This routine, as most of high level ones, first erase the current plot; in order to plot multiple graphics objects on the figure, the `Hold` property must be set to "on" via the `msHold` routine.
- *NaN* values are allowed: all triangles involved by these special non finite values are simply ignored.

*See also:* `mf/msContourF`, `mf/msTriPColor`, `mf/msTriFill`

**mf/msTriContourF** data contouring on triangles with filled regions

*First calling syntax:*

```
call msTriContourF( [ mfOut(C), ] X, Y, Z, tri           &
                   [ , nb_levels, levels, linewidth,   &
                     labels, labelcolor, labelsize ] )
```

*Second calling syntax:*

```
call msTriContourF( [ mfOut(C), ] Z, tri_connect, [ ... ] )
```

*Description:*

Similar to the **msTriContour** routine, except that the regions between the contours are filled with appropriate colors.

The whole region whose values are greater than a specified level is filled with the corresponding color. As a consequence, the region less than all specified levels is left in white. To avoid white regions, it is sufficient to add a level less than (or equal to) the smaller value in the Z array.

Be aware however that some arguments of **msTriContour** are not available here.

Lastly, be warned that the function version (*i. e.* **mfTriContourF**) returns a vector of handle(s), even if the number of handles is one. Indeed, under some circumstances, the whole triangular mesh may be splitted in many independant zones when the number of NaN values is great enough.

*See also:* **mf/msContourF**



mf/msTriQuiver

vector field plot on a triangulation

*Calling syntax:*

```
call msTriQuiver( x, y, u, v                                     &
                  [, color ] [, arrow_length ] [, arrow_head ] )
```

This routine is equivalent to the routine `msQuiver`, but for data which are spread on a triangulation.

`x`, `y`, `u` and `v` must be rank-1 (*i. e.* vectors) `mfArrays` having the same number of rows. They represent respectively the  $X$  and  $Y$  coordinates of the points where the components  $(u, v)$  of the vector field have to be drawn.

The optional `color` argument specifies the color used for drawing the arrows: it is a one-letter color symbol or an escaped sequence, as described in the `msSetGrObj` routine.

The optional `arrow_length` argument (real) specifies the length of the arrow as a multiplicative factor; by default its value is 1 so that the biggest arrow has approximately a length equal to 1/10th the full axis range.

The optional `arrow_head` argument (real) specifies the size of the arrow head; by default its value is 1.

*Remarks:*

- The drawing is always clipped at the viewport.
- An arrow is not drawn if any component of the corresponding vector  $(u, v)$  is equal to `NaN`.
- The function `mfTriQuiver` has the same argument list; it returns the (integer) handle of the created graphic object.
- This routine, as most of high level ones, first erase the current plot; in order to plot multiple graphics objects on the figure, the `Hold` property must be set to "on" via the `msHold` routine.

*See also:* `mf/msTriPColor`, `mf/msTriStreamline`

mf/msTriStreamline

vector field streamline on a triangulation

*Calling syntax:*

```
call msTriStreamline( x, y, u, v, start [, tri | tri_connect]           &
                    [, direction, n_arrow] [, color]                 &
                    [, linewidth, arrow_head] [, npt_max] [, curv_tol] )
```

This routine is similar to the routine `msStreamline`, but for data which are spread on a triangulation. In particular, the arguments `direction`, `n_arrow`, `color`, `linewidth`, `arrow_head`, `npt_max` and `curv_tol` have exactly the same meanings.

The optional arguments `tri` and `tri_connect` (see `msBuildTriConnect`) describe respectively the triangulation of the mesh and its connectivity. If they are both absent, then the triangulation and its connectivity are done by the routine itself. If the user already knows the connectivity, it is preferable to pass it to the current routine, to avoid a redundant computation. On the other hand, if the user knows only the triangulation, it should pass it as argument, and the current routine will compute only the connectivity.

*Remarks:*

- The drawing is always clipped at the viewport.
- The function `mfTriStreamline` has the same argument list; it returns the vector of the (integer) handles of the created graphic objects. Be aware that even for a single streamline, the returned handle is a vector (of size 1).
- This routine, as most of high level ones, first erase the current plot; in order to plot multiple graphics objects on the figure, the `Hold` property must be set to "on" via the `msHold` routine.
- NaN values are not allowed: an error is returned by the routine.

*See also:* `mf/msTriQuiver`

## mf/msSpy

## sparsity pattern visualization

Calling syntax:

```
call msSpy( A [, symbolspec, bitmap, continuous,           &
            color_scale, show_nnz, nz_threshold ] )
```

draws non-zero elements of the mfArray A (usually sparse).

If the optional argument `symbolspec` (string) is present, it must contain the specification for a symbol and/or a color, as described in `msSetGrObj` at `marker` and `color` entries. By default, a star ("`*`") is used, but note that it is well adapted only for small size matrices: for big matrices, a dot ("`.`") may be preferred.

If the optional argument `continuous` (logical) is present, the matrix A is drawn using a color/grey scale for the absolute value of each element, as in `msPColor`. If you intend to spy a dense matrix, the `continuous` argument must be used. Default value is `.false`.

In the `continuous` case:

- if the optional argument `color_scale` (string) is present, it must be equal to "`lin`" or "`log`". The latter case specifies the use of a logarithmic color/grey scale in the mapping between the value of the matrix elements and the color/grey index (default mapping is linear);
- if the optional argument `nz_threshold` (real) is present, it specifies the threshold value under which an element is considered as zero and, thus, not displayed. The default value is zero for the linear scale and  $\max(|A_{i,j}|) \times \epsilon$  for the logarithmic scale. The threshold for small values is used for defining the color map range.  
By setting `nz_threshold` to the special value `-1`, the threshold will be set to the minimum value of the elements of  $|A|$ .

If the optional argument `show_nnz` (logical) is present, the effective number of non-zero element is shown in the X-label. It's default value is '`.true.`'.

If the optional argument `bitmap` (character string) is present, it must contains the bitmap size (in pixels) which will be used for printing. The string reads under the form "`WIDTHxHEIGHT`" (e.g. "`3000x3000`"). This option is useful only for large, sparse matrices.

Remarks:

- The drawing is always clipped at the viewport.
- The function `mfSpy` has the same argument list; it returns the (integer) handle of the created graphic object.
- The `continuous` and `symbolspec` options are exclusive.
- The grey scale mentionned above is the default colormap when none was selected by the user. Please use the `msColormap` routine to select another one, prior to the `msSpy` call.

## 2.6 Interactive routines

*Caution:* the routines available in this chapter require the selection of the *X11* driver (which is usually selected by default). In batch mode, where the user selects the *NULL* driver (see [msSetX11Device](#)), these routines will not be available, and an error will occur if the user tries to call any of them.

A figure must be also opened (see [mf/msFigure](#)).

If you have multiple workspaces, switching from one workspace to another may breaks the interaction of the mouse with your Muesli program; therefore, it is recommended to stay in the same workspace during all the duration of the interactive process.

Some routines ([msPan](#), [msZoom](#) and [msPanAndZoom](#)) accept the use of an additional keyboard key (usually the CTRL one) to modify the action. In such a case, it is required that the figure's window have the focus; on the contrary, the use of the key do nothing.

<a href="#">mfGinput</a> , <a href="#">msGinput</a>	graphic input
<a href="#">mfGinputCustom</a>	graphic input using custom cursors with alternative
<a href="#">mfGinputRect</a>	rectangular graphic selection
<a href="#">mfGetModKeys</a>	modifier keys state
<a href="#">msPan</a>	manual scrolling
<a href="#">msZoom</a>	figure zoom
<a href="#">msPanAndZoom</a>	combine scrolling and zooming
<a href="#">msMoveLegend</a>	adjust legends frame in axes
<a href="#">msMoveGrObj</a>	move graphic object
<a href="#">msAnimation</a>	screen animation mode
<a href="#">msShowNow</a>	screen update during an animation
<a href="#">msCla</a>	clear current axes
<a href="#">msSetGBuffer</a>	graphic buffer policy
<a href="#">msBBuf</a> , <a href="#">msEBuf</a>	begin and end of graphic buffering
<a href="#">msDefineCustomCursors</a>	define custom cursors for use with <a href="#">mfGinputCustom</a>

*See also:*

[Global graphic settings](#)

[Window's and figure's management](#)

[Figure properties](#)

[Figure annotation – Low level graphic object's manipulation](#)

[High level plotting routines](#)

**mfGinput****graphic input***Interface:*

```
function mfGinput( event, key ) result ( out )  
  
    logical, intent(in), optional :: event, key  
    type(mfArray)                :: out
```

*Description:*

This function is an interactive facility to get the pointer coordinates when it is inside the current figure.

Usually, this function is called without the optional `event` and `key` argument (by default, `event` is `TRUE`): the library waits for a mouse click or a key pressed, and the cursor show a cross shape in the current active window.

The returned `mfArray` contains the coordinates  $(x, y)$  of the selected point. The point can be chosen by any mouse button (which can be also emulated via the L, M or R key). Be aware that the current routine implements a two-event procedure and therefore the location returned is that of the pointer for the second event! (*mouse up* in the usual case).

For other key pressed, the routine `mfGinput` terminates and leaves the returned `mfArray` empty.

*Remarks:*

- this routine is usually employed for graphic interaction. If the user doesn't have a mouse, the pointer can be moved via the keyboard's arrows (the `shift key` accelerates the move by a factor of 10); moreover each mouse button can be emulated by using an equivalent sequence (L, M or R followed by any other key).
- see the `msGinput` routine for more features.

When called with the `event` argument equal to `FALSE`, the library doesn't wait for a user event: it returns immediately the pointer coordinates in the `mfArray out`. A third element is added to `out`, indicating whether the pointer is inside the window (value 1) or outside (value 0); the user must use this flag to take any decision in its own program.

Moreover, if the `key` is present and equal to `TRUE`, then a fourth element is returned in `out`: the ASCII code of the key pressed recently.

*See also:* `mfGinputRect`

**msGinput****graphic input**

*Calling syntax:*

```
call msGinput( mfOut( coords, keycode [, color] )           &  
              [, whole_keyboard, rect_size, rect_inside_axes] )
```

*Description:*

This function is an interactive facility to get the pointer position inside the current figure. See [mfGinput](#) for a simpler use.

In case of multiple opened graphic windows, the cursor has a cross shape in the current active one instead of the classical pointer.

The returned `mfArray` `coords` contains the coordinates  $(x, y)$  of the selected point. The point can be chosen either by the mouse (default behavior), or by a key pressed (see below).

The returned `mfArray` `keycode` contains an equivalent code for the event detected:

- If the optional argument `whole_keyboard` is *FALSE* (default behavior), then `keycode` contains the button number (left=1, middle=2, right=3), even if the equivalent keys (L, M or R) have been used; Note that `mfArray` `coords` and `keycode` will be empty if any key different from L, M or R is pressed.
- On the contrary, `keycode` contains the value of the key pressed (actually `ichar(key_pressed)`, where `ichar` is the standard Fortran function which returns the ASCII code of the letter). `coords` will be empty only if the ESCAPE key is pressed. Only when using keyboard, the mouse wheel can be detected. The values returned are `ichar(8)=56` for wheel up, and `ichar(2)=50` for wheel down (think that on a numeric keypad, 8 is for arrow up, and 2 is for arrow down).

If present, the returned `mfArray` `color` contains the RGB triple of the colored pixel just under the pointer.

Usually (*i. e.* when the optional argument `rect_size` is not present), the cursor shown on the screen has the shape of a big crosshair, whose length is that of the selected window; on the contrary, if the `mfArray` `rect_size` is present and not empty, it must contain the size (both width and height) of a rectangle which follows the pointer during its move. This rectangle is always centered around the pointer position. Moreover, if the `logical` optional argument `rect_inside_axes` is present and equal to *TRUE*, the rectangle drawn is constrained to be entirely inside the axes.

See also: [mfGinputRect](#)

**mfGinputCustom**                      **graphic input using custom cursors with alternative**

*Description:*

The first *Calling syntax* has no argument:

```
out = mfGinput( )
```

Returns in the `mfArray` `out` the coordinates of the pointer when the mouse has been clicked, and the case used (1 or 2):

1. without the Control key pressed, displaying the first custom cursor;
2. with the Control key pressed, displaying the second custom cursor.

The other *Calling syntax* implements a magnetic grid and has one argument:

```
out = mfGinput( magnetic_grid_rule )
```

The `magnetic_grid_rule` subroutine, provided by the user, must have the following interface:

```
subroutine magnetic_grid_rule( icode, x1, y1, x2, y2, valid )
  integer,          intent(in)  :: icode
  real(kind=MF_DOUBLE), intent(in) :: x1, y1
  real(kind=MF_DOUBLE), intent(out) :: x2, y2
  logical,          intent(out) :: valid
end subroutine
```

where `x1`, `y1`, `x2`, `y2` are world-coordinates. The `(x1,y1)` is the pointer position in the figure, and the `(x2,y2)`, computed by the user, is where the user-defined cursor is displayed (`icode` is 1 or 2, according to the status of the Control Key, pressed or not, as mentioned above). If, for some reasons, no `(x2,y2)` point can be computed, then the routine must set the last argument (`valid`) to `FALSE` and in this case the cursor will show its standard shape (*i. e.* the left arrow).

In this second calling syntax, four elements are returned in the `mfArray` `out`:

1. *x*-coordinate of the position clicked.
2. *y*-coordinate of the position clicked.
3. an integer indicating whether the Control Key has been pressed or not.
4. an integer giving the validity of the position; if the validity is zero, the position should be ignored.

*Note:* Before use, the `msDefineCustomCursors` routine must be called to define the two cursor shapes.

**mfGinputRect****rectangular graphic selection***Interface:*

```
function mfGinputRect() result ( out )  
  
    type(mfArray) :: out
```

*Description:*

This function is an interactive facility to get the size and position of a rectangle drawn inside the current figure.

The returned `mfArray` contains the bounding box of the rectangle. This rectangle must be selected by the left mouse button only; for other key pressed, the routine `mfGinputRect` terminates and leaves the returned `mfArray` empty.

In case of multiple opened graphic windows, the cursor has a cross shape in the current active one, instead of the classical pointer.

*See also:* [mfGinput](#)



mfGetModKeys

modifier keys state

*Interface:*

```
function mfGetModKeys( ) result ( out )  
  
    logical :: out(2)
```

*Description:*

This function checks the state of the keyboard for the **Shift** and the **Control** keys.

It returns an array of two booleans: the **first** one (resp. the **second** one) tells if one of the **Shift** keys (resp. the **Control** keys) was down when this routine was called.

**msPan****manual scrolling***Calling syntax:*

```
call msPan( )
```

*Description:*

Activates the ‘pan’ mode for scrolling in the current figure. It ends when the [ESCAPE] key is pressed.

Scrolling is monitored via the mouse (or the equivalent keyboard key):

- click-and-drag with the *left* button (‘L’ key) scrolls through the figure to a new view;
- *middle*-click does nothing;
- *right*-click (‘R’ key) resets the view to the initial one; if the [CTRL] key is pressed during the click (or the ‘6’ key is pressed) then it centers the view with respect to the bounding box of all graphic objects.

*Remark:*

Scrolling in the current figure should be used before putting annotations on the figure, otherwise, parts of graphic objects drawn outside the axes will not be moved with this routine; however, a call to **msRedrawFigure** will fix this problem.

*See also:* **msZoom**, **msPanAndZoom**

**msZoom****figure zoom***Calling syntax:*

```
call msZoom( )
```

*Description:*

Activates the ‘zoom’ mode in the current figure. It ends when the [ESCAPE] key is pressed.

The zoom is monitored via the mouse:

- the *left* button is used to “zoom in” at the pointer location:
  - \* a single click is used to enlarge the current view with a factor of 1.41 (or 1.19 if the [CTRL] key is pressed during the click);
  - \* a click-and-drag zooms to the new selected area;
- a *middle*-click is used to “zoom out” at the pointer location (by a factor of 1.41 — or 1.19 if the [CTRL] key is pressed during the click);
- a *right*-click resets the view to the initial one; if the [CTRL] key is pressed during the click, then it sets the view to an area which shows all the graphic objects.

*See also:* [msPan](#), [msPanAndZoom](#)

**msPanAndZoom****combine scrolling and zooming***Calling syntax:*

```
call msPanAndZoom( )
```

*Description:*

Activates both the 'pan' mode for scrolling and the 'zoom' mode for zooming in the current figure. It ends when the [ESCAPE] key is pressed.

Scrolling is monitored via the three mouse buttons:

- click-and-drag with the left button scrolls the figure to a new view;
- middle-click does nothing;
- right-click resets the view to the initial one; if the [CTRL] key is pressed during the click, then it sets the view to an area which shows all the graphic objects.

Zooming is monitored via the mouse wheel by a factor of 1.41 (or 1.19 if the [CTRL] key is pressed during the click). Note that the figure remains centered during this zooming process.

*Remark:*

Scrolling in the current figure should be used before putting annotations on the figure, otherwise, parts of graphic objects drawn outside the axes will not be moved with this routine; however, a call to **msRedrawFigure** will fix this problem.

*See also:* **msPan**, **msZoom**

**msMoveLegend****adjust legends frame in axes***Calling syntax:*

```
call msMoveLegend( [ handle ] )
```

*Description:*

This interactive routine allows the user to move the legend frame inside the figure via the mouse.

When a unique legends frame has been created by **msLegend**, the routine has no argument.

Use the optional argument to move a legends frame created by **mfLegend** and referenced by its **handle**.

Note that the legend frame may be located outside the axes; this may be useful in the case where a great number of curves are plotted in the figure. During the interactive move on the screen, the legend frame may appear truncated by the window boundary under *X11*; however, printing in EPS or PDF should give correct results.

The use of this routine could follow **msPan**, **msZoom** or **msPanAndZoom** in order to optimize its position.

**msMoveGrObj****move graphic object***Interface:*

```
subroutine msMoveGrObj( handle, prompt )

    integer,          intent(in)          :: handle
    character(len=*) , intent(in), optional :: prompt
```

*Description:*

Allows the user to move some types of graphic object, by interaction with the mouse (left button click only). It ends when the [ESCAPE] key is pressed. Supported graphic object types are: *text* (generated by **mfText**), *arrow* (generated by **mfArrow**) and *polygon* (generated by **mfPatch** using a flat color).

When this routine is called, it waits for a *mouse down* event (first part of a click) while the pointer have the shape of an opened hand. To grab a *text* or *polygon* object, you can click elsewhere inside its bounding box (displayed using a gray animated dashed line); for an *arrow*, you have three hotspots (sensitive area): one is the arrow base, the second is the middle and the third is the arrow head.

When a *mouse down* event is detected, the shape of the pointer becomes a closed hand and the graphic object (referenced by its **handle**) can be moved in the figure. Note that a *text* or *polygon* object can be only translated, without changing its orientation; however, for an *arrow* and according to the selected hotspot, you can change both its direction (when you have clicked on its base or its head) and its location (when you have clicked in its middle).

When a *mouse up* event is detected (end of a click), the pointer shape changes back to an opened hand.

The **prompt** argument lets you choosing an appropriate sentence on the screen. By default, the prompt is adapted to the type of graphic object:

```
text: -> Grab and move the text string surrounded by a dashed line...
arrow: -> Grab and move the arrow wearing three hotspots...
polygon: -> Grab and move the polygon surrounded by a dashed line...
```

*Remarks:*

- Note that the graphic objects may be clipped at the axes framebox. If you move a graphic object out of the axes, it may no longer be visible; however, the dashed line(s) around it will be always visible and will be an appreciable help.
- An example of use of the **msMoveGrObj** routine can be found in the test program named **MoveGrObj\_test** inside the **tests/fgl** folder.

*See also:* [msPan](#), [msZoom](#), [msMoveLegend](#)

**msAnimation****screen animation mode**

*Calling syntax:*

```
call msAnimation( "on" | "off" )
```

*Description:*

The aim of this routine is to avoid the flickering between frames when you want to show quickly (usually in a `do` loop) a succession of graphic objects.

Note that, at the end of the animation, you will not be able to print the figure in EPS or PDF files (graphic objects are not saved into memory), unless you run yourself the same graphic commands out of the animation.

Before setting animation to "on", a window must be opened (with `msFigure`). Moreover axis must be defined as constant, by calling the `msAxis` routine before.

After drawing each frame, the only way to show the display of the graphic object in the figure is to call the `msShowNow` routine. The *MUESLI User Guide* presents a detailed example of a typical sequence of such an animation.

At the end of the animation sequence, the user should set animation to "off".

*Remarks:*

During an animation:

- the “hold” property cannot be changed by the user. Therefore, the `msHold` routine shouldn’t be used.
- all graphic objects are volatile; as a consequence the handle returned by all plotting functions beginning by `mf` is equal to zero. Therefore, you cannot use any routine requiring a valid handle.
- don’t use `msClf` (which does a complete erasing of the figure) between frames: in such a case, this will annihilate a large part of the benefit of the current routine. Use `msCla` instead.
- a varying text string may be displayed outside the axes, and erased between frames with the use of a white rectangle over it (see `mf/msPatch`).
- if the `msPColor` routine is used, then the optional arguments X and Y must be used.

**msShowNow****screen update during an animation***Calling syntax:*

```
call msShowNow( )
```

*Description:*

This routine may be called only during an animation (see [msAnimation](#)). It forces the update of the screen to show the new display of the current frame.



**msCla****clear current axes***Calling syntax:*

```
call msCla()
```

*Description:*

Clears the current axes, *i. e.* fills the rectangle inside the axes using the background color.

A typical usage concerns the animation of any graphic objects (curve, symbol, text, ...): at the beginning of a loop, the axes should be erased with `msCla` (quick way) and then graphic objects are drawn. Avoid to use `msClf` (heavy way) because this latter routine do a complete reset of the figure (among other things, the axes range is lost).

*See also:* `msFigure`, `msClose`

**msSetGBuffer****graphic buffer policy***Interface:*

```
subroutine msSetGBuffer( flag )
```

```
character(len=*), intent(in) :: flag
```

flag may be equal to "on" or "off".

*Description:*

Activates the graphic buffer (default is "on"). Usually increases the display speed.

The graphic buffer may be turned "off" for debugging purpose, for example.

*See also:* [msBBuf](#), [msEBuf](#)

**msBBuf****begin of graphic buffering***Calling syntax:*

```
call msBBuf( )
```

*Description:*

Begins to draw in the graphic buffer, instead of directly on the screen.

*Remarks:*

- this routine is active only if the graphic buffer is not turned off by the `msSetGBuffer` routine;
- actually, many internal low-level graphic routines are already buffered.

*See also:* `msSetGBuffer`, `msEBuf`

**msEBuf****end of graphic buffering***Calling syntax:*

```
call msEBuf ( )
```

*Description:*

Ends to draw in the graphics buffer.

msBBuf and msEBuf calls should always be paired.

*See also:* [msSetGBuffer](#), [msBBuf](#)

`msDefineCustomCursors`      **define custom cursors for use with `mfGinputCustom`**

*Interface:*

```
subroutine msDefineCustomCursors( cursor_1, cursor_1_mask, color_1,   &
                                cursor_2, cursor_2_mask, color_2 )

character(len=*), intent(in) :: cursor_1, cursor_1_mask, color_1,   &
                                cursor_2, cursor_2_mask, color_2
```

*Description:*

Register two customized cursors, provided by the user in the XBM format. The arguments `cursor_*` are the filenames of these images. Each cursor is defined by two bitmap images: one for the cursor shape itself and the other for the mask. A color must be also specified for each cursor.

A size of  $16 \times 16$  pixels is recommended. The cursor main image must define the Hot Spot position, for example

```
#define _x_hot 8
#define _y_hot 8
```

Last, each color is a colorname from the RGB X11 database.

*See also:* [mfGinputCustom](#)

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