Calerga

LyME 3.1

User Manual

LyME User Manual, August 2008.
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Most of the material in LyME User Manual has first been written as a set of XHTML files, with lots of cross-reference links. Since (X)HTML is not very well suited for printing, it has been converted to LaTeX with the help of a home-made conversion utility. Additional XML tags have been used to benefit from LaTeX features: e.g. raster images have been replaced with EPS images, equations have been converted from text to real mathematic notation, and a table of contents and an index have been added. The same method has been used to create the material for the `help` command. Thanks to the make utility, the whole process is completely automatic. This system has proved to be very flexible to maintain three useful formats in parallel: two for on-line help, and one for high-quality printing.

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Typesetting: 2008-8-2

Contents

Chapter 1

Using LyME

LyME is a port of LME ("Lightweight Math Engine", the heart of Sysquake) to Palm OS handheld devices. It implements about 320 native commands, functions and operators, mostly compatible with Matlab. It requires Palm OS 3.1 or higher and at least 1 MBytes of memory free.

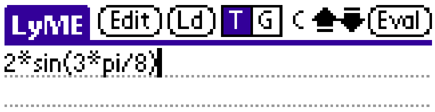
1.1 LyME Installation

Install at least MathLib.prc (unless it has already been installed for another application or it is included in the device ROM) and LyME.prc. You can also install library files (the files which end with .pdb) which add more functions to LyME.

1.2 Using LyME

Launch LyME by tapping its icon.

Figure 1.1



```
2*sin(3*pi/8)
```

Figure 1.2

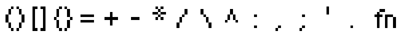


Figure 1.3

Simple expressions

Write expressions in the top field, tap the Eval button or write return (topright-to-bottomleft Graffiti stroke), and read the result in the bottom field.

To enter parenthesis or operators, you can also tap one of the symbols at the botton of the screen.

To enter a function or to check its arguments, tap `fn` and the bottom right of the screen, scroll the list, and tap the function you want. You can also tap outside the list to discard it.

Previous commands can be retrieved with the arrows at the top left of the screen. The command field can be cleared completely with a tap on the C near the arrows. An Edit menu is also available for the usual Cut/Copy/Paste/Undo commands; tap the window title "LyME" or the menu button below the screen.

To stop execution, press the Page Down key until the Eval button label is displayed.

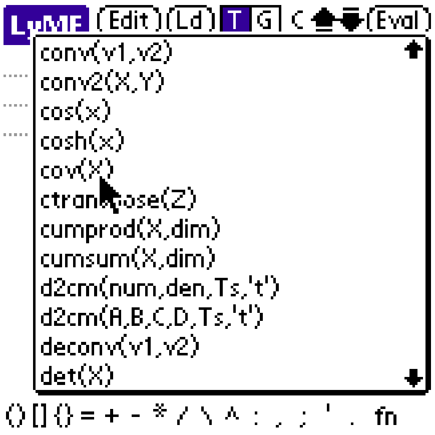
Graphics

Some commands produce graphical output. Graphics replace the text output below the command field.

Graphics and text output may be toggled with the **T** and **G** buttons at the top of the screen.

Graphics are usually scaled to fill the graphics area. No axis is drawn, because of the constrained screen size. To check the scale, tap anywhere in the graphics area and read the coordinates of the point below the pen.

Most graphical functions support an additional argument to specify the color.



```
conv(v1,v2)
conv2(X,Y)
cos(x)
cosh(x)
cov(X)
ctranspose(Z)
cumprod(X,dim)
cumsum(X,dim)
d2cm(num,den,Ts,'t')
d2cm(A,B,C,D,Ts,'t')
deconv(v1,v2)
det(X)
```

Figure 1.4

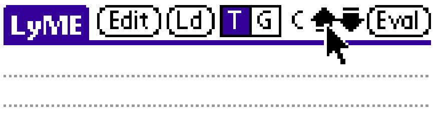
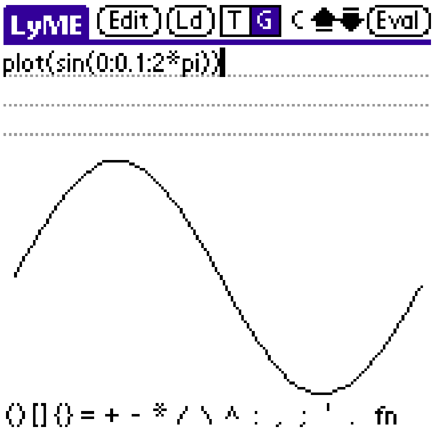
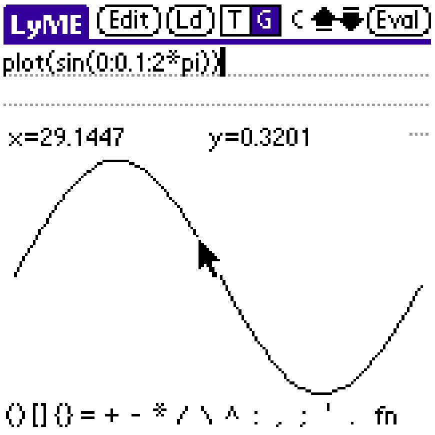


Figure 1.5



```
plot(sin(0:0.1:2*pi))
```

Figure 1.6



```
plot(sin(0:0.1:2*pi))
```

x=29.1447 y=0.3201

Figure 1.7

Programs

There are two kinds of programs in LyME: scripts and functions. Scripts are simply collections of statements, variable assignments and expressions which are evaluated exactly as if they were written in the command field. Functions (collected in libraries) have input and output arguments, and local variables. They cannot modify the workspace variables you define from the command field or from scripts. Both scripts and functions are entered in an editor window, and are saved in a persistant database. Standard Edit menu commands are available to Cut, Copy and Paste text in LyME or between LyME and other Palm applications such as Memo Pad.

Scripts

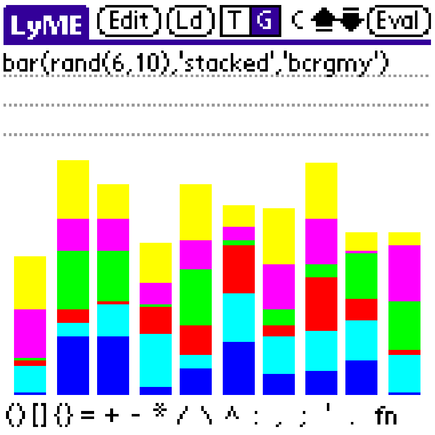
To program a script in LyME, tap the Edit button and (new). Replace "untitled" with a script name (such as "test"). Write your statements, typically one per line, below.

When you're ready, tap OK or Load. OK just stores your new script in the LyME database, while Load also executes it.

Functions

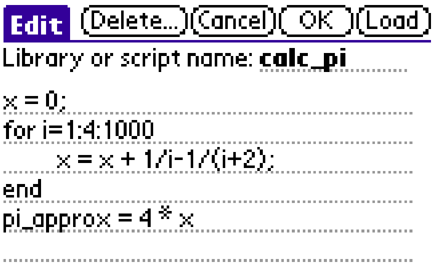
To program functions in LyME, tap the Edit button and (new). Replace "untitled" with a library name (such as "stat" or "control"). Write all your functions below.

When you're satisfied, tap OK or Load. OK stores your new library in the LyME database, while Load also issues a "use" command to LME



```
bar(rand(6,10),'stacked','bcrgmy')
```

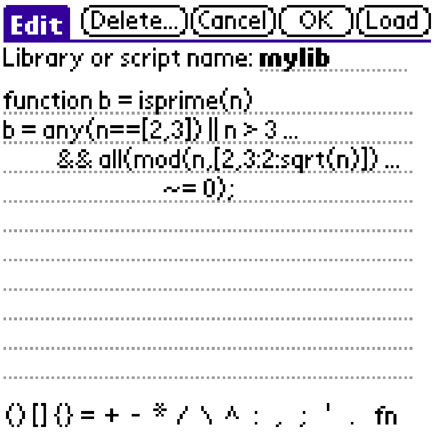
Figure 1.8



Library or script name: **calc_pi**

```
x = 0;
for i=1:4:1000
      x = x + 1/i-1/(i+2);
end
pi_approx = 4 * x
```

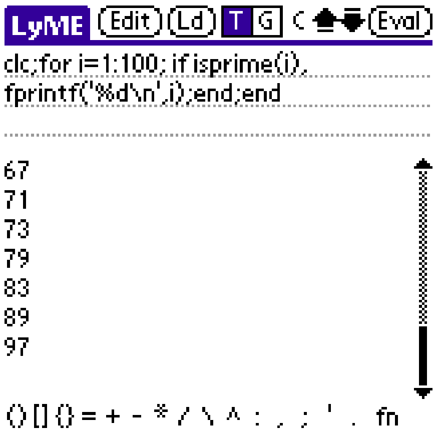
Figure 1.9



Library or script name: **mylib**

```
function b = isprime(n)
b = any(n==[2,3]) || n > 3 ...
      && all(mod(n,[2,3:2:sqrt(n)]) ...
            ~= 0);
```

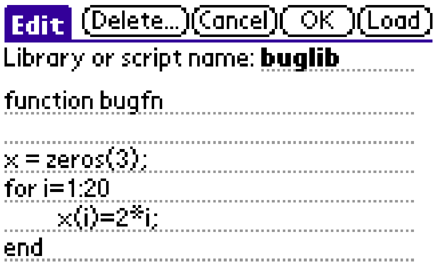
Figure 1.10



```
clc;for i=1:100; if isprime(i),
fprintf('%d\n',i);end;end

67
71
73
79
83
89
97
```

Figure 1.11



Library or script name: **buglib**

```
function bugfn

x = zeros(3);
for i=1:20
    x(i)=2*i;
end
```

Figure 1.12

to make your functions available from the command line. You can then test your library.

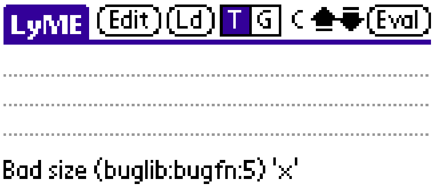
To edit again your script or your library, tap the Edit button, then pick its name from the list. The "Load" button will remove the previous definitions and replace them with the new ones.

Error correction

When you execute a function and an error occurs, the library name, the function name and the line number are displayed. If you tap somewhere on the library or function name, then tap the Edit button, LyME displays directly the offending line to help you correct the bug.

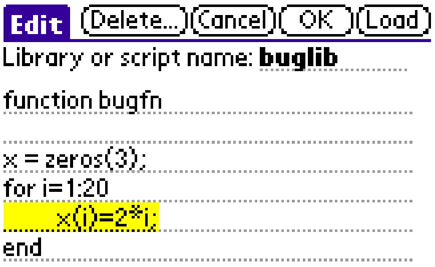
Here is an example of a problematic function.

Tap Load, then write bugfn. LyME stops when it tries to write to the 10th element of the 3-by-3 matrix.



```
Bad size (buglib:bugfn:5) 'x'
```

Figure 1.13



Library or script name: **buglib**

```
function bugfn

x = zeros(3);
for i=1:20
    x(i)=2*i;
end
```

Figure 1.14

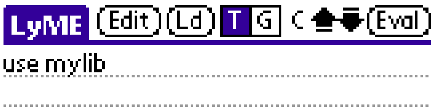
Tap the function name in the error message ("bugfn"), then tap the Edit button to jump to the line where the error occurred.

Using libraries

To use a library when you restart LyME, tap the Ld (load) button and the name of the library. The command to do the same is "use library-name".

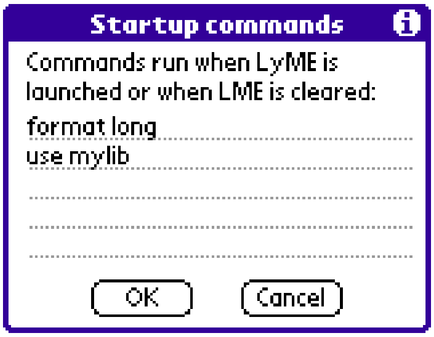
You can also use this command in another library; note however that functions in nested libraries are hidden, unless their library is explicitly used where they are called.

If you use frequently the same libraries, you may want to use them



```
use mylib
```

Figure 1.15



Commands run when LyME is launched or when LME is cleared:

format long
use mylib

Figure 1.16

automatically at startup. Select Startup Commands in the File menu, then type any command you want to be executed every time you launch LyME or Clear All.

Another useful command is `info`: `info l` lists the currently loaded libraries; `info f` lists all referenced functions, with parenthesis for those not compiled yet; `info b` lists the builtin functions; and `info v` lists the variables with their type and size.

1.3 User input

The best way to develop reusable code is to write functions with input and output arguments. Variables can be created in the context of the command line to pass values between different functions, and new values are entered directly in the command line, with access to the history of past commands, the list of functions, and buttons for common operators and symbols.

It may also be useful to prompt the user for more input in the middle of a computation. One mechanism can be used.

Standard input General input functions such as `fgets` or `fscanf` can be used with the predefined file descriptor `0`. The user can enter data and click button "OK" to resume execution, or button "Cancel" to cancel it completely. In the example below, a single integer is requested (note that the default file descriptor for `fscanf` is 0).

```
n = fscanf('%d');
```

1.4 Data exchange

Libraries are synchronized during backup, but those deleted on the Palm device are currently preserved on the desktop computer.

To transfer a library to another Palm device, you can send it via infrared or Bluetooth. Select Send in the File menu, align your device to the destination device if you use infrared, and tap the library to be sent in the list, and select the transfer type if your device offers the choice. The receiving device will display a dialog box asking if the library should be accepted; if OK, the library will be stored in the LyME database.

Another way to exchange libraries with the outside is to convert it to or from a Memo Pad note. To export a library, edit it (Edit button), then select Export in the File menu; a new Memo Pad note is created. To import a library, create a new library (Edit button, then (New)), then select Import in the File menu and choose the first line of one of the Memo Pad notes; its entire contents will be inserted in the library.

At a lower level, `serialdevopen`, in addition to the physical serial ports whose list can be obtained with `serialdevname`, accepts the four-character codes of virtual serial drivers recognized by the Palm OS function `SrmOpen`. Two codes are documented: `’ircm’` for infrared, and `’rfcm’` for Bluetooth in client mode. To open a Bluetooth connection, for instance, you can use the code below. `serialdevopen` will let the user pick a Bluetooth device from a list.

```
try
  fd = serialdevopen(’rfcm’);
  // functions like fread/fwrite/fprintf/fscanf/fgets
  fclose(fd);
catch
  // Bluetooth not supported or user cancel
```

1.5 License

LyME and its documentation: Copyright 1997-2008, Calerga. All rights reserved. LyME may not be redistributed without the prior written permission of Calerga.

The user assumes all the risks caused by the use of LyME and the results obtained with LyME. Under no circumstance will Calerga, its emplyees or resellers be responsible for any loss of money, time, data, goods, or lives.

1.6 What's more in Sysquake

While it is based on the same computation engine and language, Sysquake has a completely different graphical system, whose goal is nearly-instantaneous interactivity with the mouse. This interactivity opens a new dimension (effect of parametric variations, relationships between different figures, etc.) and permits the user to get an intuitive understanding of his/her problems and to solve them more efficiently. Sysquake also has file support, extensions, large high-quality numerical libraries, a user interface which supports many more options, print support, and a lot of other features.

LyME runs on much slower hardware (typically 1000 times slower); it is useful for small-to-medium-size problems and is located somewhere between high-end scientific calculators and desktop numeric software such as Matlab, with which it is largely compatible.

For more information about Sysquake and LyME, please visit http://www.calerga.com.

1.7 MathLib

MathLib is a free shared library that can be used by any OS 2.0+ Pilot program that needs IEEE 754 double precision math functions. It is distributed under the terms of the GNU Library General Public License, and is freely available with full source code and documentation at the MathLib Information web page. It is not a part of the LyME program, and you're not paying anything for its use; a copy is simply included in this archive for your convenience. Thanks, Rick!

Chapter 2

LME Tutorial

The remainder of this chapter introduces LME(TM) (Lightweight Math Engine), the interpreter for numerical computing used by Sysquake, and shows you how to perform basic computations. It supposes you can type commands to a command-line interface. You are invited to type the examples as you read this tutorial and to experiment on your own. For a more systematic description of LME, please consult the LME Reference chapter.

In the examples below, we assume that LME displays a prompt >. This is not the case for all applications. You should never type it yourself. Enter what follows the prompt on the same line, hit the Return key (or tap the Eval or Execute button), and observe the result.

2.1 Simple operations

LME interprets what you type at the command prompt and displays the result unless you end the command with a semicolon. Simple expressions follow the syntactic rules of many programming languages.

```
> 2+3*4
ans =
 14
> 2+3/4
ans =
 2.75
```

As you can see, the evaluation order follows the usual rules which state that the multiplication (denoted with a star) and division (slash) have a higher priority than the addition and subtraction. You can change this order with parenthesis:

```
> (2+3)*4
ans =
 20
```

The result of expressions is automatically assigned to variable ans (more about variables later), which you can reuse in the next expression:

```
> 3*ans
ans =
  60
```

Power is represented by the ^ symbol:

```
> 2^5
ans =
  32
```

LME has many mathematical functions. Trigonometric functions assume that angles are expressed in radians, and `sqrt` denotes the square root.

```
> sin(pi/4) * sqrt(2)
ans =
  1
```

2.2 Complex Numbers

In many computer languages, the square root is defined only for non-negative arguments. However, it is extremely useful to extend the set of numbers to remove this limitation. One defines i such that $i^2 = -1$, and applies all the usual algebraic rules. For instance, $\sqrt{-1} = \sqrt{i^2} = i$, and $\sqrt{-4} = \sqrt{4}\sqrt{-1} = 2i$. Complex numbers of the form $a + bi$ are the sum of a real part a and an imaginary part b. It should be mentioned that i, the symbol used by mathematicians, is called j by engineers. LME accepts both symbols as input, but it always writes it `j`. You can use it like any function, or stick an `i` or `j` after a number:

```
> 2+3*j
ans =
  2+3j
> 3j+2
ans =
  2+3j
```

Many functions accept complex numbers as argument, and return a complex result when the input requires it even if it is real:

```
> sqrt(-2)
ans =
  0+1.4142i
> exp(3+2j)
```

```
ans =
 -8.3585+18.2637j
> log(-8.3585+18.2637j)
ans =
 3+2j
```

To get the real or imaginary part of a complex number, use the functions `real` or `imag`, respectively:

```
> real(2+3j)
ans =
 2
> imag(2+3j)
ans =
 3
```

Complex numbers can be seen as vectors in a plane. Then addition and subtraction of complex numbers correspond to the same operations applied to the vectors. The absolute value of a complex number, also called its magnitude, is the length of the vector:

```
> abs(3+4j)
ans =
 5
> sqrt(3^2+4^2)
ans =
 5
```

The argument of a complex number is the angle between the x axis ("real axis") and the vector, counterclockwise. It is calculated by the `angle` function.

```
> angle(2+3j)
ans =
 0.9828
```

The last function specific to complex numbers we will mention here is `conj`, which calculates the conjugate of a complex number. The conjugate is simply the original number where the sign of the imaginary part is changed.

```
> conj(2+3j)
ans =
 2-3j
```

Real numbers are also complex numbers, with a null imaginary part; hence

```
> abs(3)
ans =
  3
 > conj(3)
 ans =
  3
 > angle(3)
 ans =
  0
 > angle(-3)
 ans =
  3.1416
```

2.3 Vectors and Matrices

LME manipulates vectors and matrices as easily as scalars. To define a matrix, enclose its contents in square brackets and use commas to separate elements on the same row and semicolons to separate the rows themselves:

```
 > [1,2;5,3]
 ans =
  1 2
  5 3
```

Column vectors are matrices with one column, and row vectors are matrices with one row. You can also use the colon operator to build a row vector by specifying the start and end values, and optionally the step value. Note that the end value is included only if the range is a multiple of the step. Negative steps are allowed.

```
 > 1:5
 ans =
  1 2 3 4 5
 > 0:0.2:1
 ans =
  0 0.2 0.4 0.6 0.8 1
 > 0:-0.3:1
 ans =
  0 -0.3 -0.6 -0.9
```

There are functions to create special matrices. The `zeros`, `ones`, `rand`, and `randn` functions create matrices full of zeros, ones, random numbers uniformly distributed between 0 and 1, and random numbers normally distributed with a mean of 0 and a standard deviation of 1, respectively. The `eye` function creates an identity matrix, i.e. a matrix with ones on the main diagonal and zeros elsewhere. All of these functions can take one scalar argument `n` to create a square n-by-n matrix, or two arguments `m` and `n` to create an m-by-n matrix.

```
> zeros(3)
ans =
 0 0 0
 0 0 0
 0 0 0
> ones(2,3)
ans =
 1 1 1
 1 1 1
> rand(2)
ans =
 0.1386 0.9274
 0.3912 0.8219
> randn(2)
ans =
 0.2931  1.2931
 -2.3011 0.9841
> eye(3)
ans =
 1 0 0
 0 1 0
 0 0 1
> eye(2,3)
ans =
 1 0 0
 0 1 0
```

You can use most scalar functions with matrices; functions are applied to each element.

```
> sin([1;2])
ans =
 0.8415
 0.9093
```

There are also functions which are specific to matrices. For example, `det` calculates the determinant of a square matrix:

```
> det([1,2;5,3])
ans =
 -7
```

Arithmetic operations can also be applied to matrices, with their usual mathematical behavior. Additions and subtractions are performed on each element. The multiplication symbol ∗ is used for the product of two matrices or a scalar and a matrix.

```
> [1,2;3,4] * [2;7]
ans =
 16
 34
```

The division symbol / denotes the multiplication by the inverse of the right argument (which must be a square matrix). To multiply by the inverse of the left argument, use the symbol \. This is handy to solve a set of linear equations. For example, to find the values of x and y such that $x + 2y = 2$ and $3x + 4y = 7$, type

```
> [1,2;3,4] \ [2;7]
ans =
 3
 -0.5
```

Hence $x = 3$ and $y = -0.5$. Another way to solve this problem is to use the `inv` function, which return the inverse of its argument. It is sometimes useful to multiply or divide matrices element-wise. The `.*`, `./` and `.\` operators do exactly that. Note that the + and - operators do not need special dot versions, because they perform element-wise anyway.

```
> [1,2;3,4] * [2,1;5,3]
ans =
 12 7
 26 15
> [1,2;3,4] .* [2,1;5,3]
ans =
 2  2
 15 12
```

Some functions change the order of elements. The transpose operator (tick) reverses the columns and the rows:

```
> [1,2;3,4;5,6]'
ans =
 1 3 5
 2 4 6
```

When applied to complex matrices, the complex conjugate transpose is obtained. Use dot-tick if you just want to reverse the rows and columns. The `flipud` function flips a matrix upside-down, and `fliplr` flips a matrix left-right.

```
> flipud([1,2;3,4])
ans =
 3 4
 1 2
> fliplr([1,2;3,4])
ans =
 2 1
 4 3
```

To sort the elements of each column of a matrix, or the elements of a row vector, use the `sort` function:

```
> sort([2,4,8,7,1,3])
ans =
 1 2 3 4 7 8
```

To get the size of a matrix, you can use the `size` function, which gives you both the number of rows and the number of columns unless you specify which of them you want in the optional second argument:

```
> size(rand(13,17))
ans =
 13 17
> size(rand(13,17), 1)
ans =
 13
> size(rand(13,17), 2)
ans =
 17
```

2.4 Polynomials

LME handles only numerical values. Therefore, it cannot differentiate functions like $f(x) = sin(e^x)$. However, a class of functions has a paramount importance in numerical computing, the polynomials. Polynomials are weighted sums of powers of a variable, such as $2x^2+3x-5$. LME, which handles only matrices, stores the coefficients of polynomials in row vectors; i.e. $2x^2+3x-5$ is represented as `[2,3,-5]`, and $2x^5+3x$ as `[2,0,0,0,3,0]`.

Adding two polynomials would be like adding the coefficient vectors if they had the same size; in the general case, however, you had better use the function `addpol`, which can also be used for subtraction:

```
> addpol([1,2],[3,7])
ans =
 4 9
> addpol([1,2],[2,4,5])
ans =
 2 5 7
> addpol([1,2],-[2,4,5])
ans =
 -2 -3 -3
```

Multiplication of polynomials corresponds to convolution (no need to understand what it means here) of the coefficient vectors.

```
> conv([1,2],[2,4,5])
ans =
 2 8 13 10
```

Hence $(x+2)(2x^2)+4x+5 = 2x^3+8x^2+13x+10$.

2.5 Strings

You type strings by bracketing them with single quotes:

```
> 'Hello, World!'
ans =
 Hello, World!
```

If you want single quotes in a string, double them:

```
> 'Easy, isn''t it?'
ans =
 Easy, isn't it?
```

Some control characters have a special representation. For example, the line feed, used in LME as an end-of-line character, is \n:

```
> 'Hello,\nWorld!'
ans =
 Hello,
 World!
```

Strings are actually matrices of characters. You can use commas and semicolons to build larger strings:

```
> ['a','bc';'de','f']
ans =
 abc
 def
```

2.6 Variables

You can store the result of an expression into what is called a variable. You can have as many variables as you want and the memory permits. Each variable has a name to retrieve the value it contains. You can change the value of a variable as often as you want.

```
> a = 3;
> a + 5
ans =
 8
> a = 4;
> a + 5
ans =
 9
```

Note that a command terminated by a semicolon does not display its result. To see the result, remove the semicolon, or use a comma if you have several commands on the same line. Implicit assignment to variable ans is not performed when you assign to another variable or when you just display the contents of a variable.

```
> a = 3
 a =
  3
> a = 7, b = 3 + 2 * a
 a =
  7
 b =
  17
```

2.7 Loops and Conditional Execution

To repeat the execution of some commands, you can use either a `for/end` block or a `while/end` block. With `for`, you use a variable as a counter:

```
> for i=1:3;i,end
 i =
  1
 i =
  2
 i =
  3
```

With `while`, the commands are repeated as long as some expression is true:

```
> i = 1; while i < 10; i = 2 * i, end
 i =
  2
 i =
  4
 i =
  8
```

You can choose to execute some commands only if a condition holds true :

```
> if 2 < 3;'ok',else;'amazing...',end
ans =
 ok
```

2.8 Functions

LME permits you to extend its set of functions with your own. This is convenient not only when you want to perform the same computation on different values, but also to make you code clearer by dividing the whole task in smaller blocks and giving names to them. To define a new function, you have to write its code in a file; you cannot do it from the command line. In Sysquake, put them in a function block.

Functions begin with a header which specifies its name, its input arguments (parameters which are provided by the calling expression) and its output arguments (result of the function). The input and output arguments are optional. The function header is followed by the code which is executed when the function is called. This code can use arguments like any other variables.

We will first define a function without any argument, which just displays a magic square, the sum of each line, and the sum of each column:

```
function magicsum3
  magic_3 = magic(3)
  sum_of_each_line = sum(magic_3, 2)
  sum_of_each_column = sum(magic_3, 1)
```

You can call the function just by typing its name in the command line:

```
> magicsum3
 magic_3 =
   8 1 6
   3 5 7
   4 9 2
 sum_of_each_line =
   15
   15
   15
 sum_of_each_column =
   15 15 15
```

This function is limited to a single size. For more generality, let us add an input argument:

```
function magicsum(n)
  magc = magic(n)
  sum_of_each_line = sum(magc, 2)
  sum_of_each_column = sum(magc, 1)
```

When you call this function, add an argument:

```
> magicsum(2)
 magc =
   1 3
   4 2
 sum_of_each_line =
   4
   6
 sum_of_each_column =
   5 5
```

Note that since there is no 2-by-2 magic square, `magic(2)` gives something else... Finally, let us define a function which returns the sum of each line and the sum of each column:

```
function (sum_of_each_line, sum_of_each_column) = magicSum(n)
  magc = magic(n);
  sum_of_each_line = sum(magc, 2);
  sum_of_each_column = sum(magc, 1);
```

Since we can obtain the result by other means, we have added semicolons after each statement to suppress any output. Note the uppercase S in the function name: for LME, this function is different from the previous one. To retrieve the results, use the same syntax:

```
> (sl, sc) = magicSum(3)
 sl =
   15
   15
   15
 sc =
   15 15 15
```

You do not have to retrieve all the output arguments. To get only the first one, just type

```
> sl = magicSum(3)
 sl =
   15
   15
   15
```

When you retrieve only one output argument, you can use it directly in an expression:

```
> magicSum(3) + 3
ans =
   18
   18
   18
```

One of the important benefits of defining function is that the variables have a limited scope. Using a variable inside the function does not make it available from the outside; thus, you can use common names (such as `x` and `y`) without worrying about whether they are used in some other part of your whole program. For instance, let us use one of the variables of `magicSum`:

```
> magc = 77
 magc =
   77
 > magicSum(3) + magc
 ans =
    92
    92
    92
 > magc
  magc =
    77
```

2.9 Local and Global Variables

When a value is assigned to a variable which has never been referenced, a new variable is created. It is visible only in the current context: the base workspace for assignments made from the command-line interface, or the current function invocation for functions. The variable is discarded when the function returns to its caller.

Variables can also be declared to be global, i.e. to survive the end of the function and to support sharing among several functions and the base workspace. Global variables are declared with keyword `global`:

```
global x
global y z
```

A global variable is unique if its name is unique, even if it is declared in several functions.

In the following example, we define functions which implement a queue which contains scalar numbers. The queue is stored in a global variable named `QUEUE`. Elements are added at the front of the vector with function `queueput`, and retrieved from the end of the vector with function `queueget`.

```
function queueput(x)
  global QUEUE;
  QUEUE = [x, QUEUE];

function x = queueget
  global QUEUE;
  x = QUEUE(end);
  QUEUE(end) = [];
```

Both functions must declare `QUEUE` as global; otherwise, the variable would be local, even if there exists also a global variable defined elsewhere. The first time a global variable is defined, its value is set to the empty matrix `[]`. In our case, there is no need to initialized it to another value.

Here is how these functions can be used.

```
> queueput(1);
> queueget
ans =
   1
> queueput(123);
> queueput(2+3j);
> queueget
ans =
   123
> queueget
ans =
   2 + 3j
```

To observe the value of `QUEUE` from the command-line interface, `QUEUE` must be declared global there. If a local variable already exists, it is discarded.

```
> global QUEUE
> QUEUE
QUEUE =
   []
> queueput(25);
> queueput(17);
> QUEUE
QUEUE =
   17 25
```

Chapter 3

LME Reference

This chapter describes LME (Lightweight Math Engine), the interpreter for numerical computing used by Sysquake.

3.1 Program format

Statements

An LME program, or a code fragment typed at a command line, is composed of statements. A statement can be either a simple expression, a variable assignment, or a programming construct. Statements are separated by commas, semicolons, or end of lines. The end of line has the same meaning as a comma, unless the line ends with a semicolon. When simple expressions and assignments are followed by a comma (or an end of line), the result is displayed to the standard output; when they are followed by a semicolon, no output is produced. What follows programming constructs does not matter.

When typed at the command line, the result of simple expressions is assigned to the variable ans; this makes easy reusing intermediate results in successive expressions.

Continuation characters

A statement can span over several lines, provided all the lines but the last one end with three dots. For example,

```
1 + ...
2
```

is equivalent to `1 + 2`. After the three dots, the remaining of the line, as well as empty lines and lines which contain only spaces, are ignored.

Inside parenthesis or braces, line breaks are permitted even if they are not escaped by three dots. Inside brackets, line breaks are matrix row separators, like semicolons.

Comments

Unless when it is part of a string enclosed between single ticks, a single percent character or two slash characters mark the beginning of a comment, which continues until the end of the line and is ignored by LME. Comments must follow continuation characters, if any.

```
a = 2;    % comment at the end of a line
x = 5;    // another comment
% comment spanning the whole line
b = ...   % comment after the continuation characters
    a;
a = 3%   no need to put spaces before the percent sign
s = '%';  % percent characters in a string
```

Comments may also be enclosed between `/*` and `*/`; in that case, they can span several lines.

Pragmas

Pragmas are directives for LME compiler. They can be placed at the same location as LME statements, i.e. in separate lines or between semicolons or commas. They have the following syntax:

```
_pragma name arguments
```

where `name` is the pragma name and `arguments` are additional data whose meaning depends on the pragma.

Currently, only one pragma is defined. Pragmas with unknown names are ignored.

Name	Arguments	Effect
`line`	*n*	Set the current line number to *n*

`_pragma line 120` sets the current line number as reported by error messages or used by the debugger or profiler to 120. This can be useful when the LME source code has been generated by processing another file, and line numbers displayed in error messages should refer to the original file.

3.2 Function Call

Functions are fragments of code which can use *input arguments* as parameters and produce *output arguments* as results. They can be built in LME (*built-in functions*), loaded from optional extensions, or defined with LME statements (*user functions*).

A *function call* is the action of executing a function, maybe with input and/or output arguments. LME supports different syntaxes.

```
fun
fun()
fun(in1)
fun(in1, in2,...)
out1 = fun...
(out1, out2, ...) = fun...
[out1, out2, ...] = fun...
[out1 out2 ...] = fun...
```

Input arguments are enclosed between parenthesis. They are passed to the called function by value, which means that they cannot be modified by the called function. When a function is called without any input argument, parenthesis may be omitted.

Output arguments are assigned to variables or part of variables (structure field, list element, or array element). A single output argument is specified on the left on an equal character. Several output arguments must be enclosed between parenthesis or square brackets (arguments can simply be separated by spaces when they are enclosed in brackets). Parenthesis and square brackets are equivalent as far as LME is concerned; parenthesis are preferred in LME code, but square brackets are available for compatibility with third-party applications.

In some cases, a simpler syntax can be used when the function has only literal character strings as input arguments. The following conditions must be satisfied:

- No output argument.
- Each input argument must be a literal string
  - without any space, tabulator, comma or semicolon,
  - beginning with a letter, a digit or one of '-/.:*' (minus, slash, dot, colon, or star),
  - containing at least one letter or digit.

In that case, the following syntax is accepted; left and right columns are equivalent.

```
fun str1        fun('str1')
fun str1 str2   fun('str1','str2')
fun abc,def     fun('abc'),def
```

Arguments can also be quoted strings; in that case, they may contain spaces, tabulators, commas, semicolons, and escape sequences beginning with a backslash (see below for a description of the string data type). Quoted and unquoted arguments can be mixed:

```
fun 'a bc\n'       fun('a bc\n')
fun str1 'str 2'  fun('str1','str 2')
```

This *command syntax* is especially useful for functions which accept well-known options represented as strings, such as `format loose`.

3.3 Libraries

Libraries are collections of user functions, identified in LME by a name. Typically, they are stored in a file whose name is the library name with a ".lml" suffix (for instance, library `stdlib` is stored in file "stdlib.lml"). Before a user function can be called, its library must be loaded with the use statement. use statements have an effect only in the context where they are placed, i.e. in a library, or the command-line interface, or a Sysquake SQ file; this way, different libraries may define functions with the same name provided they are not used in the same context.

In a library, functions can be public or private. Public functions may be called from any context which use the library, while private functions are visible only from the library they are defined in.

3.4 Types

Numerical, logical, and character arrays

The basic type of LME is the two-dimensional array, or matrix. Scalar numbers and row or column vectors are special kinds of matrices. Arrays with more than two dimensions are also supported. All elements have the same type, which are described in the table below. Two non-numerical types exist for character arrays and logical (boolean) arrays. Cell arrays, which contain composite types, are described in a section below.

Type	**Description**
double	64-bit IEEE number
complex double	Two 64-bit IEEE numbers
single	32-bit IEEE number
complex single	Two 32-bit IEEE numbers
uint32	32-bit unsigned integer
int32	32-bit signed integer
uint16	16-bit unsigned integer
int16	16-bit signed integer
uint8	8-bit unsigned integer
int8	8-bit signed integer
uint64	64-bit unsigned integer
int64	64-bit signed integer

64-bit integer numbers are not supported by all applications on all platforms.

These basic types can be used to represent many mathematic objects:

Scalar One-by-one matrix.

Vector n-by-one or one-by-n matrix. Functions which return vectors usually give a column vector, i.e. n-by-one.

Empty object 0-by-0 matrix (0-by-n or n-by-0 matrices are always converted to 0-by-0 matrices).

Polynomial of degree d 1-by-(d+1) vector containing the coefficients of the polynomial of degree d, highest power first.

List of n polynomials of same degree d n-by-(d+1) matrix containing the coefficients of the polynomials, highest power at left.

List of n roots n-by-1 matrix.

List of n roots for m polynomials of same degree n n-by-m matrix.

Single index One-by-one matrix.

List of indices Any kind of matrix; the real part of each element taken row by row is used.

Sets Numerical array, or list or cell array of strings (see below).

Boolean value One-by-one logical array; 0 means false, and any other value (including nan) means true (comparison and logical operators and functions return logical values). In programs and expressions, constant boolean values are entered as `false` and `true`. Scalar boolean values are displayed as `false` or `true`; in arrays, respectively as F or T.

String Usually 1-by-n char array, but any shape of char arrays are also accepted by most functions.

Unless a conversion function is used explicitly, numbers are represented by double or complex values. Most mathematical functions accept as input any type of numerical value and convert them to double; they return a real or complex value according to their mathematical definition.

Basic element-wise arithmetic and comparison operators accept directly integer types ("element-wise" means the operators + - .* ./ .\ and the functions `mod` and `rem`, as well as operators * / \ with a scalar multiplicand or divisor). If their arguments do not have the same type, they are converted to the size of the largest argument size, in the following order:

`double` > `uint64` > `int64` > `uint32` > `int32` > `uint16` > `int16` > `uint8` > `int8`

Functions which manipulate arrays (such as `reshape` which changes their size or `repmat` which replicates them) preserve their type.

To convert arrays to numerical, char, or logical arrays, use functions + (unary operator), `char`, or `logical` respectively. To convert the numerical types, use functions `double`, `single`, or `uint8` and similar functions.

Numbers

Double and complex numbers are stored as floating-point numbers, whose finite accuracy depends on the number magnitude. During computations, round-off errors can accumulate and lead to visible artifacts; for example, `2-sqrt(2)*sqrt(2)`, which is mathematically `0`, yields `-4.4409e-16`. Integers whose absolute value is smaller than 2ˆ52 (about 4.5e15) have an exact representation, though.

Literal double numbers (constant numbers given by their numerical value) have an optional sign, an integer part, an optional fractional part following a dot, and an optional exponent. The exponent is the power of ten which multiplies the number; it is made of the letter 'e' or 'E' followed by an optional sign and an integer number. Numbers too large to be represented by the floating-point format are changed to plus or minus infinity; too small numbers are changed to 0. Here are some examples (numbers on the same line are equivalent):

```
123 +123 123. 123.00 12300e-2
-2.5 -25e-1 -0.25e1 -0.25e+1
0 0.0 -0 1e-99999
inf 1e999999
-inf -1e999999
```

Literal integer numbers may also be expressed in hexadecimal with prefix `0x`, in octal with prefix `0`, or in binary with prefix `0b`. The four literals below all represent 11, stored as double:

```
0xb
013
0b1011
11
```

Literal integer numbers stored as integers and literal single numbers are followed by a suffix to specify their type, such as `2int16` for the number 2 stored as a two-byte signed number or `0x300uint32` for the number whose decimal representation is 768 stored as a four-byte unsigned number. All the integer types are valid, as well as `single`. This syntax gives the same result as the call to the corresponding function (e.g. `2int16` is the same as `int16(2)`), except when the integer number cannot be represented with a double; then the number is rounded to the nearest value which can be represented with a double. Compare the expressions below:

Expression	**Value**
`uint64(123456789012345678)`	`123456789012345696`
`123456789012345678uint64`	`123456789012345678`

Literal complex numbers are written as the sum or difference of a real number and an imaginary number. Literal imaginary numbers are written as double numbers with an `i` or `j` suffix, like `2i`, `3.7e5j`, or `0xffj`. Functions `i` and `j` can also be used when there are no variables of the same name, but should be avoided for safety reasons.

The suffices for single and imaginary can be combined as `isingle` or `jsingle`, in this order only:

```
2jsingle
3single + 4isingle
```

Command `format` is used to specify how numbers are displayed.

Strings

Strings are stored as arrays (usually row vectors) of 16-bit unsigned numbers. Literal strings are enclosed in single quotes:

```
'Example of string'
''
```

The second string is empty. For special characters, the following escape sequences are recognized:

Character	**Escape seq.**	**Character code**
Null	\0	0
Bell	\a	7
Backspace	\b	8
Horizontal tab	\t	9
Line feed	\n	10
Vertical tab	\v	11
Form feed	\f	12
Carriage return	\r	13
Single tick	\’	39
Single tick	’’ (two ’)	39
Backslash	\\	92
Hexadecimal number	\xhh	hh
Octal number	\ooo	ooo
16-bit UTF-16	\uhhhh	unicode UTF-16 code

For octal and hexadecimal representations, up to 3 (octal) or 2 (hexadecimal) digits are decoded; the first non-octal or non-hexadecimal digit marks the end of the sequence. The null character can conveniently be encoded with its octal representation, `\0`, provided it is not followed by octal digits (it should be written `\000` in that case). It is an error when another character is found after the backslash. Single ticks can be represented either by a backslash followed by a single tick, or by two single ticks.

Depending on the application and the operating system, strings can contain directly Unicode characters encoded as UTF-8, or MBCS (multibyte character sequences). 16-bit characters encoded with \uhhhh escape sequences are always accepted and handled correctly by all built-in LME functions (low-level input/output to files and devices which are byte-oriented is an exception; explicit UTF-8 conversion should be performed if necessary).

Lists and cell arrays

Lists are ordered sets of other elements. They may be made of any type, including lists. Literal lists are enclosed in braces; elements are separated with commas.

```
{1,[3,6;2,9],'abc',{1,'xx'}}
```

Lists can be empty:

```
{}
```

List’s purpose is to collect any kind of data which can be assigned to variables or passed as arguments to functions.

Cell arrays are arrays whose elements (or cells) contain data of any type. They differ from lists only by having more than one dimension.

Most functions which expect lists also accept cell arrays; functions which expect cell arrays treat lists of n elements as 1-by-n cell arrays.

To create a cell array with 2 dimensions, cells are written between braces, where rows are separated with semicolons and row elements with commas:

```
{1, 'abc'; 27, true}
```

Since the use of braces without semicolon produces a list, there is no direct way to create a cell array with a single row, or an empty cell array. Most of the time, this is not a problem since lists are accepted where cell arrays are expected. To force the creation of a cell array, the `reshape` function can be used:

```
reshape({'ab', 'cde'}, 1, 2)
```

Structures

Like lists and cell arrays, structures are sets of data of any type. While list elements are ordered but unnamed, structure elements, called *fields*, have a name which is used to access them. There are two ways to make structures: with the `struct` function, or by setting each field in an assignment. `s.f` refers to the value of the field named `f` in the structure `s`. Usually, `s` is the name of a variable; but unless it is in the left part of an assignment, it can be any expression which evaluates to a structure.

```
a = struct('name', 'Sysquake',
           'os', {'Windows', 'Mac OS X', 'Linux'});

b.x = 200;
b.y = 280;
b.radius = 90;

c.s = b;
```

With the assignments above, `a.os{3}` is `'Linux'` and `c.s.radius` is `90`.

Structure arrays

While structure fields can contain any type of array and cell arrays can have structures stored in their cells, structure arrays are arrays where each element has the same named fields. Structures are structure arrays of size `[1,1]`, like scalar numbers are arrays of size `[1,1]`.

Values are specified first by indices between parenthesis, then by field name. Braces are invalid to access elements of structure arrays (they can be used to access elements of cell arrays stored in structure array fields).

Structure arrays are created from cell arrays with functions `structarray` or `cell2struct`, or by assigning values to fields.

```
A = structarray('name', {'dog','cat'},
                'weight', {[3,100],[3,18]});

B = cell2struct({'dog','cat';[3,100],[3,18]},
                {'name','weight'});

C(1,1).name = 'dog';
C(1,1).weight = [3,100];
C(1,2).name = 'cat';
C(1,2).weight = [3,18];
```

Value sequences

Value sequences are usually written as values separated with commas. They are used as function input arguments or row elements in arrays or lists.

When expressions involving lists, cell arrays or structure arrays evaluate to multiple values, these values are considered as a value sequence, or part of a value sequence, and used as such in context where value sequences are expected. The number of values can be known only at execution time, and may be zero.

```
L = {1, 2};
v = [L{:}];  // convert L to a row vector
c = complex(L{:});  // convert L to a complex number
```

Value sequences can arise from element access of list or cell arrays with brace indexing, or from structure arrays with field access with or without parenthesis indexing.

Function references

Function references are equivalent to the name of a function together with the context in which they are created. Their main use is as argument to other functions. They are obtained with operator @.

Inline and anonymous functions

Inline and anonymous functions encapsulate executable code. They differ only in the way they are created: inline functions are made with function `inline`, while anonymous functions have special syntax and semantics where the values of variables in the current context can be captured implicitly without being listed as argument. Their main use is as argument to other functions.

Sets

Sets are represented with numerical arrays of any type (integer, real or complex double or single, character, or logical), or lists or cell arrays of strings. Members correspond to an element of the array or list. All set-related functions accept sets with multiple values, which are always reduced to unique values with function `unique`. They implement membership test, union, intersection, difference, and exclusive or. Numerical sets can be mixed; the result has the same type as when mixing numerical types in array concatenation. Numerical sets and list or cell arrays os strings cannot be mixed.

Objects

Objects are the basis of *Object-Oriented Programming* (OOP), an approach of programming which puts the emphasis on encapsulated data with a known programmatic interface (the objects). Two OOP languages in common use today are C++ and Java.

The exact definition of OOP varies from person to person. Here is what it means when it relates to LME:

Data encapsulation Objects contain data, but the data cannot be accessed directly from the outside. All accesses are performed via special functions, called *methods*. What links a particular method to a particular object is a `class`. Class are identified with a name. When an object is created, its class name is specified. The names of methods able to act on objects of a particular class are prefixed with the class name followed with two colons. Objects are special structures whose contents are accessible only to its methods.

Function and operator overloading Methods may have the same name as regular functions. When LME has to call a function, it first checks the type of the input arguments. If one of them is an object, the corresponding method is called, rather than the function defined for non-object arguments. A method which has the same name as a function or another method is said to *overload* it. User functions as well as built-in ones can be overloaded. Operators which have a function name (for instance `x+y` can also be written `plus(x,y)`) can also be overloaded. Special functions, called object *constructors*, have the same name as the class and create new objects. They are also methods of the class, even if their input arguments are not necessarily objects.

Inheritance A class (*subclass*) may extend the data and methods of another class (*base class* or *parent*). It is said to *inherit* from the parent. In LME, objects from a subclass contain in a special field an object of the parent class; the field name has the same name as the parent class. If LME does not find a method for an object, it tries to find one for its parent, great-parent, etc. if any. An object can also inherit from several parents.

Here is an example of the use of `polynom` objects, which (as can be guessed from their name) contain polynomials. Statement `use classes` imports the definitions of methods for class `polynom` and others.

```
use classes;
p = polynom([1,5,0,1])
  p =
    x^3+5x^2+1
q = p^2 + 3 * p / polynom([1,0])
  q =
    x^6+10x^5+25x^4+2x^3+13x^2+15x+1
```

3.5 Input and Output

LME identifies channels for input and output with non-negative integer numbers called *file descriptors*. File descriptors correspond to files, devices such as serial port, network connections, etc. They are used as input argument by most functions related to input and output, such as `fprintf` for formatted data output or `fgets` for reading a line of text.

Note that the description below applies to most LME applications. For some of them, files, command prompts, or standard input are irrelevant or disabled; and standard output does not always correspond to the screen.

At least four file descriptors are predefined:

Value	**Input/Output**	**Purpose**
0	Input	Standard input from keyboard
1	Output	Standard output to screen
2	Output	Standard error to screen
3	Output	Prompt for commands

You can use these file descriptors without calling any opening function first, and you cannot close them. For instance, to display the value of π, you can use `fprintf`:

```
fprintf(1, 'pi = %.6f\n', pi);
  pi = 3.141593
```

Some functions use implicitly one of these file descriptors. For instance `disp` displays a value to file descriptor 1, and `warning` displays a warning message to file descriptor 2.

File descriptors for files and devices are obtained with specific functions. For instance `fopen` is used for reading from or writing to a file. These functions have as input arguments values which specify what to open and how (file name, host name on a network, input or output mode, etc.), and as output argument a file descriptor. Such file descriptors are valid until a call to `fclose`, which closes the file or the connection.

3.6 Error Messages

When an error occurs, the execution is interrupted and an error message explaining what happened is displayed, unless the code is enclosed in a try/catch block. The whole error message can look like

```
> use stat
> iqr(123})

Index out of range for variable 'M' (stat/prctile;61)
-> stat/iqr;69
```

The first line contains an error message, the location in the source code where the error occurred, and the name of the function or operator involved. Here `stat` is the library name, `prctile` is the function name, and 61 is the line number in the file which contains the library. If the function where the error occurs is called itself by another function, the whole chain of calls is displayed; here, `prctile` was called by `iqr` at line 69 in library `stat`.

Here is the list of errors which can occur. For some of them, LME attempts to solve the problem itself, e.g. by allocating more memory for the task.

Stack overflow Too complex expression, or too many nested function calls.

Data stack overflow Too large objects on the stack (in expressions or in nested function calls).

Variable overflow Not enough space to store the contents of a variable.

Code overflow Not enough memory for compiling the program.

Not enough memory Not enough memory for an operation outside the LME core.

Algorithm does not converge A numerical algorithm does not converge to a solution, or does not converge quickly enough. This usually means that the input arguments have invalid values or are ill-conditioned.

Incompatible size Size of the arguments of an operator or a function do not agree together.

Bad size Size of the arguments of a function are invalid.

Non-vector array A row or column vector was expected, but a more general array was found.

Not a column vector A column vector was expected, but a more general array was found.

Not a row vector A row vector was expected, but a more general array was found.

Non-matrix array A matrix was expected, but an array with more than 2 dimensions was found.

Non-square matrix A square matrix was expected, but a rectangular matrix was found.

Index out of range Index negative or larger than the size of the array.

Wrong type String or complex array instead of real, etc.

Non-integer argument An argument has a fractional part while an integer is required.

Argument out of range An argument is outside the permitted range of values.

Non-scalar argument An argument is an array while a scalar number is required.

Non-object argument An object is required as argument.

Not a permutation The argument is not a permutation of the integers from 1 to n.

Bad argument A numerical argument has the wrong site or the wrong value.

Unknown option A string option has an invalid value.

Object too large An object has a size larger than some fixed limit.

Undefined variable Attempt to retrieve the contents of a variable which has not been defined.

Undefined input argument Attempt to retrieve the contents of an input argument which was neither provided by the caller nor defined in the function.

Undefined function Attempt to call a function not defined.

Too few or too many input arguments Less or more arguments in the call than what the function accepts.

Too few or too many output arguments Less or more left-side variables in an assignment than the function can return.

Syntax error Unspecified compile-time error.

"function" keyword without function name Incomplete function header.

Bad function header Syntax error in a function header

Missing expression Statement such as `if` or `while` without expression.

Unexpected expression Statement such as end or `else` followed by an expression.

Incomplete expression Additional elements were expected during the compilation of an expression, such as right parenthesis or a sub-expression at the right of an operator.

"for" not followed by a single assignment `for` is followed by an expression or an assignment with multiple variables.

Bad variable name The left-hand part of an assignment is not a valid variable name (e.g. 2=3)

String without right quote The left quote of a string was found, but the right quote is missing.

Unknown escape character sequence In a string, the backslash character is not followed by a valid escape sequence.

Unexpected right parenthesis Right parenthesis which does not match a left parenthesis.

Unexpected right bracket Right bracket which does not match a left bracket.

Unrecognized or unexpected token An unexpected character was found during compilation (such as (1+))

"end" not in an index expression end was used outside of any index sub-expression in an expression.

"beginning" not in an index expression `beginning` was used outside of any index sub-expression in an expression.

"matrixcol" not in an index expression `matrixcol` was used outside of any index sub-expression in an expression.

"matrixrow" not in an index expression `matrixrow` was used outside of any index sub-expression in an expression.

"matrixrow" or "matrixcol" used in the wrong index `matrixrow` was used in an index which was not the first one, or `matrixcol` was used in an index which was not the only one or the second one.

Compilation overflow Not enough memory during compilation.

Too many nested subexpressions The number of nested of subexpressions is too high.

Variable table overflow A single statement attempts to define too many new variables at once.

Expression too large Not enough memory to compile a large expression.

Too many nested (), [] and {} The maximum depth of nested subexpressions, function argument lists, arrays and lists is reached.

Too many nested programming structures Not enough memory to compile that many nested programming structures such as `if`, `while`, `switch`, etc.

Wrong number of input arguments Too few or too many input arguments for a built-in function during compilation.

Wrong number of output arguments Too few or too many output arguments for a built-in function during compilation.

Too many indices More than two indices for a variable.

Variable not found A variable is referenced, but appears neither in the arguments of the function nor in the left part of an assignment.

Unbounded language construct `if`, `while`, `for`, `switch`, or `try` without end.

Unexpected "end" The end statement does not match an `if`, `switch`, `while`, `for`, or `catch` block.

"case" or "otherwise" without "switch" The `case` or `otherwise` statement is not inside a `switch` block.

"catch" without "try" The `catch` statement does not match a `try` block.

"break" or "continue" not in a loop The `break` or `continue` statement is not inside a `while` or `for block`.

Variable name reused Same variable used twice as input or as output argument.

Too many user functions Not enough memory for that many user functions.

Attempt to redefine a function A function with the same name already exists.

Can't find function definition Cannot find a function definition during compilation.

Unexpected end of expression Missing right parenthesis or square bracket.

Unexpected statement Expression expected, but a statement is found (e.g. `if`).

Null name Name without any character (when given as a string in functions like `feval` and `struct`).

Name too long More than 32 characters in a variable or function name.

Unexpected function header A function header (keyword "function") has been found in an invalid place, for example in the argument of `eval`.

Function header expected A function header was expected but not found.

Bad variable in the left part of an assignment The left part of an assignment does not contain a variable, a structure field, a list element, or the part of an array which can be assigned to.

Bad variable in a for loop The left part of the assignment of a for loop is not a variable.

Source code not found The source code of a function is not available.

File not found `fopen` does not find the file specified.

Bad file ID I/O function with a file descriptor which neither is standard nor corresponds to an open file or device.

Cannot write to file Attempt to write to a read-only file.

Bad seek Seek out of range or attempted on a stream file.

Too many open files Attempt to open too many files.

End of file Attempt to read data past the end of a file.

Timeout Input or output did not succeed before a too large amount of time elapsed.

No more OS memory The operating system cannot allocate more memory.

Bad context Call of a function when it should not (application-dependent).

Not supported The feature is not supported, at least in the current version.

3.7 Variable Assignment and Subscripting

Variable assignment

Assignment to a variable or to some elements of a matrix variable.

Syntax

```
var = expr
(var1, var2, ...) = function(...)
```

Description

`var = expr` assigns the result of the expression `expr` to the variable `var`. When the expression is a naked function call, `(var1,var2,...) = function(...)` assigns the value of the output arguments of the function to the different variables. Usually, providing less variables than the function can provide just discards the superfluous output arguments; however, the function can also choose to perform in a different way (an example of such a function is `size`, which returns the number of rows and the number of columns of a matrix either as two numbers if there are two output arguments, or as a 1-by-2 vector if there is a single output argument). Providing more variables than what the function can provide is an error.

Variables can store any kind of contents dynamically: the size and type can change from assignment to assignment.

A subpart of a matrix variable can be replaced with the use of parenthesis. In this case, the size of the variable is expanded when required; padding elements are 0 for numeric arrays and empty arrays [] for cell arrays and lists.

See also

Operator (), operator {}, `clear`, `exist`, `for`, `subsasgn`

beginning

First index of an array.

Syntax

```
v(...beginning...)
A(...beginning...)
function e = C::beginning(obj, i, n)
```

Description

In an expression used as an index to access some elements of an array, `beginning` gives the index of the first element (line or column, depending of the context). It is always 1 for native arrays.

`beginning` can be overloaded for objects of used-defined classes. Its definition should be have a header equivalent to `function e=C::beginning(obj,i,n)`, where `C` is the name of the class, `obj` is the object to be indexed, `i` is the position of the index expression where `beginning` is used, and `n` is the total number of index expressions.

See also

Operator (), operator {}, `beginning`, `end`, `matrixcol`, `matrixrow`

end

Last index of an array.

Syntax

```
v(...end...)
A(...end...)
function e = C::end(obj, i, n)
```

Description

In an expression used as an index to access some elements of an array, end gives the index of the last element (line or column, depending of the context).

end can be overloaded for objects of used-defined classes. Its definition should be have a header equivalent to `function e=C::end(obj,i,n)`, where `C` is the name of the class, `obj` is the object to be indexed, `i` is the position of the index expression where end is used, `n` is the total number of index expressions.

Examples

Last 2 elements of a vector:

```
a = 1:5; a(end-1:end)
    4 5
```

Assignment to the last element of a vector:

```
a(end) = 99
  a =
    1 2 3 4 99
```

Extension of a vector:

```
a(end + 1) = 100
  a =
    1 2 3 4 99 100
```

See also

Operator `()`, operator `{}`, `size`, `length`, `beginning`, `matrixcol`, `matrixrow`

global persistent

Declaration of global or persistent variables.

Syntax

```
global x y ...
persistent x y ...
```

Description

By default, all variables are *local* and created the first time they are assigned to. Local variables can be accessed only from the body of the function where they are defined, but not by any other function, even the ones they call. They are deleted when the function exits. If the function is called recursively (i.e. if it calls itself, directly or indirectly), distinct variables are defined for each call. Similarly, local variables defined in the workspace using the command-line interface cannot be referred to in functions.

On the other hand, *global variables* can be accessed by multiple functions and continue to exist even after the function which created them exits. Global variables must be declared with `global` in each functions which uses them. They can also be declared in the workspace. There exists only a single variable for each different name.

Declaring a global variable has the following result:

- If a previous local variable with the same name exists, it is deleted.
- If the global variable does not exist, it is created and initialized with the empty array `[]`.
- Every access which follows the declaration in the same function or workspace uses the global variable.

Like global variables, *persistent variables* are preserved between function calls; but they cannot be shared between different functions. They are declared with `persistent`. They cannot be declared outside a function. Different persistent functions can have the same name in different functions.

Examples

Functions to reset and increment a counter:

```
function reset
  global counter;
  counter = 0;

function value = increment
  global counter;
  counter = counter + 1;
  value = counter;
```

Here is how the counter can be used:

```
reset;
i = increment
```

```
  i =
    1
j = increment
  j =
    2
```

See also

`function`

matrixcol

First index in a subscript expression.

Syntax

```
A(...matrixcol...)
function e = C::matrixcol(obj, i, n)
```

Description

In an expression used as a single subscript to access some elements of an array `A(expr)`, `matrixcol` gives an array of the same size as `A` where each element is the column index. For instance for a 2-by-3 matrix, `matrixcol` gives the 2-by-3 matrix `[1,1,1;2,2,2]`.

In an expression used as the second of multiple subscripts to access some elements of an array `A(...,expr)` or `A(...,expr,...)`, `matrixcol` gives a row vector of length `size(A,2)` whose elements are the indices of each column. It is equivalent to the range `(beginning:end)`.

`matrixcol` is useful in boolean expressions to select some elements of an array.

`matrixcol` can be overloaded for objects of used-defined classes. Its definition should have a header equivalent to `function e=C::matrixcol(obj,i,n)`, where `C` is the name of the class, `obj` is the object to be indexed, `i` is the position of the index expression where `matrixcol` is used, and `n` is the total number of index expressions.

Example

Set to 0 the NaN values which are not in the first column:

```
A = [1, nan, 5; nan, 7, 2; 3, 1, 2];
A(matrixcol > 1 & isnan(A)) = 0
  A =
      1   0   5
    nan   7   2
      3   1   2
```

See also

`matrixrow`, `beginning`, `end`

matrixrow

First index in a subscript expression.

Syntax

```
A(...matrixrow...)
function e = C::matrixrow(obj, i, n)
```

Description

In an expression used as a single subscript to access some elements of an array `A(expr)`, `matrixrow` gives an array of the same size as `A` where each element is the row index. For instance for a 2-by-3 matrix, `matrixrow` gives the 2-by-3 matrix `[1,2,3;1,2,3]`.

In an expression used as the first of multiple subscripts to access some elements of an array `A(expr,...)`, `matrixrow` gives a row vector of length `size(A,1)` whose elements are the indices of each row. It is equivalent to the range `(beginning:end)`.

`matrixrow` is useful in boolean expressions to select some elements of an array.

`matrixrow` can be overloaded for objects of used-defined classes. Its definition should be have a header equivalent to `function e=C::matrixrow(obj,i,n)`, where `C` is the name of the class, `obj` is the object to be indexed, `i` is the position of the index expression where `matrixrow` is used, and `n` is the total number of index expressions.

See also

`matrixcol`, `beginning`, `end`

subsasgn

Assignment to a part of an array, list, or structure.

Syntax

```
A = subsasgn(A, s, B)
```

Description

When an assignment is made to a subscripted part of an object in a statement like `A(s1,s2,...)=B`, LME executes `A=subsasgn(A,s,B)`, where `subsasgn` is a method of the class of variable `A` and `s` is a structure with two fields: `s.type` which is `'()'`, and `s.subs` which is the list of subscripts `{s1,s2,...}`. If a subscript is the colon character which stands for all elements along the corresponding dimensions, it is represented with the string `':'` in `s.subs`.

When an assignment is made to a subscripted part of an object in a statement like `A{s}=B`, LME executes `A=subsasgn(A,s,B)`, where `subsasgn` is a method of the class of variable `A` and `s` is a structure with two fields: `s.type` which is `'{}'`, and `s.subs` which is the list containing the single subscript `{s}`.

When an assignment is made to the field of an object in a statement like `A.f=B`, LME executes `A=subsasgn(A,s,B)`, where `s` is a structure with two fields: `s.type` which is `'.'`, and `s.subs` which is the name of the field (`'f'` in this case).

While the primary purpose of `subsasgn` is to permit the use of subscripts with objects, a built-in implementation of `subsasgn` is provided for arrays when `s.type` is `'()'`, for lists when `s.type` is a list, and for structures when `s.type` is `'.'`.

Examples

```
A = [1,2;3,4];
subsasgn(A, struct('type','()','subs',{1,':'}), 999)
  999 999
    3   4
subsasgn(A, struct('type','()','subs',{':',1}), [])
    2
    4
```

See also

Operator `()`, operator `{}`, `subsref`, `beginning`, `end`

subsref

Reference to a part of an array, list, or structure.

Syntax

```
B = subsref(A, s)
```

Description

When an object variable is subscripted in an expression like `A(s1,s2,...)`, LME evaluates `subsref(A,s)`, where `subsref` is a method of the class of variable `A` and `s` is a structure with two fields: `s.type` which is `'()'`, and `s.subs` which is the list of subscripts `{s1,s2,...}`. If a subscript is the colon character which stands for all elements along the corresponding dimensions, it is represented with the string `':'` in `s.subs`.

When an object variable is subscripted in an expression like `A{s}`, LME evaluates `subsref(A,s)`, where `subsref` is a method of the class of variable `A` and `s` is a structure with two fields: `s.type` which is `'{}'`, and `s.subs` which is the list containing the single subscript `{s}`.

When the field of an object variable is retrieved in an expression like `A.f`, LME executes `subsref(A,s)`, where `s` is a structure with two fields: `s.type` which is `'.'`, and `s.subs` which is the name of the field (`'f'` in this case).

While the primary purpose of `subsref` is to permit the use of subscripts with objects, a built-in implementation of `subsref` is provided for arrays when `s.type` is `'()'`, for lists when `s.type` is `'{}'`, and for structures when `s.type` is `'.'`.

Examples

```
A = [1,2;3,4];
subsref(A, struct('type','()','subs',{1,':'}))
  1 2
```

See also

Operator `()`, operator `{}`, `subsasgn`, `beginning`, `end`

3.8 Programming Constructs

Programming constructs are the backbone of any LME program. Except for the variable assignment, all of them use reserved keywords which may not be used to name variables or functions. In addition to the constructs described below, the following keywords are reserved for future use:

```
  classdef    goto
```

break

Terminate loop immediately.

Syntax

```
break
```

Description

When a `break` statement is executed in the scope of a loop construct (`while`, `repeat` or `for`), the loop is terminated. Execution continues at the statement which follows end. Only the innermost loop where `break` is located is terminated.

The loop must be in the same function as `break`. It is an error to execute `break` outside any loop.

See also

`while`, `repeat`, `for`, `continue`, `return`

case

Conditional execution of statements depending on a number or a string.

See also

`switch`

catch

Error recovery.

See also

`try`

continue

Continue loop from beginning.

Syntax

```
continue
```

Description

When a `continue` statement is executed in the scope of a loop construct (`while`, `repeat` or `for`), statements following `continue` are ignored and a new loop is performed if the loop termination criterion is not fulfilled.

The loop must be in the same function as `continue`. It is an error to execute `continue` outside any loop.

See also

`while`, `repeat`, `for`, `break`

define

Definition of a constant.

Syntax

```
define c = expr
define c = expr;
```

Description

`define c=expr` assign permanently expression `expr` to `c`. It is equivalent to

```
function y = c
  y = expr;
```

Since `c` does not have any input argument, the expression is usually constant. A semicolon may follow the definition, but it does not have any effect. `define` must be the first element of the line (spaces and comments are skipped).

Examples

```
define e = exp(1);
define g = 9.81;
define c = 299792458;
define G = 6.672659e-11;
```

See also

`function`

for

Loop controlled by a variable which takes successively the value of the elements of a vector or a list.

Syntax

```
for v = vect
    s1
    ...
end

for v = list
    s1
    ...
end
```

Description

The statements between the `for` statement and the corresponding end are executed repeatedly with the control variable v taking successively every column of `vect` or every element of list `list`. Typically, `vect` is a row vector defined with the range operator.

You can change the value of the control variable in the loop; however, next time the loop is repeated, that value is discarded and the next column of `vect` is fetched.

Examples

```
for i = 1:3; i, end
  i =
    1
  i =
    2
  i =
    3
```

```
for i = (1:3)'; i, end
  i =
    1
    2
    3
for i = 1:2:5; end; i
  i =
    5
for i = 1:3; break; end; i
  i =
    1
for el = {1,'abc',{2,5}}; el, end
  el =
    1
  el =
    abc
  el =
    {2,5}
```

See also

while, repeat, break, continue, variable assignment

function endfunction

Definition of a function, operator, or method.

Syntax

```
function f
   statements

function f(x1, x2, ...)
   statements

function f(x1, x2 = expr2, ...)
   statements

function y = f(x1, x2, ...)
   statements

function (y1,y2,...) = f(x1,x2,...)
   statements

function ... class::method ...
   statements

function ...
```

```
    statements
  endfunction
```

Description

New functions can be written to extend the capabilities of LME. They begin with a line containing the keyword `function`, followed by the list of output arguments (if any), the function name, and the list of input arguments between parenthesis (if any). The output arguments must be enclosed between parenthesis or square brackets if they are several. One or more variable can be shared in the list of input and output arguments. When the execution of the function terminates (either after the last statement or because of the command `return`), the current value of the output arguments, as set by the function's statements, is given back to the caller. All variables used in the function's statements are local; their value is undefined before the first assignment (and it is illegal to use them in an expression), and is not shared with variables in other functions or with recursive calls of the same function. Different kinds of variables can be declared explicitly with `global` and `persistent`.

When multiple functions are defined in the same code source (for instance in a library), the body of a function spans from its header to the next function or until the `endfunction` keyword, whichever comes first. Function definitions cannot be nested. `endfunction` is required only when the function definition is followed by code to be executed outside the scope of any function. This includes mixed code and function definitions entered in one large entry in a command-line interface, or applications where code is mainly provided as statements, but where function definitions can help and separate libraries are not wished (note that libraries cannot contain code outside function definitions; they do never require `endfunction`). Like `function`, `endfunction` must be the first element of a line.

Not all of the input and output arguments are necessarily used. The caller fixes the number of input and output arguments, which can be retrieved by the called function with `nargin` and `nargout`, respectively. The unused input arguments (from nargin+1 to the last one) are undefined, unless a default value is provided in the function definition: with the definition `function f(x,y=2)`, y is 2 when `f` is called with a single input argument. The unused output arguments (from nargout+1 to the last one) do not have to be set, but may be.

To redefine an operator (which is especially useful for object methods; see below), use the equivalent function, such as `plus` for operator +. The complete list is given in the section about operators.

To define a method which is executed when one of the input arguments is an object of class `class` (or a child in the classes hierarchy), add `class::` before the method (function) name. To call it, use only the method name, not the class name.

Examples

Function with optional input and output arguments:

```
function (Sum, Prod) = calcSumAndProd(x, y)
  if nargout == 0
    return;           % nothing to be computed
  end
  if nargin == 0      % make something to be computed...
    x = 0;
  end
  if nargin <= 1       % sum of elements of x
    Sum = sum(x);
  else                % sum of x and y
    Sum = x + y;
  end
  if nargout == 2     % also compute the product
    if nargin == 1    % product of elements of x
      Prod = prod(x);
    else              % product of x and y
      Prod = x .* y;
    end
  end
```

Two equivalent definitions:

```
function S = area(a, b = a, ellipse = false)
  S = ellipse ? pi * a * b / 4 : a * b;

function S = area(a, b, ellipse)
  if nargin < 2
    b = a;
  end
  if nargin < 3
    ellipse = false;
  end
  S = ellipse ? pi * a * b / 4 : a * b;
```

See also

`return`, `nargin`, `nargout`, `define`, `inline`, `global`, `persistent`

if elseif else end

Conditional execution depending on the value of one or more boolean expressions.

Syntax

```
if expr
    s1
    ...
end

if expr
    s1
    ...
else
    s2
    ...
end

if expr1
    s1
    ...
elseif expr2
    s2
    ...
else
    s3
    ...
end
```

Description

If the expression following `if` is true (nonempty and all elements different from 0 and false), the statements which follow are executed. Otherwise, the expressions following `elseif` are evaluated, until one of them is true. If all expressions are false, the statements following `else` are executed. Both `elseif` and `else` are optional.

Example

```
if x > 2
  disp('large');
elseif x > 1
  disp('medium');
else
  disp('small');
end
```

See also

`switch`, `while`

include

Include libraries.

Syntax

```
include lib
```

Description

`include lib` inserts the contents of the library file `lib`. Its effect is similar to the `use` statement, except that the functions and constants in `lib` are defined in the same context as the library where `include` is located. Its main purpose is to permit to define large libraries in multiple files in a transparent way for the user. `include` statements must not follow other statements on the same line, and can reference only one library which is searched at the same locations as `use`. They can be used only in libraries.

Since LME replaces `include` with the contents of `lib`, one should be cautious about the public or private context which is preserved between the libraries. It is possible to include a fragment of function without a function header.

See also

`use`, `includeifexists`, `private`, `public`

includeifexists

Include library if it exists.

Syntax

```
includeifexists lib
```

Description

`includeifexists lib` inserts the contents of the library file `lib` if it exists; if the library does not exists, it does nothing.

See also

`include`, `useifexists`, `private`, `public`

otherwise

Conditional execution of statements depending on a number or a string.

See also

`switch`

private

Mark the beginning of a sequence of private function definitions in a library.

Syntax

```
private
```

Description

In a library, functions which are defined after the `private` keyword are private. `private` may not be placed in the same line of source code as any other command (comments are possible, though).

In a library, functions are either public or private. Private functions can only be called from the same library, while public functions can also be called from contexts where the library has been imported with a use command. Functions are public by default.

Example

Here is a library for computing the roots of a second-order polynomial. Only function `roots2` may be called from the outside of the library.

```
private
function d = discr(a, b, c)
  d = b^2 - 4 * a * c;
public
function r = roots2(p)
  a = p(1);
  b = p(2);
  c = p(3);
  d = discr(a, b, c);
  r = [-b+sqrt(d); -b-sqrt(d)] / (2 * a);
```

See also

`public`, `function`, `use`

public

Mark the beginning of a sequence of public function definitions in a library.

Syntax

```
public
```

Description

In a library, functions which are defined after the `public` keyword are public. `public` may not be placed in the same line of source code as any other command (comments are possible, though).

In a library, functions are either public or private. Private functions can only be called from the same library, while public functions can also be called from contexts where the library has been imported with a `use` command. Functions are public by default: the `public` keyword is not required at the beginning of the library.

See also

`private`, `function`, `use`

repeat

Loop controlled by a boolean expression.

Syntax

```
repeat
    s1
    ...
until expr
```

Description

The statements between the `repeat` statement and the corresponding `until` are executed repeatedly (at least once) until the expression of the `until` statement yields true (nonempty and all elements different from 0 and false).

Example

```
v = [];
repeat
  v = [v, sum(v)+1];
until v(end) > 100;
v
    1   2   4   8  16  32  64 128
```

See also

`while`, `for`, `break`, `continue`

return

Early return from a function.

Syntax

```
return
```

Description

`return` stops the execution of the current function and returns to the calling function. The current value of the output arguments, if any, is returned. `return` can be used in any control structure, such as `if`, `while`, or `try`, or at the top level.

Example

```
function dispFactTable(n)
  % display the table of factorials from 1 to n
  if n == 0
    return;  % nothing to display
  end
  fwrite(' i   i!\n');
  for i = 1:n
    fwrite('%2d  %3d\n', i, prod(1:i));
  end
```

See also

`function`

switch

Conditional execution of statements depending on a number or a string.

Syntax

```
switch expr
    case e1
        s1
        ...
    case [e2,e3,...]
        s23
        ...
    case {e4,e5,...}
        s45
        ...
    otherwise
        so
        ...
end

switch string
    case str1
        s1
        ...
    case str2
        s2
        ...
    case {str3,str4,...}
        s34
        ...
    otherwise
        so
        ...
end
```

Description

The expression of the `switch` statement is evaluated. If it yields a number, it is compared successively to the result of the expressions of the case statements, until it matches one; then the statements which follow the `case` are executed until the next `case`, `otherwise` or end. If the case expression yields a vector or a list, a match occurs if the switch expression is equal to any of the elements of the case expression. If no match is found, but `otherwise` is present, the statements following `otherwise` are executed. If the switch expression yields a string, a match occurs only in case of equality with a case string expression or any element of a case list expression.

Example

```
switch option
  case 'arithmetic'
    m = mean(data);
  case 'geometric'
    m = prod(data)^(1/length(data));
  otherwise
    error('unknown option');
end
```

See also

`if`

try

Error recovery.

Syntax

```
try
  ...
end

try
  ...
catch
  ...
end
```

Description

The statements after `try` are executed. If an error occurs, execution is switched to the statements following `try`, if any, or to the statements following end. The error message can be retrieved with `lasterr` or `lasterror`. If no error occurs, the statements between `try` and end are ignored.

`try` ignores two errors:

– the interrupt key (Control-Break on Windows, Command-. on Mac OS X, Control-C on other operating systems with a keyboard, timeout in Sysquake Remote);

– an attempt to execute an untrusted function in a sandbox. The error can be handled only outside the sandbox.

Examples

```
a = 1;
a(2), 555
  Index out of range ’a’
try, a(2), end, 555
  555
try, a(2), catch, 333, end, 555
  333
  555
try, a, catch, 333, end, 555
  a =
    1
  555
```

See also

`lasterr`, `lasterror`, `error`

until

End of repeat/until loop.

See also

`repeat`

use

Import libraries.

Syntax

```
use lib
use lib1, lib2, ...
```

Description

Functions may be defined in separate files, called *libraries*. `use` makes them available in the current context, so that they may be called by the functions or statements which follow. Using a library does not make available functions defined in its sublibraries; however, libraries may be used multiple times, in each context where their functions are referenced.

All `use` statements are parsed before execution begins. They may be placed anywhere in the code, typically before the first function.

They cannot be skipped by placing them after an `if` statement. Likewise, `try/catch` cannot be used to catch errors; `useifexists` should be used if the absence of the library is to be ignored.

See also

`useifexists`, `include`, `function`, `private`, `public`, `info`

useifexists

Import libraries if they exist.

Syntax

```
useifexists lib
useifexists lib1, lib2, ...
```

Description

`useifexists` has the same syntax and effect as `use`, except that libraries which are not found are ignored without error.

See also

`use`, `include`, `function`, `private`, `public`, `info`

while

Loop controlled by a boolean expression.

Syntax

```
while expr
    s1
    ...
end
```

Description

The statements between the `while` statement and the corresponding `end` are executed repeatedly as long as the expression of the `while` statement yields true (nonempty and all elements different from 0 and false).

If a `break` statement is executed in the scope of the while loop (i.e. not in an enclosed loop), the loop is terminated.

If a continue statement is executed in the scope of the while loop, statements following continue are ignored and a new loop is performed if the while statement yields true.

Example

```
e = 1;
i = 2;
while true  % forever
  eNew = (1 + 1/i) ^ i;
  if abs(e - eNew) < 0.001
    break;
  end
  e = eNew;
  i = 2 * i;
end
e
  2.717
```

See also

repeat, for, break, continue, if

3.9 Debugging Commands

dbclear

Remove a breakpoint.

Syntax

```
dbclear fun
dbclear fun line
dbclear('fun', line)
dbclear
```

Description

dbclear fun removes all breakpoints in function fun. dbclear fun line or dbclear('fun',line) removes the breakpoint in function fun at line number line.

Without argument, dbclear removes all breakpoints.

See also

dbstop, dbstatus

dbcont

Resume execution.

Syntax

```
dbcont
```

Description

When execution has been suspended by a breakpoint or `dbhalt`, it can be resumed from the command-line interface with `dbcont`.

See also

`dbstop`, `dbhalt`, `dbstep`, `dbquit`

dbhalt

Suspend execution.

Syntax

```
dbhalt
```

Description

In a function, `dbhalt` suspends normal execution as if a breakpoint had been reached. Commands `dbstep`, `dbcont` and `dbquit` can then be used from the command line to resume or abort execution.

See also

`dbstop`, `dbcont`, `dbquit`

dbquit

Abort suspended execution.

Syntax

```
dbquit
```

Description

When execution has been suspended by a breakpoint or `dbhalt`, it can be aborted completely from the command-line interface with `dbquit`.

See also

`dbstop`, `dbcont`, `dbhalt`

dbstack

Chain of function calls.

Syntax

```
dbstack
s = dbstack
dbstack all
s = dbstack('all')
```

Description

`dbstack` displays the chain of function calls which lead to the current execution point, with the line number where the call to the subfunction is made. It can be executed in a function or from the command-line interface when execution is suspended with a breakpoint or `dbhalt`.

`dbstack all` (or `dbstack('all')`) displays the whole stack of function calls. For instance, if two executions are successively suspended at breakpoints, `dbstack` displays only the second chain of function calls, while `dbstack all` displays all functions.

With an output argument, `dbstack` returns the result as a structure array. Field `name` contains the function name (or class and method names), and field `line` the line number. Note that you cannot assign the result of `dbstack` to a new variable in suspended mode.

Examples

```
use stat
dbstop prctile
iqr(rand(1,1000))
  <prctile:45>  if nargin < 3
dbstack
  stat/prctile;45
  stat/iqr;69
```

See also

`dbstop`, `dbhalt`

dbstatus

Display list of breakpoints.

Syntax

```
dbstatus
dbstatus fun
```

Description

`dbstatus` displays the list of all breakpoints. `dbstatus fun` displays the list of breakpoints in function `fun`.

See also

`dbstop`, `dbclear`, `dbtype`

dbstep

Execute a line of instructions.

Syntax

```
dbstep
dbstep in
dbstep out
```

Description

When normal execution is suspended after a breakpoint set with `dbstop` or the execution of function `dbhalt`, `dbstep`, issued from the command line, executes the next line of the suspended function. If the line is the last one of the function, execution resumes in the calling function.

`dbstep in` has the same effect as `dbstep`, except if a subfunction is called. In this case, execution is suspended at the beginning of the subfunction.

`dbstep out` resumes execution in the current function and suspends it in the calling function.

Example

Load library `stdlib` and put a breakpoint at the beginning of function `linspace`:

```
use stdlib
dbstop linspace
```

Start execution of function `linspace` until the breakpoint is reached (the next line to be executed is displayed):

```
v = linspace(1,2,5)
  <linspace:8>   if nargin < 3
```

When the execution is suspended, any function can be called. Local variables of the function can be accessed and changed; but no new variable can be created. Here, the list of variables and the value of x2 are displayed:

```
info v
  r (not defined)
  x1 (1x1)
  x2 (1x1)
  n (1x1)
x2
  x2 =
    2
```

Display the stack of function calls:

```
dbstack
  stdlib/linspace;8
```

Execute next line:

```
dbstep
  <linspace:11>     r = x1 + (x2 - x1) * (0:n-1) / (n-1);
```

Execute last line; then normal execution is resumed:

```
dbstep
  v =
    1  1.25  1.5  1.75  2
```

Display breakpoint and clear it:

```
dbstatus
  stdlib/linspace;0
dbclear
```

See also

`dbstop`, `dbcont`, `dbquit`

dbstop

Set a breakpoint.

Syntax

```
dbstop fun
dbstop fun line
dbstop('fun', line)
```

Description

`dbstop fun` sets a breakpoint at the beginning of function `fun`. `dbstop fun line` or `dbstop('fun',line)` sets a breakpoint in function `fun` at line `line`.

When LME executes a line where a breakpoint has been set, it suspends execution and returns to the command-line interface. The user can inspect or change variables, executes expressions or other functions, continue execution with `dbstep` or `dbcont`, or abort execution with `dbquit`.

Example

```
use stdlib
dbstop linspace
dbstatus
  stdlib/linspace;0
dbclear linspace
```

See also

`dbhalt`, `dbclear`, `dbstatus`, `dbstep`, `dbcont`, `dbquit`, `dbtype`

dbtype

Display source code with line numbers, breakpoints, and current execution point.

Syntax

```
dbtype fun
dbtype
```

Description

dbtype fun displays the source code of function fun with line numbers, breakpoints, and the position where execution is suspended (if it is in fun). Without argument, dbtype displays the function which is suspended.

dbtype can be used at any time to check the source code of any function known to LME.

Example

```
use stdlib
dbstop linspace
linspace(1,2,5);
  <linspace:8>   if nargin < 3
dbstep
  <linspace:11>    r = x1 + (x2 - x1) * (0:n-1) / (n-1);
dbtype
   #   6 function r = linspace(x1, x2, n)
       7
       8  if nargin < 3
       9    n = 100;
      10  end
  >   11  r = x1 + (x2 - x1) * (0:n-1) / (n-1);
```

See also

dbstatus, dbstack, echo

echo

Echo of code before its execution.

Syntax

```
echo on
echo off
echo fun on
echo(state)
echo(state, fd)
echo(fun, state)
echo(fun, state, fd)
```

Description

echo on enables the display of an echo of each line of function code before execution. The display includes the function name and the line number. `echo off` disables the echo.

The argument can also be passed as a boolean value with the functional form `echo(state)`: `echo on` is equivalent to `echo(true)`.

`echo fun on` enables echo for function named `fun` only. `echo fun off` disables echo (the function name is ignored); `echo off` has the same effect.

By default, the echo is output to the standard error channel (file descriptor 2). Another file descriptor can be specified as an additional numeric argument, with the functional form only.

Example

Trace of a function:

```
use stdlib
echo on
C = compan([2,5,4]);
  compan  26  if min(size(v)) > 1
  compan  29  v = v(:).';
  compan  30  n = length(v);
  compan  31  M = [-v(2:end)/v(1); eye(n-2, n-1)];
```

Echo stored into a file `'log.txt'`:

```
fd = fopen('log.txt', 'w');
echo(true, fd);
...
echo off
fclose(fd);
```

See also

`dbtype`

3.10 Miscellaneous Functions

This section describes functions related to programming: function arguments, error processing, evaluation, memory.

assert

Check that an assertion is true.

Syntax

```
assert(expr)
assert(expr, str)
assert(expr, format, arg1, arg2, ...)
assert(expr, identifier, format, arg1, arg2, ...)
```

Description

`assert(expr)` checks that `expr` is true and throws an error otherwise. Expression `expr` is considered to be true if it is a non-empty array whose elements are all non-zero.

With more input arguments, `assert` checks that `expr` is true and throws the error specified by remaining arguments otherwise. These arguments are the same as those expected by function `error`.

When the intermediate code is optimized, `assert` can be ignored. It should be used only to produce errors at an early stage or as a debugging aid, not to trigger the `try/catch` mechanism. The expression should not have side effects. The most common use of `assert` is to check the validity of input arguments.

Example

```
function y = fact(n)
  assert(length(n)==1 && isreal(n) && n==round(n), 'LME:nonIntArg');
  y = prod(1:n);
```

See also

`error`, `warning`, `try`

builtin

Built-in function evaluation.

Syntax

```
(argout1, ...) = builtin(fun, argin1, ...)
```

Description

`(y1,y2,...)=builtin(fun,x1,x2,...)` evaluates the built-in function `fun` with input arguments `x1`, `x2`, etc. Output arguments are assigned to `y1`, `y2`, etc. Function `fun` is specified by its name as a string.

`builtin` is useful to execute a built-in function which has been redefined.

Example

Here is the definition of operator `plus` so that it can be used with character strings to concatenate them.

```
function r = plus(a, b)
  if ischar(a) && ischar(b)
    r = [a, b];
  else
    r = builtin('plus', a, b);
  end
```

The original meaning of `plus` for numbers is preserved:

```
1 + 2
  3
'ab' + 'cdef'
  abcdef
```

See also

`feval`

clear

Discard the contents of a variable.

Syntax

```
clear
clear(v1, v2, ...)
clear -functions
```

Description

Without argument, `clear` discards the contents of all the local variables, including input arguments. With string input arguments, `clear(v1,v2,...)` discards the contents of the enumerated variables. Note that the variables are specified by strings; `clear` is a normal function which evaluates its arguments if they are enclosed between parenthesis. You can also omit parenthesis and quotes and use command syntax.

`clear` is usually not necessary, because local variables are automatically discarded when the function returns. It may be useful if a large variable is used only at the beginning of a function, or at the command-line interface.

`clear -functions` or `clear -f` removes the definition of all functions. It can be used only from the command-line interface, not in a function.

Examples

In the example below, `clear(b)` evaluates its argument and clears the variable whose name is `’a’`; `clear b`, without parenthesis and quotes, does not evaluate it; the argument is the literal string `’b’`.

```
a = 2;
b = ’a’;
clear(b)
a
  Undefined variable ’a’
b
  a
clear b
b
  Undefined variable b
```

See also

variable assignment

deal

Copy input arguments to output arguments.

Syntax

```
(v1, v2, ...) = deal(e)
(v1, v2, ...) = deal(e1, e2, ...)
```

Description

With a single input argument, `deal` provides a copy of it to all its output arguments. With multiple input arguments, `deal` provides them as output arguments in the same order.

`deal` can be used to assign a value to multiple variables, to swap the contents of two variables, or to assign the elements of a list to different variables.

Examples

Swap variable a and b:

```
a = 2;
b = ’abc’;
(a, b) = deal(b, a)
  a =
    abc
  b =
    2
```

Copy the same random matrix to variables x, y, and z:

```
(x, y, z) = deal(rand(5));
```

Assign the elements of list `l` to variables v1, v2, and v3:

```
l = {1, 'abc', 3:5};
(v1, v2, v3) = deal(l{:})
  v1 =
    1
  v2 =
    abc
  v3 =
    3 4 5
```

See also

`varargin`, `varargout`, operator {}

dumpvar

Dump the value of an expression as an assignment to a variable.

Syntax

```
dumpvar(value)
dumpvar(name,value)
dumpvar(fd,name,value)
str = dumpvar(value)
str = dumpvar(name,value)
```

Description

`dumpvar(fd,name,value)` writes to the channel `fd` (the standard output by default) a string which would set the variable `name` to `value`, if it was evaluated by LME. If `name` is omitted, only the textual representation of `value` is written.

With an output argument, `dumpvar` stores result into a string and produces no output.

Examples

```
dumpvar(2+3)
  5
a = 6; dumpvar('a', a)
  a = 6;
s = 'abc'; dumpvar('string', s)
  string = 'abc';
```

See also

`fprintf`, `sprintf`, `str2obj`

error

Display an error message and abort the current computation.

Syntax

```
error(str)
error(format, arg1, arg2, ...)
error(identifier, format, arg1, arg2, ...)
```

Description

Outside a try block, `error(str)` displays string `str` as an error message and the computation is aborted. With more arguments, `error` use the first argument as a format string and displays remaining arguments accordingly, like `fprintf`.

In a `try` block, `error(str)` throws a user error without displaying anything.

An error identifier may be added in front of other arguments. It is a string made of at least two segments separated by semicolons. Each segment has the same syntax as variable or function name (i.e. it begins with a letter or an underscore, and it continues with letters, digits and underscores.) The identifier can be retrieved with `lasterr` or `lasterror` in the `catch` part of a `try/catch` construct and helps to identify the error. For errors thrown by LME built-in functions, the first segment is always LME.

Examples

```
error('Invalid argument.');
  Invalid argument.
o = 'ground';
error('robot:hit', 'The robot is going to hit %s', o);
  The robot is going to hit ground
```

```
lasterror
  message: 'The robot is going to hit ground'
  identifier: 'robot:hit'
```

See also

`warning`, `try`, `lasterr`, `lasterror`, `assert`, `fprintf`

eval

Evaluate the contents of a string as an expression or statements.

Syntax

```
x = eval(str_expression)
eval(str_statement)
```

Description

If `eval` has output argument(s), the input argument is evaluated as an expression whose result(s) is returned. Without output arguments, the input argument is evaluated as statement(s). `eval` can evaluate and assign to existing variables, but cannot create new ones.

Examples

```
eval('1+2')
  3
a = eval('1+2')
  a = 3
eval('a=2+3')
  a = 5
```

See also

`feval`

exist

Existence of a function or variable.

Syntax

```
b = exist(name)
b = exist(name, type)
```

Description

exist returns true if its argument is the name of an existing function or variable, or false otherwise. A second argument can restrict the lookup to builtin functions ('builtin'), user functions ('function'), or variable ('variable').

Examples

```
exist('sin')
  true
exist('cos', 'function')
  false
```

See also

info

feval

Function evaluation.

Syntax

```
(argout1,...) = feval(fun,argin1,...)
```

Description

(y1,y2,...)=feval(fun,x1,x2,...) evaluates function fun with input arguments x1, x2, etc. Output arguments are assigned to y1, y2, etc. Function fun is specified by either its name as a string, a function reference, or an anonymous or inline function.

If a variable f contains a function reference or an anonymous or inline function, f(arguments) is equivalent to feval(f,arguments).

Examples

```
y = feval('sin', 3:5)
  y =
    0.1411 -0.7568 -0.9589
y = feval(@(x) sin(2*x), 3:5)
  y =
    -0.2794 0.9894 -0.544
fun = @(x) sin(2*x);
y = fun(3:5)
  y =
    -0.2794 0.9894 -0.544
```

See also

`builtin`, `eval`, `fevalx`, `apply`, `inline`, operator @

fevalx

Function evaluation with array expansion.

Syntax

```
(Y1,...) = fevalx(fun,X1,...)
```

Description

`(Y1,Y2,...)=fevalx(fun,X1,X2,...)` evaluates function `fun` with input arguments X1, X2, etc. Arguments must be arrays, which are expanded if necessary along singleton dimensions so that all dimensions match. For instance, three arguments of size 3x1x2, 1x5 and 1x1 are replicated into arrays of size 3x5x2. Output arguments are assigned to Y1, Y2, etc. Function `fun` is specified by either by its name as a string, a function reference, or an inline function.

Example

```
fevalx(@plus, 1:5, (10:10:30)')
    11    12    13    14    15
    21    22    23    24    25
    31    32    33    34    35
```

See also

`feval`, `meshgrid`, `repmat`, `inline`, operator @

fun2str

Name of a function given by reference or source code of an inline function.

Syntax

```
str = fun2str(funref)
str = fun2str(inlinefun)
```

Description

`fun2str(funref)` gives the name of the function whose reference is `funref`.

`fun2str(inlinefun)` gives the source code of the inline function `inlinefun`.

Examples

```
fun2str(@sin)
  sin
fun2str(inline('x+2*y', 'x', 'y'))
  function y=f(x,y);y=x+2*y;
```

See also

operator @, `str2fun`

info

Information about LME.

Syntax

```
info
info builtin
info functions
info methods
info variables
info global
info persistent
info libraries
info usedlibraries
info size
info threads
str = info
SA = info(kind)
```

Description

`info` displays the language version. With an output argument, the language version is given as a string.

`info builtin` displays the list of built-in functions with their module name (modules are subsets of built-in functions). A letter `u` is displayed after each untrusted function (functions which cannot be executed in the sandbox). With an output argument, `info('builtin')` gives a structure array which describes each built-in function, with the following fields:

`name`	function name
`module`	module name
`trusted`	true if the function is trusted

`info operators` displays the list of operators. With an output argument, `info('operators')` gives a list of structures, like `info('builtin')`.

`info functions` displays the list of user-defined functions with the library where they are defined. Parenthesis denote functions known by LME, but not loaded; they also indicate spelling errors in function or variable names. With an output argument, `info('functions')` gives a structure array which describes each user-defined function, with the following fields:

`library`	library name
`name`	function name
`loaded`	true if loaded

`info methods` displays the list of methods. With an output argument, `info('methods')` gives a structure array which describes each method, with the following fields:

`library`	library name
`class`	class name
`name`	function name
`loaded`	true if loaded

`info variables` displays the list of variables with their type and size. With an output argument, `info('variables')` gives a structure array which describes each variable, with the following fields:

`name`	function name
`defined`	true if defined

`info global` displays the list of all global variables. With an output argument, `info('global')` gives the list of the global variable names.

`info persistent` displays the list of all persistent variables. With an output argument, `info('persistent')` gives the list of the persistent variable names.

`info libraries` displays the list of all loaded libraries. With an output argument, `info('libraries')` gives the list of the library names.

`info usedlibraries` displays the list of libraries available in the current context. With an output argument, `info('usedlibraries')` gives the list of the names of these libraries.

`info size` displays the size in bytes of integer numbers (as used for indices and most internal computations) and of pointers. With an output argument, `info('size')` gives them in a structure of two fields:

`int`	integer size
`ptr`	pointer size

`info threads` displays the ID of all threads. With an output argument, `info('threads')` gives a structure array which describes each thread, with the following fields:

`id`	thread ID
`totaltime`	execution time in seconds

Only the first character of the argument is meaningful; `info b` is equivalent to `info builtin`.

Examples

```
info
  LME 5.1
info s
  int: 8 bytes
  ptr: 8 bytes
info b
  abs
  acos
  acosh
  (etc.)
info v
  ans (1x1 complex)
vars = info('v')
  var =
    2x1 struct array (2 fields)
```

See also

`inmem`, `which`, `exist`

inline

Creation of inline function.

Syntax

```
fun = inline(funstr)
fun = inline(expr)
fun = inline(expr, arg1, ...)
fun = inline(funstr, param)
fun = inline(expr, arg1, ..., paramstruct)
fun = inline(expr, ..., true)
```

Description

Inline function are LME objects which can be evaluated to give a result as a function of their input arguments. Contrary to functions declared with the `function` keyword, inline functions can be assigned to variables, passed as arguments, and built dynamically. Evaluating them with `feval` is faster than using `eval` with a string, because they are compiled only once to an intermediate code. They can also be used as the argument of functions such as `fzero` and `fmin`.

`inline(funstr)` returns an inline function whose source code is `funstr`. Input argument `funstr` follows the same syntax as a plain function. The function name is ignored.

`inline(expr)` returns an inline function with one implicit input argument and one result. The input argument `expr` is a string which evaluates to the result. The implicit input argument of the inline function is a symbol made of a single lower-case letter different from `i` and `j`, such as `x` or `t`, which is found in `expr`. If several such symbols are found, the one closer to `x` in alphabetical order is picked.

`inline(expr,arg1,...)` returns an inline function with one result and the specified arguments `arg1` etc. These arguments are also given as strings.

Inline functions also accept an additional input argument which correspond to fixed parameters provided when the function is executed. `inline(funstr,param)`, where `funstr` is a string which contains the source code of a function, stores `param` together with the function. When the function is called, `param` is prepended to the list of input arguments.

`inline(expr,args...,paramstruct)` is a simplified way to create an inline function when the code consists of a single expression. `args` is the names of the arguments which must be supplied when the inline function is called, as strings; `paramstruct` is a structure whose fields define fixed parameters.

`inline(expr,...,true)` defines a function which can return as many output arguments as what `feval` (or other functions which call the inline function) expects. Argument `expr` must be a function call itself.

Anonymous functions are an alternative, often easier way of creating inline functions. The result is the same. Since `inline` is a normal function, it must be used in contexts where fixed parameters cannot be created as separate variables.

Examples

A simple expression, evaluated at x=1 and x=2:

```
fun = inline('cos(x)*exp(-x)');
y = feval(fun, 2)
```

```
   y =
     -5.6319e-2
 y = feval(fun, 5)
   y =
     1.9113e-3
```

A function of x and y:

```
 fun = inline('exp(-x^2-y^2)', 'x', 'y');
```

A function with two output arguments (the string is broken in three lines to have a nice program layout):

```
 fun = inline(['function (a,b)=f(v);',...
               'a=mean(v);',...
               'b=prod(v)^(1/length(v));']);
 (am, gm) = feval(fun, 1:10)
   am =
     5.5
   gm =
     4.5287
```

Simple expression with fixed parameter a:

```
 fun = inline('cos(a*x)', 'x', struct('a',2));
 feval(fun, 3)
   0.9602
```

An equivalent function where the source code of a complete function is provided:

```
 fun = inline('function y=f(a,x); y=cos(a*x);', 2);
 feval(fun, 3)
   0.9602
```

A function with two fixed parameters a and b whose values are provided in a list:

```
 inline('function y=f(p,x);(a,b)=deal(p{:});y=a*x+b;',{2,3})
```

An inline function with a variable number of output arguments:

```
 fun = inline('eig(exp(x))',true);
 e = feval(fun, magic(3))
 e =
   2867.4882
   3173.2074
  -2903.9354
 (V,D) = feval(fun, magic(3))
   V =
       -0.0642    0.9579    0.8916
       -0.3370   -0.1013    0.1596
        0.9393   -0.2687    0.4238
   D =
     -2903.9354    0.0000    0.0000
        0.0000 2867.4882    0.0000
        0.0000    0.0000 3173.2074
```

See also

`function`, operator @, `feval`, `eval`

inmem

List of functions loaded in memory.

Syntax

```
inmem
SA = inmem
```

Description

`inmem` displays the list of user-defined functions loaded in memory with the library where they are defined. With an output argument, `inmem` gives the result as a structure array which describes each user-defined function loaded in memory, with the following fields:

`library`	library name
`class`	class name (`''` for functions)
`name`	function name

See also

`info`, `which`

isglobal

Test for the existence of a global variable.

Syntax

```
b = isglobal(str)
```

Description

`isglobal(str)` returns true if the string `str` is the name of a global variable, defined as such in the current context.

See also

`info`, `exist`, `which`

iskeyword

Test for a keyword name.

Syntax

```
b = iskeyword(str)
list = iskeyword
```

Description

`iskeyword(str)` returns true if the string `str` is a reserved keyword which cannot be used as a function or variable name, or false otherwise. Keywords include `if` and `global`, but not the name of built-in functions like `sin` or `i`.

Without input argument, `iskeyword` gives the list of all keywords.

Examples

```
iskeyword('otherwise')
  true
iskeyword
  {'break','case','catch','continue','else','elseif',
   'end','endfunction','for','function','global','if',
   'otherwise','persistent','private','public','repeat',
   'return','switch','try','until','use','useifexists',
   'while'}
```

See also

`info`, `which`

lasterr

Last error message.

Syntax

```
msg = lasterr
(msg, identifier) = lasterr
```

Description

`lasterr` returns a string which describes the last error. With two output arguments, it also gives the error identifier. It can be used in the `catch` part of the `try` construct.

Example

```
x = 2;
x(3)
  Index out of range
(msg, identifier) = lasterr
  msg =
    Index out of range
  identifier =
    LME:indexOutOfRange
```

See also

`lasterror`, `try`, `error`

lasterror

Last error structure.

Syntax

```
s = lasterror
```

Description

`lasterror` returns a structure which describes the last error. It contains the following fields:

`identifier`	string	short tag which identifies the error
`message`	string	error message

The structure can be used as argument to `rethrow` in the `catch` part of a `try/catch` construct to propagate the error further.

Example

```
x = 2;
x(3)
  Index out of range
lasterror
  message: 'Index out of range'
  identifier: 'LME:indexOutOfRange'
```

See also

`lasterr`, `try`, `rethrow`, `error`

nargin

Number of input arguments.

Syntax

```
n = nargin
n = nargin(fun)
```

Description

Calling a function with less arguments than what the function expects is permitted. In this case, the trailing variables are not defined. The function may use the `nargin` function to know how many arguments were passed by the caller to avoid accessing the undefined variables.

Note that if you want to have an optional argument before the end of the list, you have to interpret the meaning of the variables yourself. LME always sets the `nargin` first arguments.

There are two other ways to let a function accept a variable number of input arguments: to define default values directly in the function header, or to call `varargin` to collect some or all of the input arguments in a list.

With one argument, `nargin(fun)` returns the (maximum) number of input arguments a function accepts. `fun` may be the name of a built-in or user function, a function reference, or an inline function. Functions with a variable number of input arguments (such as `fprintf`) give `-1`.

Examples

A function with a default value (`pi`) for its second argument:

```
function x = multiplyByScalar(a,k)
if nargin < 2  % multiplyByScalar(x)
  k = pi;         % same as multiplyByScalar(x,pi)
end
x = k * a;
```

A function with a default value (standard output) for its first argument. Note how you have to interpret the arguments.

```
function fprintstars(fd,n)
if nargin == 1  % fprintstars(n) to standard output
  fprintf(repmat('*',1,fd));  % n is actually stored in fd
else
  fprintf(fd, repmat('*',1,n));
end
```

Number of input arguments of function `plus` (usually written "+"):

```
nargin('plus')
  2
```

See also

`nargout`, `varargin`, `function`

nargout

Number of output arguments.

Syntax

```
n = nargout
n = nargout(fun)
```

Description

A function may be called with between 0 and the number of output arguments listed in the function definition. The function can use `nargout` to check whether some output arguments are not used, so that it can avoid computing them or do something else.

With one argument, `nargout(fun)` returns the (maximum) number of output arguments a function can provide. `fun` may be the name of a built-in or user function, a function reference, or an inline function. Functions with a variable number of output arguments (such as `feval`) give `-1`.

Example

A function which prints nicely its result when it is not assigned or used in an expression:

```
function y = multiplyByTwo(x)
if nargout > 0
  y = 2 * x;
else
  fprintf('The double of %f is %f\n', x, 2*x);
end
```

Maximum number of output arguments of `svd`:

```
nargout('svd')
  3
```

See also

`nargin`, `varargout`, `function`

rethrow

Throw an error described by a structure.

Syntax

```
rethrow(s)
```

Description

`rethrow(s)` throws an error described by structure `s`, which contains the same fields as the output of `lasterror`. `rethrow` is typically used in the `catch` part of a `try/catch` construct to propagate further an error; but it can also be used to initiate an error, like `error`.

Example

The error whose identifier is `'LME:indexOutOfRange'` is handled by `catch`; other errors are not.

```
try
  ...
catch
  err = lasterror;
  if err.identifier === 'LME:indexOutOfRange'
    ...
  else
```

```
    rethrow(err);
  end
end
```

See also

`lasterror`, `try`, `error`

str2fun

Function reference.

Syntax

```
funref = str2fun(str)
```

Description

`str2fun(funref)` gives a function reference to the function whose name is given in string `str`. It has the same effect as operator @, which is preferred when the function name is fixed.

Examples

```
str2fun('sin')
  @sin
@sin
  @sin
a = 'cos';
str2fun(a)
  @cos
```

See also

operator @, `fun2str`

str2obj

Convert to an object its string representation.

Syntax

```
obj = str2obj(str)
```

Description

`str2obj(str)` evaluates string `str` and gives its result. It has the inverse effect as `dumpvar` with one argument. It differs from `eval` by restricting the syntax it accepts to literal values and to the basic constructs for creating complex numbers, arrays, lists, structures, objects, and other built-in types.

Examples

```
str2obj('1+2j')
  1 + 2j
str = dumpvar({1, 'abc', 1:100})
  str =
    {1, ...
     'abc', ...
     [1:100]}
str2obj(str)
  {1,'abc',real 1x100}
eval(str)
  {1,'abc',real 1x100}
str2obj('sin(2)')
  Bad argument 'str2obj'
eval('sin(2)')
  0.9093
```

See also

`eval`, `dumpvar`

varargin

Remaining input arguments.

Syntax

```
function ... = fun(..., varargin)
l = varargin
```

Description

`varargin` is a special variable which may be used to collect input arguments. In the function declaration, it must be used as the last (or unique) input argument. When the function is called with more arguments than what can be assigned to the other arguments, remaining ones are collected in a list and assigned to `varargin`. In the body of the function, `varargin` is a normal variable. Its elements may be accessed with the brace notation `varargin{i}`. `nargin` is always the total number of arguments passed to the function by the caller.

When the function is called with fewer arguments than what is declared, `varargin` is set to the empty list, `{}`.

Example

Here is a function which accepts any number of square matrices and builds a block-diagonal matrix:

```
function M = blockdiag(varargin)
  M = [];
  for block = varargin
    // block takes the value of each input argument
    (m, n) = size(block);
    M(end+1:end+m,end+1:end+n) = block;
  end
```

In the call below, `varargin` contains the list `{ones(3),2*ones(2),3}`.

```
blockdiag(ones(3),2*ones(2),3)
     1     1     1     0     0     0
     1     1     1     0     0     0
     1     1     1     0     0     0
     0     0     0     2     2     0
     0     0     0     2     2     0
     0     0     0     0     0     3
```

See also

`nargin`, `varargout`, `function`

varargout

Remaining output arguments.

Syntax

```
function (..., varargout) = fun(...)
varargout = ...
```

Description

`varargout` is a special variable which may be used to dispatch output arguments. In the function declaration, it must be used as the last (or unique) output argument. When the function is called with more output arguments than what can be obtained from the other arguments, remaining ones are extracted from the list `varargout`. In the body of the function, `varargout` is a normal variable. Its value can be set globally with the brace notation `{...}` or element by element with `varargout{i}`. `nargout` may be used to know how many output arguments to produce.

Example

Here is a function which differentiates a vector of values as many times as there are output arguments:

```
function varargout = multidiff(v)
  for i = 1:nargout
    v = diff(v);
    varargout{i} = v;
  end
```

In the call below, `[1,3,7,2,5,3,1,8]` is differentiated four times.

```
(v1, v2, v3, v4) = multidiff([1,3,7,2,5,3,1,8])
v1 =
     2     4    -5     3    -2    -2     7
v2 =
     2    -9     8    -5     0     9
v3 =
   -11    17   -13     5     9
v4 =
    28   -30    18     4
```

See also

`nargout`, `varargin`, `function`

variables

Contents of the variables as a structure.

Syntax

```
v = variables
```

Description

`variables` returns a structure whose fields contain the variables defined in the current context.

Example

```
a = 3;
b = 1:5;
variables
  a: 3
  b: real 1x5
  ...
```

See also

`info`

warning

Write a warning to the standard error channel.

Syntax

```
warning(msg)
warning(format, arg1, arg2, ...)
```

Description

`warning(msg)` displays the string `msg`. It should be used to notify the user about potential problems, *not* as a general-purpose display function.

With more arguments, `warning` uses the first argument as a format string and displays remaining arguments accordingly, like `fprintf`.

Example

```
warning('Doesn\'t converge.');
```

See also

`error`, `disp`, `fprintf`

which

Library where a function is defined.

Syntax

```
fullname = which(name)
```

Description

`which(name)` returns an indication of where function name is defined. If name is a user function or a method prefixed with its class and two colons, the result is name prefixed with the library name and a slash. If name is a built-in function, it is prefixed with `(builtin)`. If it is a variable, it is prefixed with `(var)`. If name is neither a function nor a variable, `which` returns the empty string.

Examples

```
which logspace
  stdlib/logspace
which polynom::plus
  classes/polynom::plus
which sin
  (builtin)/sin
x = 2;
which x
  (var)/x
```

See also

`info`

3.11 Sandbox Function

sandbox

Execute untrusted code in a secure environment.

Syntax

```
sandbox(str)
sandbox(str, varin)
varout = sandbox(str)
varout = sandbox(str, varin)
```

Description

`sandbox(str)` executes the statements in string `str`. Functions which might do harm if used improperly are disabled; they include those related to the file system, to devices and to the network. Global and persistent variables are forbidden as well; but local variables can be created. The same restrictions apply to functions called directly or indirectly by statements in `str`. The purpose of sandbox is to permit the evaluation of code which comes from untrusted sources, such as the Internet.

`sandbox(str,varin)` evaluates the statements in string `str` in a context with local variables equal to the fields of structure `varin`.

With an output argument, `sandbox` collects the contents of all variables in the fields of a single structure.

An error is thrown when the argument of `sandbox` attempts to execute one of the functions which are disabled. This error can be caught by a `try`/`catch` construct outside `sandbox`, but not inside its argument, so that unsuccessful attempts to circumvent the sandbox are always reported to the appropriate level.

Examples

Evaluation of two assignments; the second value is displayed, and the variables are discarded at the end of the evaluation.

```
sandbox('a=2; b=3:5');
b =
  3 4 5
```

Evaluation of two assignments; the contents of the variables are stored in structure `result`.

```
result = sandbox('a=2; b=3:5;')
  result =
    a: 2
    b: real 1x3
```

Evaluation with local variables `x` and `y` initialized with the field of a structure. Variable `z` is local to the sandbox.

```
in.x = 12;
in.y = 1:10;
sandbox('z = x + y', in);
  z =
    13 14 15 16 17 18 19 20 21 22
```

Attempt to execute the untrusted function `fopen` and to hide it from the outside. Both attempts fail: `fopen` is trapped and the security violation error is propagated outside the sandbox.

```
sandbox('try; fd=fopen('/etc/passwd'); end');
  Security violation 'fopen'
```

See also

`sandboxtrust`, `eval`, `variables`

sandboxtrust

Escape the sandbox restrictions.

Syntax

```
sandboxtrust(fun)
```

Description

`sandboxtrust(fun)` sets a flag associated with function `fun` so that `fun` is executed without restriction, even when called from a sandbox. All functions called directly or indirectly from a trusted function are executed without restriction, except if a nested call to `sandbox` is performed. Argument `fun` can be a function reference or the name of a function as a string; the function must be a user function, not a built-in one.

The purpose of `sandboxtrust` is to give back some of the capabilities of unrestricted code to code executed in a sandbox. For instance, if unsecure code must be able to read the contents of a specific file, a trusted function should be written for that. It is very important for the trusted function to check carefully its arguments, such as file paths or URL.

Example

Function which reads the contents of file `'data.txt'`:

```
function data = readFile
  fd = fopen('data.txt');
  data = fread(fd, inf, '*char');
  fclose(fd);
```

Execution of unsecure code which may read this file:

```
sandboxtrust(@readFile);
sandbox('d = readFile;');
```

See also

`sandbox`

3.12 Operators

Operators are special functions with a syntax which mimics mathematical arithmetic operations like the addition and the multiplication.

They can be infix (such as x+y), separating their two arguments (called *operands*); prefix (such as `-x`), placed before their unique operand; or postfix (such as `M'`), placed after their unique operand. In Sysquake, their arguments are always evaluated from left to right. Since they do not require parenthesis or comma, their priority matters. Priority specifies when subexpressions are considered as a whole, as the argument of some operator. For instance, in the expression a+b*c, where * denotes the multiplication, the evaluation could result in (a+b)*c or a+(b*c); however, since operator *'s priority is higher than operator +'s, the expression yields a+(b*c) without ambiguity.

Here is the list of operators, from higher to lower priority:

```
' .'
^ .^
- (unary)
* .* / ./ \ .\
+ -
== ~= < > <= >= === ~==
~
&
|
&&
||
: ?
,
;
```

Most operators have also a functional syntax; for instance, a+b can also be written `plus(a,b)`. This enables their overriding with new definitions and their use in functions such as `feval` which take the name of a function as an argument.

Here is the correspondence between operators and functions:

`[a;b]`	`vertcat(a,b)`	`a-b`	`minus(a,b)`
`[a,b]`	`horzcat(a,b)`	`a*b`	`mtimes(a,b)`
`a:b`	`colon(a,b)`	`a/b`	`mrdivide(a,b)`
`a:b:c`	`colon(a,b,c)`	`a\b`	`mldivide(a,b)`
`a|b`	`or(a,b)`	`a.*b`	`times(a,b)`
`a&b`	`and(a,b)`	`a./b`	`rdivide(a,b)`
`a<=b`	`le(a,b)`	`a.\b`	`ldivide(a,b)`
`a<b`	`lt(a,b)`	`a^b`	`mpower(a,b)`
`a>=b`	`ge(a,b)`	`a.^b`	`power(a,b)`
`a>b`	`gt(a,b)`	`~a`	`not(a)`
`a==b`	`eq(a,b)`	`-a`	`uminus(a)`
`a~=b`	`ne(a,b)`	`+a`	`uplus(a)`
`a===b`	`same(a,b)`	`a'`	`ctranspose(a)`
`a~==b`	`unsame(a,b)`	`a.'`	`transpose(a)`
`a+b`	`plus(a,b)`		

Operator which do *not* have a corresponding function are `?:`, `&&` and `||` because unlike functions, they do not always evaluate all of their operands.

Operator `()`

Parenthesis.

Syntax

```
(expr)
v(:)
v(index)
v(index1, index2)
v(:, index)
v(index, :)
v(select)
v(select1, select2)
v(:,:)
```

Description

A pair of parenthesis can be used to change the order of evaluation. The subexpression it encloses is evaluated as a whole and used as if it was a single object. Parenthesis serve also to indicate a list of input or output parameters; see the description of the `function` keyword.

The last use of parenthesis is for specifying some elements of an array or list variable.

Arrays: In LME, any numerical object is considered as an array of two dimensions or more. Therefore, at least two indices are required to specify a single element; the first index specifies the row, the second the column, and so on. In some circumstances, however, it is sometimes convenient to consider an array as a vector, be it a column vector, a row vector, or even a matrix whose elements are indexed row-wise. For this way of handling arrays, a single index is specified.

The first valid value of an index is always 1. The array whose elements are extracted is usually a variable, but can be any expression: an expression like `[1,2;3,4](1,2)` is valid and gives the 2nd element of the first row, i.e. 3.

In all indexing operations, several indices can be specified simultaneously to extract more than one element along a dimension. A single colon means all the elements along the corresponding dimension.

Instead of indices, the elements to be extracted can be selected by the true values in a logical array of the same size as the variable (the result is a column vector), or in a logical vector of the same size as the corresponding dimension. Calculating a boolean expression based on the variable itself used as a whole is the easiest way to get a logical array.

Variable indexing can be used in an expression or in the left hand side of an assignment. In this latter case, the right hand size can be one of the following:

– An array of the same size as the extracted elements.

– A scalar, which is assigned to each selected element of the variable.

– An empty matrix `[]`, which means that the selected elements should be deleted. Only whole rows or columns (or (hyper)planes for arrays of more dimensions) can be deleted; i.e. `a(2:5,:) = []` and `b([3,6:8]) = []` (if `b` is a row or column vector) are legal, while `c(2,3) = []` is not.

When indices are larger than the dimensions of the variable, the variable is expanded; new elements are set to 0 for numeric arrays, false for logical arrays, the nul character for character array, and the empty array `[]` for cell arrays.

Lists: In LME, lists have one dimension; thus a single index is required. Be it with a single index or a vector of indices, indexed elements are grouped in a list. New elements, also provided in a list, can be assigned to indexed elements; if the list to be assigned has a single element, the element is assigned to every indexed element of the variable.

Cell arrays: cell arrays are subscripted like other arrays. The result, or the right-hand side of an assignment, is also a cell array, or a list for the syntax `v(select)` (lists are to cell arrays what column vectors are to non-cell arrays). To create a single logical array for selecting some elements, function `cellfun` may be useful. To remove cells, the right-hand side of the assignment can be the empty list {} or the empty array [].

Structure arrays: access to structure array fields combines subscripting with parenthesis and structure field access with dot notation. When the field is not specified, parenthesis indexing returns a structure or structure array. When indexing results in multiple elements and a field is specified, the result is a value sequence.

Examples

Ordering evaluation:

```
(1+2)*3
  9
```

Extracting a single element, a row, and a column:

```
a = [1,2,3; 4,5,6];
a(2,3)
  6
a(2,:)
  4 5 6
a(:,3)
  3
  6
```

Extracting a sub-array with contiguous rows and non-contiguous columns:

```
a(1:2,[1,3])
  1 3
  4 6
```

Array elements as a vector:

```
a(3:5)
  3
  4
  5
a(:)
  1
  2
  3
  4
  5
  6
```

Selections of elements where a logical expression is true:

```
a(a>=5)
  5
  6
a(:, sum(a,1) > 6)
  2 3
  5 6
```

Assignment:

```
a(1,5) = 99
  a =
    1 2 3 0 99
    4 5 6 0 0
```

Extraction and assignment of elements in a list:

```
a = {1,[2,7,3],'abc',magic(3),'x'};
a([2,5])
  {[2,7,3],'x'}
a([2,5]) = {'ab','cde'}
  a =
    {1,'ab','abc',[8,1,6;3,5,7;4,9,2],'cde'}
a([2,5]) = {[3,9]}
  a =
    {1,[3,9],'abc',[8,1,6;3,5,7;4,9,2],[3,9]}
```

Removing elements in a list ({} and [] have the same effect here):

```
a(4) = {}
  a =
    {1,[3,9],'abc',[3,9]}
a([1, 3]) = []
  a =
    {[3,9],[3,9]}
```

Replacing NaN with empty arrays in a cell array:

```
C = {'abc', nan; 2, false};
C(cellfun(@(x) any(isnan(x(:))), C)) = {[]};
```

Element in a structure array:

```
SA = structarray('a',{1,[2,3]},'b',{'ab','cde'});
SA(1).a
  2 3
SA(2).b = 'X';
```

When assigning a new field and/or a new element of a structure array, the new field is added to each element and the size of the array is expanded; fields are initialized to the empty array [].

```
SA(3).c = true;
SA(1).c
  []
```

See also

Operator `{}`, operator `.`, `end`, `reshape`, variable assignment, operator `[]`, `subsref`, `subsasgn`, `cellfun`

Operator `[]`

Brackets.

Syntax

```
[matrix_elements]
```

Description

A pair of brackets is used to define a 2-d array given by its elements or by submatrices. The operator `,` (or spaces) is used to separate elements on the same row, and the operator `;` (or newline) is used to separate rows. Since the space is considered as a separator when it is in the direct scope of brackets, it should not be used at the top level of expressions; as long as this rule is observed, each element can be given by an expression.

Inside brackets, commas and semicolons are interpreted as calls to `horzcat` and `vertcat`. Brackets themselves have no other effect than changing the meaning of commas, semicolons, spaces, and new lines: the expression `[1]`, for instance, is strictly equivalent to `1`. The empty array `[]` is a special case.

Since `horzcat` and `vertcat` also accept cell arrays, brackets can be used to concatenate cell arrays, too.

Examples

```
[1, 2, 3+5]
  1 2 8
[1:3; 2 5 , 9 ]
  1 2 3
  2 5 9
[5-2, 3]
  3 3
[5 -2, 3]
  5 -2 3
[(5 -2), 3]
  3 3
[1 2
3 4]
  1 2
  3 4
```

```
[]
  []
```

Concatenation of two cell arrays:

```
C1 = {1; 2};
C2 = {'ab'; false};
[C1, C2]
  2x2 cell array
```

Compare this with the effect of braces, where elements are not concatenated but used as cells:

```
{C1, C2}
  1x2 cell array
```

See also

Operator {}, operator (), operator ,, operator ;

Operator {}

Braces.

Syntax

```
{list_elements}
{cells}
v{index}
v{index1, index2, ...}
v{index} = expr
fun(...,v{:},...)
```

Description

A pair of braces is used to define a list or a cell array given by its elements. In a list, the operator , is used to separate elements. In a cell array, the operator , is used to separate cells on the same row; the operator ; is used to separate rows. Braces without semicolons produce a list; braces with semicolon(s) produce a cell array.

v{index} is the element of list variable v whose index is given. index must be an integer between 1 (for the first element) and length(v) (for the last element). v{index} may be used in an expression to extract an element, or on the left hand-side of the equal sign to assign a new value to an element. Unless it is the target of an assignment, v may also be the result of an expression. If v is a cell array, v{index} is the element number index.

`v{index1,index2,...}` gives the specified cell of a cell array.

`v` itself may be an element or a field in a larger variable, provided it is a list; i.e. complicated assignments like `a{2}.f{3}(2,5)=3` are accepted. In an assignment, when the index (or indices) are larger than the list or cell array size, the variable is expanded with empty arrays `[]`.

In the list of the input arguments of a function call, `v{:}` is replaced with its elements. `v` may be a list variable or the result of an expression.

Examples

```
x = {1, 'abc', [3,5;7,1]}
  x =
    {1,string,real 2x2}
x{3}
    3 5
    7 1
x{2} = 2+3j
  x =
    {1,2+3j,real 2x2}
x{3} = {2}
  x =
    {1,2+3j,list}
x{end+1} = 123
  x =
    {1,2+3j,list,123}
C = {1, false; 'ab', magic(3)}
  2x2 cell array
C{2, 1}
  ab
a = {1, 3:5};
fprintf('%d ', a{:}, 99);
  1 3 4 5 99
```

See also

operator `,`, operator `[]`, operator `()`, operator `;`, operator `.`, `subsref`, `subsasgn`

Operator `.` (dot)

Structure field access.

Syntax

```
v.field
v.field = expr
```

Description

A dot is used to access a field in a structure. In `v.field`, v is the name of a variable which contains a structure, and `field` is the name of the field. In expressions, `v.field` gives the value of the field; it is an error if it does not exist. As the target of an assignment, the value of the field is replaced if it exists, or a new field is added otherwise; if v itself is not defined, a structure is created from scratch.

v itself may be an element or a field in a larger variable, provided it is a structure (or does not exists in an assignment); i.e. complicated assignments like `a{2}.f{3}(2,5)=3` are accepted.

If `V` is a structure array, `V.field` is a value sequence which contains the specified field of each element of `V`.

The syntax `v.(expr)` permits to specify the field name dynamically at run-time, as the result of evaluating expression `expr`. `v('f')` is equivalent to `v.f`. This syntax is more elegant than functions `getfield` and `setfield`.

Examples

```
s.f = 2
  s =
    f: 2
s.g = 'hello'
  s =
    f: 2
    s: string
s.f = 1:s.f
  s =
    f: real 1x2
    g: string
```

See also

Operator `()`, operator `{}`, `getfield` `setfield`, `subsref`, `subsasgn`

Operator +

Addition.

Syntax

```
x + y
M1 + M2
M + x
plus(x, y)
+x
+M
uplus(x)
```

Description

With two operands, both operands are added together. If both operands are matrices with a size different from 1-by-1, their size must be equal; the addition is performed element-wise. If one operand is a scalar, it is added to each element of the other operand.

With one operand, no operation is performed, except that the result is converted to a number if it was a string or a logical value, like with all mathematical operators and functions. For strings, each character is replaced with its numerical encoding. The prefix + is actually a synonym of `double`.

`plus(x,y)` is equivalent to `x+y`, and `uplus(x)` to `+x`. They can be used to redefine these operators for objects.

Example

```
2 + 3
  5
[1 2] + [3 5]
  4 7
[3 4] + 2
  5 6
```

See also

operator `-`, `sum`, `addpol`, `double`

Operator -

Subtraction or negation.

Syntax

```
x - y
M1 - M2
M - x
minus(x, y)
```

```
-x
-M
uminus(x)
```

Description

With two operands, the second operand is subtracted from the first operand. If both operands are matrices with a size different from 1-by-1, their size must be equal; the subtraction is performed element-wise. If one operand is a scalar, it is repeated to match the size of the other operand.

With one operand, the sign of each element is changed.

`minus(x,y)` is equivalent to `x-y`, and `uminus(x)` to `-x`. They can be used to redefine these operators for objects.

Example

```
2 - 3
  -1
[1 2] - [3 5]
  -2 -3
[3 4] - 2
  1 2
-[2 2-3j]
  -2 -2+3j
```

See also

operator +, `conj`

Operator *

Matrix multiplication.

Syntax

```
x * y
M1 * M2
M * x
mtimes(x, y)
```

Description

`x*y` multiplies the operands together. Operands can be scalars (plain arithmetic product), matrices (matrix product), or mixed scalar and matrix.

`mtimes(x,y)` is equivalent to `x*y`. It can be used to redefine this operator for objects.

Example

```
2 * 3
  6
[1,2;3,4] * [3;5]
  13
  29
[3 4] * 2
  6 8
```

See also

operator `.*`, operator `/`, `prod`

Operator `.*`

Scalar multiplication.

Syntax

```
x .* y
M1 .* M2
M .* x
times(x, y)
```

Description

`x.*y` is the element-wise multiplication. If both operands are matrices with a size different from 1-by-1, their size must be equal; the multiplication is performed element-wise. If one operand is a scalar, it multiplies each element of the other operand.

`times(x,y)` is equivalent to `x.*y`. It can be used to redefine this operator for objects.

Example

```
[1 2] .* [3 5]
  3 10
[3 4] .* 2
  6 8
```

See also

operator `*`, operator `./`, operator `.^`

Operator /

Matrix right division.

Syntax

```
a / b
A / B
A / b
mrdivide(a, b)
```

Description

`a/b` divides the first operand by the second operand. If the second operand is a scalar, it divides each element of the first operand.

If the second operand is Otherwise, it must be a square matrix; `M1/M2` is equivalent to `M1*inv(M2)`.

`mrdivide(x,y)` is equivalent to `x/y`. It can be used to redefine this operator for objects.

Example

```
9 / 3
  3
[2,6] / [1,2;3,4]
  5 -1
[4 10] / 2
  2 5
```

See also

operator `\`, `inv`, operator `./`, `deconv`

Operator ./

Scalar right division.

Syntax

```
x ./ y
M1 ./ M2
M ./ x
x ./ M
rdivide(x, y)
```

Description

The first operand is divided by the second operand. If both operands are matrices with a size different from 1-by-1, their size must be equal; the division is performed element-wise. If one operand is a scalar, it is repeated to match the size of the other operand.

`rdivide(x,y)` is equivalent to `x./y`. It can be used to redefine this operator for objects.

Examples

```
 [3 10] ./ [3 5]
  1 2
[4 8] ./ 2
  2 4
10 ./ [5 2]
  2 5
```

See also

operator `/`, operator `.*`, operator `.^`

Operator \

Matrix left division.

Syntax

```
x \ y
M1 \ M2
x \ M
mldivide(x, y)
```

Description

`x\y` divides the second operand by the first operand. If the first operand is a scalar, it divides each element of the second operand. Otherwise, it must be a square matrix; `M1\M2` is equivalent to `inv(M1)*M2`.

`mldivide(x,y)` is equivalent to `x\y`. It can be used to redefine this operator for objects.

Examples

```
3 \ 9
  3
[1,2;3,4] \ [2;6]
  2
  0
2 \ [4 10]
  2 5
```

See also

operator `/`, `inv`, operator `.\`

Operator `.\`

Scalar left division.

Syntax

```
M1 .\ M2
M1 .\ x
ldivide(x, y)
```

Description

The second operand is divided by the first operand. If both operands are matrices with a size different from 1-by-1, their size must be equal; the division is performed element-wise. If one operand is a scalar, it is repeated to match the size of the other operand.

`ldivide(x,y)` is equivalent to `x.\y`. It can be used to redefine this operator for objects.

Example

```
[1 2 3] .\ [10 11 12]
  10 5.5 4
```

See also

operator `\`, operator `./`

Operator ^

Matrix power.

Syntax

```
x ^ y
M ^ k
x ^ M
mpower(x, y)
```

Description

x^y calculates x to the y power, provided that either

- both operands are scalar;
- the first operand is a square matrix and the second operand is an integer;
- or the first operand is a scalar and the second operand is a square matrix.

Other cases yield an error.

`mpower(x,y)` is equivalent to x^y. It can be used to redefine this operator for objects.

Examples

```
2 ^ 3
  8
[1,2;3,4] ^ 2
  7  10
  15 22
2 ^ [1,2;3,4]
  10.4827 14.1519
  21.2278 31.7106
```

See also

operator `.^`, `expm`

Operator .^

Scalar power.

Syntax

```
M1 .^ M2
x .^ M
M .^ x
power(x, y)
```

Description

`M1.^M2` calculates `M1` to the `M2` power, element-wise. Both arguments must have the same size, unless one of them is a scalar.

`power(x,y)` is equivalent to `x.^y`. It can be used to redefine this operator for objects.

Examples

```
[1,2;3,4].^2
  1  4
  9 16
[1,2,3].^[5,4,3]
  1 16 27
```

See also

operator ^, exp

Operator '

Complex conjugate transpose.

Syntax

```
M'
ctranspose(M)
```

Description

`M'` is the transpose of the real matrix `M`, i.e. columns and rows are permuted. If `M` is complex, the result is the complex conjugate transpose of `M`. If `M` is an array with multiple dimensions, the first two dimensions are permuted.

`ctranspose(M)` is equivalent to `M'`. It can be used to redefine this operator for objects.

Examples

```
[1,2;3,4]'
  1 3
  2 4
[1+2j, 3-4j]'
  1-2j
  3+4j
```

See also

operator `.'`, `conj`

Operator `.'`

Transpose.

Syntax

```
M.'
transpose(M)
```

Description

`M.'` is the transpose of the matrix `M`, i.e. columns and rows are permuted. `M` can be real or complex. If `M` is an array with multiple dimensions, the first two dimensions are permuted.

`transpose(M)` is equivalent to `M.'`. It can be used to redefine this operator for objects.

Example

```
[1,2;3,4].'
  1 3
  2 4
[1+2j, 3-4j].'
  1+2j
  3-4j
```

See also

operator `'`, `permute`, `fliplr`, `flipud`, `rot90`

Operator ==

Equality.

Syntax

```
x == y
eq(x, y)
```

Description

`x == y` is true if x is equal to y, and false otherwise. Comparing NaN (not a number) to any number yields false, including to NaN. If x and/or y is an array, the comparison is performed element-wise and the result has the same size.

`eq(x,y)` is equivalent to x==y. It can be used to redefine this operator for objects.

Example

```
1 == 1
  true
1 == 1 + eps
  false
1 == 1 + eps / 2
  true
inf == inf
  true
nan == nan
  false
[1,2,3] == [1,3,3]
  T F T
```

See also

operator ~=, operator <, operator <=, operator >, operator >=, operator ===, operator ~==, `strcmp`

Operator ===

Object equality.

Syntax

```
a === b
same(a, b)
```

Description

a === b is true if a is the same as b, and false otherwise. a and b must have exactly the same internal representation to be considered as equal; with IEEE floating-point numbers, nan===nan is true and 0===-0 is false. Contrary to the equality operator ==, === returns a single boolean even if its operands are arrays.

same(a,b) is equivalent to a===b.

Example

```
(1:5) === (1:5)
  true
(1:5) == (1:5)
  T T T T T
[1,2,3] === [4,5]
  false
[1,2,3] == [4,5]
  Incompatible size
nan === nan
  true
nan == nan
  false
```

See also

operator ~==, operator ==, operator ~=, operator <, operator <=, operator >, operator >=, operator ==, operator ~=, strcmp

Operator ~=

Inequality.

Syntax

```
x ~= y
ne(x, y)
```

Description

x ~= y is true if x is not equal to y, and false otherwise. Comparing NaN (not a number) to any number yields true, including to NaN. If x and/or y is an array, the comparison is performed element-wise and the result has the same size.

ne(x,y) is equivalent to x~=y. It can be used to redefine this operator for objects.

Example

```
1 ~= 1
  false
inf ~= inf
  false
nan ~= nan
  true
[1,2,3] ~= [1,3,3]
  F T F
```

See also

operator ==, operator <, operator <=, operator >, operator >=, operator ===, operator ~==, `strcmp`

Operator ~==

Object inequality.

Syntax

```
a ~== b
unsame(a, b)
```

Description

`a ~== b` is true if `a` is not the same as `b`, and false otherwise. `a` and `b` must have exactly the same internal representation to be considered as equal; with IEEE numbers, nan~==nan is false and `0~==-0` is true. Contrary to the inequality operator, ~== returns a single boolean even if its operands are arrays.

`unsame(a,b)` is equivalent to a~==b.

Example

```
(1:5) ~== (1:5)
  false
(1:5) ~= (1:5)
  F F F F F
[1,2,3] ~== [4,5]
  true
[1,2,3] ~= [4,5]
  Incompatible size
nan ~== nan
  false
nan ~= nan
  true
```

See also

operator ===, operator ==, operator ~=, operator <, operator <=, operator >, operator >=, `strcmp`

Operator <

Less than.

Syntax

```
x < y
lt(x, y)
```

Description

`x < y` is true if `x` is less than `y`, and false otherwise. Comparing NaN (not a number) to any number yields false, including to NaN. If `x` and/or `y` is an array, the comparison is performed element-wise and the result has the same size.

`lt(x,y)` is equivalent to `x<y`. It can be used to redefine this operator for objects.

Example

```
[2,3,4] < [2,4,2]
  F T F
```

See also

operator ==, operator ~=, operator <=, operator >, operator >=

Operator >

Greater than.

Syntax

```
x > y
gt(x, y)
```

Description

x > y is true if x is greater than y, and false otherwise. Comparing NaN (not a number) to any number yields false, including to NaN. If x and/or y is an array, the comparison is performed element-wise and the result has the same size.

gt(x,y) is equivalent to x>y. It can be used to redefine this operator for objects.

Example

```
[2,3,4] > [2,4,2]
  F F T
```

See also

operator ==, operator ~=, operator <, operator <=, operator >=

Operator <=

Less or equal to.

Syntax

```
x <= y
le(x, y)
```

Description

x <= y is true if x is less than or equal to y, and false otherwise. Comparing NaN (not a number) to any number yields false, including to NaN. If x and/or y is an array, the comparison is performed element-wise and the result has the same size.

le(x,y) is equivalent to x<=y. It can be used to redefine this operator for objects.

Example

```
[2,3,4] <= [2,4,2]
  T T F
```

See also

operator ==, operator ~=, operator <, operator >, operator >=

Operator >=

Greater or equal to.

Syntax

```
x >= y
ge(x, y)
```

Description

`x >= y` is true if x is greater than or equal to y, and false otherwise. Comparing NaN (not a number) to any number yields false, including to NaN. If x and/or y is an array, the comparison is performed element-wise and the result has the same size.

`ge(x,y)` is equivalent to x>=y. It can be used to redefine this operator for objects.

Example

```
[2,3,4] >= [2,4,2]
  T F T
```

See also

operator ==, operator ~=, operator <, operator <=, operator >

Operator ~

Not.

Syntax

```
~b
not(b)
```

Description

~b is false (logical 0) if b is different from 0 or false, and `true` otherwise. If b is an array, the operation is performed on each element.

`not(b)` is equivalent to ~b. It can be used to redefine this operator for objects.

Examples

```
~true
  false
~[1,0,3,false]
  F T F T
```

See also

operator ~=, `bitcmp`

Operator &

And.

Syntax

```
b1 & b2
and(b1, b2)
```

Description

`b1&b2` performs the logical AND operation between the corresponding elements of `b1` and `b2`; the result is true (logical 1) if both operands are different from false or 0, and false (logical 0) otherwise.

`and(b1,b2)` is equivalent to `b1&b2`. It can be used to redefine this operator for objects.

Example

```
[false, false, true, true] & [false, true, false, true]
  F F F T
```

See also

operator |, `xor`, operator ~, operator &&, `all`

Operator &&

And with lazy evaluation.

Syntax

```
b1 && b2
```

Description

b1&&b2 is b1 if b1 is false, and b2 otherwise. Like with `if` and `while` statements, b1 is true if it is a nonempty array with only non-zero elements. b2 is evaluated only if b1 is true.

b1&&b2&&...&&bn returns the last operand which is false (remaining operands are not evaluated), or the last one.

Example

Boolean value which is true if the vector v is made of pairs of equal values:

```
mod(length(v),2) == 0 && v(1:2:end) == v(2:2:end)
```

The second operand of && is evaluated only if the length is even.

See also

operator ||, operator ?, operator &, `if`

Operator |

Or.

Syntax

```
b1 | b2
or(b1, b2)
```

Description

b1|b2 performs the logical OR operation between the corresponding elements of b1 and b2; the result is false (logical 0) if both operands are false or 0, and true (logical 1) otherwise.

`or(b1,b2)` is equivalent to b1|b2. It can be used to redefine this operator for objects.

Example

```
[false, false, true, true] | [false, true, false, true]
  F T T T
```

See also

operator &, `xor`, operator ˜, operator ||, any

Operator ||

Or with lazy evaluation.

Syntax

```
b1 || b2
```

Description

b1||b2 is b1 if b1 is true, and b2 otherwise. Like with if and while statements, b1 is true if it is a nonempty array with only non-zero elements. b2 is evaluated only if b1 is false.

b1||b2||...||bn returns the last operand which is true (remaining operands are not evaluated), or the last one.

Example

Boolean value which is true if the vector v is empty or if its first element is NaN:

```
isempty(v) || isnan(v(1))
```

See also

operator &&, operator ?, operator |, if

Operator ?

Alternative with lazy evaluation.

Syntax

```
b ? x : y
```

Description

b?x:y is x if b is true, and y otherwise. Like with if and while statements, b is true if it is a nonempty array with only non-zero elements. Only one of x and y is evaluated depending on b.

Operators ? and : have the same priority; parenthesis or brackets should be used if e.g. x or y is a range.

Example

Element of a vector `v`, or default value 5 if the index `ind` is out of range:

```
ind < 1 || ind > length(v) ? 5 : v(ind)
```

See also

operator &&, operator ||, `if`

Operator `,`

Horizontal matrix concatenation.

Syntax

```
[M1, M2]
[M1 M2]
horzcat(M1, M2)
```

Description

Between brackets, the comma is used to separate elements on the same row in a matrix. Elements can be scalars, vector or matrices; their number of rows must be the same, unless one of them is an empty matrix.

Outside brackets or between parenthesis, the comma is used to separate statements or the arguments of functions.

`horzcat(M1,M2)` is equivalent to `[M1,M2]`. It can be used to redefine this operator for objects.

Between braces, the comma separates cells on the same row.

Examples

```
[1,2]
  1 2
[[3;5],ones(2)]
  3 1 1
  5 1 1
['abc','def']
  abcdef
```

See also

operator `[]`, operator `;`, `cat`, `join`, operator `{}`

Operator ;

Vertical matrix concatenation.

Syntax

```
[M1; M2]
vertcat(M1, M2)
```

Description

Between brackets, the semicolon is used to separate rows in a matrix. Rows can be scalars, vector or matrices; their number of columns must be the same, unless one of them is an empty matrix.

Outside brackets, the comma is used to separate statements; they loose any meaning between parenthesis and give a syntax error.

`vertcat(M1,M2)` is equivalent to `[M1;M2]`. It can be used to redefine this operator for objects.

Between braces, the semicolon separates rows of cells.

Examples

```
[1;2]
  1
  2
[1:5;3,2,4,5,1]
  1 2 3 4 5
  3 2 4 5 1
['abc';'def']
  abc
  def
```

See also

operator `[]`, operator `,`, `join`, operator `{}`

Operator :

Range.

Syntax

```
x1:x2
x1:step:x2
colon(x1,x2)
colon(x1,step,x2)
```

Description

x1:x2 gives a row vector with the elements x1, x1+1, x1+2, etc. until x2. The last element is equal to x2 only if x2-x1 is an integer, and smaller otherwise. If x2<x1, the result is an empty matrix.

x1:step:x2 gives a row vector with the elements x1, x1+step, x1+2*step, etc. until x2. The last element is equal to x2 only if (x2-x1)/step is an integer. With fractional numbers, rounding errors may cause x2 to be discarded even if (x2-x1)/step is "almost" an integer. If x2*sign(step)<x1*sign(step), the result is an empty matrix.

If x1 or step is complex, a complex vector is produced, with the expected contents. The following algorithm is used to generate each element:

```
z = x1
while real((z - x1)/(x2 - x1)) <= 1
    add z to the vector
    z = z + step
end
```

This algorithm is robust enough to stop even if x2 is not on the complex straight line defined by x1 and step. If x2-x1 and step are orthogonal, it is attempted to produce an infinite number of elements, which will obviously trigger an out of memory error. This is similar to having a null step in the real case.

Note that the default step value is always 1 for consistency with real values. Choosing for instance sign(x2-x1) would have made the generation of lists of indices more difficult. Hence for a vector of purely imaginary numbers, always specify a step.

colon(x1,x2) is equivalent to x1:x2, and colon(x1,step,x2) to x1:step:x2. It can be used to redefine this operator for objects.

The colon character is also used to separate the alternatives of a conditional expression b?x:y.

Example

```
2:5
  2 3 4 5
2:5.3
  2 3 4 5
3:3
  3
3:2
  []
2:2:8
  2 4 6 8
5:-1:2
```

```
   5 4 3 2
 0:1j:10j
   0 1j 2j 3j 4j 5j 6j 7j 8j 9j 10j
 1:1+1j:5+4j
   1 2+1j 3+2j 4+3j 5+4j
 0:1+1j:5
   0 1+1j 2+2j 3+3j 4+4j 5+5j
```

See also

`repmat`, operator ?

Operator `@`

Function reference or anonymous function.

Syntax

```
 @fun
 @(arguments) expression
```

Description

`@fun` gives a reference to function `fun` which can be used wherever an inline function can. Its main use is as the argument of functions like `feval` or quad, but it may also be stored in lists, cell arrays, or structures. A reference cannot be cast to a double (unlike characters or logical values), nor can it be stored in an array.

Anonymous functions are an alternative, more compact syntax for inline functions. In `@(args) expr`, `args` is a list of input arguments and `expr` is an expression which contains two kinds of variables:

– input arguments, provided when the anonymous expression is executed;

– captured variables (all variables which do not appear in the list of input arguments), which have the value of variables of the same name existing when and where the anonymous function is created. These values are fixed.

If the top-level element of the anonymous function is itself a function, multiple output arguments can be specified for the call of the anonymous function, as if a direct call was performed.

Anonymous functions are a convenient way to provide the glue between functions like `fzero` and ode45 and the function they accept as argument. Additional parameters can be passed directly in the anonymous function with captured variables, instead of being supplied as additional arguments; the code becomes clearer.

Examples

Function reference:

```
quad(@sin, 0, pi)
  2
```

Anonymous function:

```
a = 2;
fun = @(x) sin(a * x);
fun(3)
  -0.2794
quad(fun, 0, 2)
  0.8268
```

Without anonymous function, parameter a should be passed as an additional argument after all the input arguments defined for quad, including those which are optional when parameters are missing:

```
quad(inline('sin(a * x)', 'x', 'a'), 0, 2, [], false, a)
  0.8268
```

Anonymous functions are actually stored as inline functions with all captured variables:

```
dumpvar(fun)
  inline('function y=f(a,x);y=sin(a*x);',2)
```

Anonymous function with multiple output arguments:

```
fun = @(A) size(A);
s = fun(ones(2,3))
  s =
    2 3
(m, n) = fun(ones(2,3))
  m =
    2
  n =
    3
```

See also

`fun2str`, `str2fun`, `inline`, `feval`, `apply`

3.13 Mathematical Functions

abs

Absolute value.

Syntax

```
x = abs(z)
```

Description

abs takes the absolute value of each element of its argument. The result is an array of the same size as the argument; each element is non-negative.

Example

```
abs([2,-3,0,3+4j]
  2 3 0 5
```

See also

`angle`, `sign`, `real`, `imag`, `hypot`

acos

Arc cosine.

Syntax

```
y = acos(x)
```

Description

`acos(x)` gives the arc cosine of x, which is complex if x is complex or if `abs(x)>1`.

Examples

```
acos(2)
  0+1.3170j
acos([0,1+2j])
  1.5708 1.1437-1.5286j
```

See also

`cos`, `asin`, `acosh`

acosh

Inverse hyperbolic cosine.

Syntax

```
y = acosh(x)
```

Description

acosh(x) gives the inverse hyperbolic cosine of x, which is complex if x is complex or if x<1.

Examples

```
acosh(2)
  1.3170
acosh([0,1+2j])
  0+1.5708j 1.5286+1.1437j
```

See also

cosh, asinh, acos

acot

Inverse cotangent.

Syntax

```
y = acot(x)
```

Description

acot(x) gives the inverse cotangent of x, which is complex if x is.

See also

cot, acoth, cos

acoth

Inverse hyperbolic cotangent.

Syntax

```
y = acoth(x)
```

Description

acoth(x) gives the inverse hyperbolic cotangent of x, which is complex if x is complex or is in the range (-1,1).

See also

`coth`, `acot`, `atanh`

acsc

Inverse cosecant.

Syntax

```
 y = acsc(x)
```

Description

acsc(x) gives the inverse cosecant of x, which is complex if x is complex or is in the range (-1,1).

See also

`csc`, `acsch`, `asin`

acsch

Inverse hyperbolic cosecant.

Syntax

```
 y = acsch(x)
```

Description

acsch(x) gives the inverse hyperbolic cosecant of x, which is complex if x is.

See also

`csc`, `acsc`, `asinh`

angle

Phase angle of a complex number.

Syntax

```
phi = angle(z)
```

Description

`angle(z)` gives the phase of the complex number `z`, i.e. the angle between the positive real axis and a line joining the origin to `z`. `angle(0)` is 0.

Examples

```
angle(1+3j)
  1.2490
angle([0,1,-1])
  0 0 3.1416
```

See also

`abs`, `sign`, `atan2`

asec

Inverse secant.

Syntax

```
y = asec(x)
```

Description

asec(x) gives the inverse secant of x, which is complex if x is complex or is in the range (-1,1).

See also

`sec`, `asech`, `acos`

asech

Inverse hyperbolic secant.

Syntax

```
y = asech(x)
```

Description

asech(x) gives the inverse hyperbolic secant of x, which is complex if x is complex or strictly negative.

See also

sech, asec, acosh

asin

Arc sine.

Syntax

```
y = asin(x)
```

Description

asin(x) gives the arc sine of x, which is complex if x is complex or if abs(x)>1.

Examples

```
asin(0.5)
  0.5236
asin(2)
  1.5708-1.317j
```

See also

sin, acos, asinh

asinh

Inverse hyperbolic sine.

Syntax

```
y = asinh(x)
```

Description

`asinh(x)` gives the inverse hyperbolic sine of `x`, which is complex if `x` is complex.

Examples

```
asinh(2)
  1.4436
asinh([0,1+2j])
  0 1.8055+1.7359j
```

See also

`sinh`, `acosh`, `asin`

atan

Arc tangent.

Syntax

```
y = atan(x)
```

Description

`atan(x)` gives the arc tangent of `x`, which is complex if `x` is complex.

Example

```
atan(1)
  0.7854
```

See also

`tan`, `asin`, `acos`, `atan2`, `atanh`

atan2

Direction of a point given by its Cartesian coordinates.

Syntax

```
phi = atan2(y,x)
```

Description

`atan2(y,x)` gives the direction of a point given by its Cartesian coordinates x and y. Imaginary component of complex numbers is ignored. `atan2(y,x)` is equivalent to `atan(y/x)` if `x>0`.

Examples

```
atan2(1, 1)
  0.7854
atan2(-1, -1)
  -2.3562
atan2(0, 0)
  0
```

See also

`atan`, `angle`

atanh

Inverse hyperbolic tangent.

Syntax

```
y = atanh(x)
```

Description

`atan(x)` gives the inverse hyperbolic tangent of x, which is complex if x is complex or if `abs(x)>1`.

Examples

```
atanh(0.5)
  0.5493
atanh(2)
  0.5493 + 1.5708j
```

See also

`asinh`, `acosh`, `atan`

beta

Beta function.

Syntax

```
y = beta(z,w)
```

Description

`beta(z,w)` gives the beta function of `z` and `w`. Arguments and result are real (imaginary part is discarded). The beta function is defined as

$$B(z,w) = \int_0^1 t^{z-1}(1-t)^{w-1}\,\mathrm{d}t$$

Example

```
beta(1,2)
  0.5
```

See also

`gamma`, `betaln`, `betainc`

betainc

Incomplete beta function.

Syntax

```
y = betainc(x,z,w)
```

Description

`betainc(x,z,w)` gives the incomplete beta function of `x`, `z` and `w`. Arguments and result are real (imaginary part is discarded). `x` must be between 0 and 1. The incomplete beta function is defined as

$$I_x(z,w) = \frac{1}{B(z,w)} \int_0^x t^{z-1}(1-t)^{w-1}\,\mathrm{d}t$$

Example

```
betainc(0.2,1,2)
  0.36
```

See also

`beta`, `betaln`, `gammainc`

betaln

Logarithm of beta function.

Syntax

```
y = betaln(z,w)
```

Description

`betaln(z,w)` gives the logarithm of the beta function of `z` and `w`. Arguments and result are real (imaginary part is discarded).

Example

```
betaln(0.5,2)
  0.2877
```

See also

`beta`, `betainc`, `gammaln`

cast

Type conversion.

Syntax

```
Y = cast(X, type)
```

Description

`cast(X,type)` converts the numeric array `X` to the type given by string `type`, which can be `'double'`, `'single'`, `'int8'` or any other signed or unsigned integer type, `'char'`, or `'logical'`. The number value is preserved when possible; conversion to integer types discards most significant bytes. If `X` is an array, conversion is performed on each element; the result has the same size. The imaginary part, if any, is discarded only with conversions to integer types.

Example

```
cast(pi, 'int8')
  3int8
```

See also

`uint8` and related functions, `double`, `single`, `typecast`

cdf

Cumulative distribution function.

Syntax

```
y = cdf(distribution,x)
y = cdf(distribution,x,a1)
y = cdf(distribution,x,a1,a2)
```

Description

`cdf(distribution,x)` calculates the integral of a probability density function from $-\infty$ to `x`. The distribution is specified with the first argument, a string; case is ignored ('t' and 'T' are equivalent). Additional arguments must be provided for some distributions. The distributions are given in the table below. Default values for the parameters, when mentioned, mean that the parameter may be omitted.

Distribution	**Name**	**Parameters**
Beta	`beta`	a and b
Cauchy	`cauchy`	a and b
χ	`chi`	deg. of freedom ν
χ^2	`chi2`	deg. of freedom ν
γ	`gamma`	shape α and λ
exponential	`exp`	mean
F	`f`	deg. of freedom ν_1 and ν_2
half-normal	`half-normal`	ϑ
Laplace	`laplace`	mean and scale
lognormal	`logn`	mean (0) and st. dev. (1)
normal	`norm`	mean (0) and st. dev. (1)
Rayleigh	`rayl`	b
Student's T	`t`	deg. of freedom ν
uniform	`unif`	limits of the range (0 and 1)
Weibull	`weib`	a and b

See also

`pdf`, `icdf`, `erf`

ceil

Rounding towards +infinity.

Syntax

```
y = ceil(x)
```

Description

`ceil(x)` gives the smallest integer larger than or equal to `x`. If the argument is a complex number, the real and imaginary parts are handled separately.

Examples

```
ceil(2.3)
  3
ceil(-2.3)
  -2
ceil(2.3-4.5j)
  3-4j
```

See also

`floor`, `fix`, `round`

complex

Make a complex number.

Syntax

```
z = complex(x, y)
```

Description

`complex(x,y)` makes a complex number from its real part x and imaginary part y. The imaginary part of its input arguments is ignored.

Examples

```
complex(2, 3)
  2 + 3j
complex(1:5, 2)
  1+2j 2+2j 3+2j 4+2j 5+2j
```

See also

`real`, `imag`, `i`

conj

Complex conjugate value.

Syntax

```
w = conj(z)
```

Description

`conj(z)` changes the sign of the imaginary part of the complex number `z`.

Example

```
conj([1+2j,-3-5j,4,0])
  1-2j -3+5j 4 0
```

See also

`imag`, `angle`, `j`, operator `-`

cos

Cosine.

Syntax

```
y = cos(x)
```

Description

`cos(x)` gives the cosine of `x`, which is complex if `x` is complex.

Example

```
cos([0, 1+2j])
  1 2.0327-3.0519j
```

See also

`sin`, `acos`, `cosh`

cosh

Hyperbolic cosine.

Syntax

```
 y = cosh(x)
```

Description

`cos(x)` gives the hyperbolic cosine of x, which is complex if x is complex.

Example

```
 cosh([0, 1+2j])
   1 -0.6421+1.0686j
```

See also

`sinh`, `acosh`, `cos`

cot

Cotangent.

Syntax

```
 y = cot(x)
```

Description

cot(x) gives the cotangent of x, which is complex if x is.

See also

`acot`, `coth`, `tan`

coth

Hyperbolic cotangent.

Syntax

```
y = coth(x)
```

Description

coth(x) gives the hyperbolic cotangent of x, which is complex if x is.

See also

`acoth`, `cot`, `tanh`

csc

Cosecant.

Syntax

```
y = csc(x)
```

Description

csc(x) gives the cosecant of x, which is complex if x is.

See also

`acsc`, `csch`, `sin`

csch

Hyperbolic cosecant.

Syntax

```
y = csch(x)
```

Description

csch(x) gives the hyperbolic cosecant of x, which is complex if x is.

See also

`acsch`, `csc`, `sinh`

diln

Dilogarithm.

Syntax

```
y = diln(x)
```

Description

`diln(x)` gives the dilogarithm, or Spence's integral, of `x`. Argument and result are real (imaginary part is discarded). The dilogarithm is defined as

$$\mathrm{diln}(x) = \int_1^x \frac{\log(t)}{t-1}\,\mathrm{d}t$$

Example

```
diln([0.2, 0.7, 10])
  -1.0748  -0.3261   3.9507
```

double

Conversion to double-precision numbers.

Syntax

```
B = double(A)
```

Description

`double(A)` converts number or array `A` to double precision. `A` can be any kind of numeric value (real, complex, or integer), or a character or logical array.

To keep the integer type of logical and character arrays, the unitary operator + should be used instead.

Examples

```
double(uint8(3))
  3
double('AB')
  65 66
islogical(double(1>2))
  false
```

See also

`uint8` and related functions, `single`, `cast`, operator +, `setstr`, `char`, `logical`

ellipam

Jacobi elliptic amplitude.

Syntax

```
phi = ellipam(u, m)
phi = ellipam(u, m, tol)
```

Description

`ellipam(u,m)` gives the Jacobi elliptic amplitude `phi`. Parameter `m` must be in [0,1]. The Jacobi elliptic amplitude is the inverse of the Jacobi integral of the first kind, such that $u = F(\varphi|m)$.

`ellipam(u,m,tol)` uses tolerance `tol`; the default tolerance is `eps`.

Example

```
phi = ellipam(2.7, 0.6)
  phi =
    2.0713
u = ellipf(phi, 0.6)
  u =
    2.7
```

See also

`ellipf`, `ellipj`

ellipe

Jacobi elliptic integral of the second kind.

Syntax

```
u = ellipe(phi, m)
```

Description

`ellipe(phi,m)` gives the Jacobi elliptic integral of the second kind, defined as

$$E(\varphi|m) = \int_0^\varphi \sqrt{1 - m \sin^2 t}\, \mathrm{d}t$$

Complete elliptic integrals of first and second kinds, with `phi=pi/2`, can be obtained with `ellipke`.

See also

`ellipf`, `ellipke`

ellipf

Jacobi elliptic integral of the first kind.

Syntax

```
u = ellipf(phi, m)
```

Description

`ellipf(phi,m)` gives the Jacobi elliptic integral of the first kind, defined as

$$F(\varphi|m) = \int_0^\varphi \frac{\mathrm{d}t}{\sqrt{1 - m \sin^2 t}}$$

Complete elliptic integrals of first and second kinds, with `phi=pi/2`, can be obtained with `ellipke`.

See also

`ellipe`, `ellipke`, `ellipam`

ellipj

Jacobi elliptic functions.

Syntax

```
(sn, cn, dn) = ellipj(u, m)
(sn, cn, dn) = ellipj(u, m, tol)
```

Description

`ellipj(u,m)` gives the Jacobi elliptic function sn, cn, and dn. Parameter `m` must be in [0,1]. These functions are based on the Jacobi elliptic amplitude φ, the inverse of the Jacobi elliptic integral of the first kind which can be obtained with `ellipam`):

$$u = F(\varphi|m)$$

$$\mathrm{sn}(u|m) = \sin(\varphi)$$

$$\mathrm{cn}(u|m) = \cos(\varphi)$$

$$\mathrm{dn}(u|m) = \sqrt{1 - m\sin^2\varphi}$$

`ellipj(u,m,tol)` uses tolerance `tol`; the default tolerance is `eps`.

Examples

```
(sn, cn, dn) = ellipj(2.7, 0.6)
  sn =
    0.8773
  cn =
    -0.4799
  dn =
    0.7336
sin(ellipam(2.7, 0.6))
  0.8773
ellipj(0:5, 0.3)
  0.0000    0.8188    0.9713    0.4114   -0.5341   -0.9930
```

See also

`ellipam`, `ellipke`

ellipke

Complete elliptic integral.

Syntax

```
(K, E) = ellipke(m)
(K, E) = ellipke(m, tol)
```

Description

(K,E)=ellipke(m) gives the complete elliptic integrals of the first kind K=F(m) and second kind E=E(m), defined as

$$F(m) = \int_0^{\pi/2} \frac{\mathrm{d}t}{\sqrt{1 - m\sin^2 t}}$$

$$E(m) = \int_0^{\pi/2} \sqrt{1 - m\sin^2 t}\,\mathrm{d}t$$

Parameter m must be in [0,1].

ellipke(m,tol) uses tolerance tol; the default tolerance is eps.

Example

```
(K, E) = ellipke(0.3)
  K =
    1.7139
  E =
    1.4454
```

See also

ellipj

eps

Difference between 1 and the smallest number x such that x > 1.

Syntax

```
e = eps
e = eps(x)
e = eps(type)
```

Description

Because of the floating-point encoding of "real" numbers, the absolute precision depends on the magnitude of the numbers. The relative precision is characterized by the number given by eps, which is the smallest double positive number such that 1+eps can be distinguished from 1.

eps(x) gives the smallest number e such that x+e has the same sign as x and can be distinguished from x. It takes into account whether x is a double or a single number. If x is an array, the result has the same size; each element corresponds to an element of the input.

eps('single') gives the smallest single positive number e such that 1single+e can be distinguished from 1single. eps('double') gives the same value as eps without input argument.

Examples

```
eps
  2.2204e-16
1 + eps - 1
  2.2204e-16
eps / 2
  1.1102e-16
1 + eps / 2 - 1
  0
```

See also

inf, realmin, pi, i, j

erf

Error function.

Syntax

```
y = erf(x)
```

Description

erf(x) gives the error function of x. Argument and result are real (imaginary part is discarded). The error function is defined as

$$\mathrm{erf}(x) = \frac{2}{\sqrt{\pi}} \int_0^x e^{-t^2}\,\mathrm{d}t$$

Example

```
erf(1)
  0.8427
```

See also

erfc, erfinv

erfc

Complementary error function.

Syntax

```
y = erfc(x)
```

Description

`erfc(x)` gives the complementary error function of `x`. Argument and result are real (imaginary part is discarded). The complementary error function is defined as

$$\mathrm{erfc}(x) = 1 - \mathrm{erf}(x) = \frac{2}{\sqrt{\pi}} \int_x^\infty e^{-t^2}\,\mathrm{d}t$$

Example

```
erfc(1)
  0.1573
```

See also

`erf`, `erfinv`

erfinv

Inverse error function.

Syntax

```
x = erfinv(y)
```

Description

`erfinv(y)` gives the value `x` such that `y=erf(x)`. Argument and result are real (imaginary part is discarded). `y` must be in the range [-1,1]; values outside this range give nan.

Example

```
y = erf(0.8)
  y =
    0.7421
erfinv(y)
  0.8
```

See also

`erf`, `erfc`

exp

Exponential.

Syntax

```
y = exp(x)
```

Description

`exp(x)` is the exponential of x, i.e. `2.7182818284590446...^`x.

Example

```
exp([0,1,0.5j*pi])
  1 2.7183 1j
```

See also

`log`, `expm1`, `expm`, operator `.^`

expm1

Exponential minus one.

Syntax

```
y = expm1(x)
```

Description

`expm1(x)` is `exp(x)-1` with improved precision for small x.

Example

```
expm1(1e-15)
  1e-15
exp(1e-15)-1
  1.1102e-15
```

See also

`exp`, `log1p`

factor

Prime factors.

Syntax

```
v = factor(n)
```

Description

`factor(n)` gives a row vector which contains the prime factors of `n` in ascending order. Multiple prime factors are repeated.

Example

```
factor(350)
  2  5  5  7
```

See also

`isprime`

factorial

Factorial.

Syntax

```
y = factorial(n)
```

Description

`factorial(n)` gives the factorial `n!` of nonnegative integer `n`. If the input argument is negative or noninteger, the result is NaN. The imaginary part is ignored.

Examples

```
factorial(5)
  120
factorial([-1,0,1,2,3,3.14])
  nan   1   1   2   6 nan
```

See also

`gamma`, `nchoosek`

fix

Rounding towards 0.

Syntax

```
 y = fix(x)
```

Description

`fix(x)` truncates the fractional part of `x`. If the argument is a complex number, the real and imaginary parts are handled separately.

Examples

```
 fix(2.3)
   2
 fix(-2.6)
   -2
```

See also

`floor`, `ceil`, `round`

floor

Rounding towards -infinity.

Syntax

```
 y = floor(x)
```

Description

`floor(x)` gives the largest integer smaller than or equal to `x`. If the argument is a complex number, the real and imaginary parts are handled separately.

Examples

```
floor(2.3)
  2
floor(-2.3)
  -3
```

See also

`ceil`, `fix`, `round`

gamma

Gamma function.

Syntax

```
y = gamma(x)
```

Description

`gamma(x)` gives the gamma function of `x`. Argument and result are real (imaginary part is discarded). The gamma function is defined as

$$\Gamma(x) = \int_0^\infty t^{x-1} e^{-t}\,\mathrm{d}t$$

For positive integer values, $\Gamma(n) = (n-1)!$.

Examples

```
gamma(5)
  24
gamma(-3)
  inf
gamma(-3.5)
  0.2701
```

See also

`beta`, `gammaln`, `gammainc`, `factorial`

gammainc

Incomplete gamma function.

Syntax

```
y = gammainc(x,a)
```

Description

`gammainc(x,a)` gives the incomplete gamma function of `x` and `a`. Arguments and result are real (imaginary part is discarded). `x` must be nonnegative. The incomplete gamma function is defined as

$$\mathrm{gammainc}(x,a) = \frac{1}{\Gamma(a)} \int_0^x t^{a-1} e^{-t} \, \mathrm{d}t$$

Example

```
gammainc(2,1.5)
  0.7385
```

See also

`gamma`, `gammaln`, `betainc`

gammaln

Logarithm of gamma function.

Syntax

```
y = gammaln(x)
```

Description

`gammaln(x)` gives the logarithm of the gamma function of `x`. Argument and result are real (imaginary part is discarded). `gammaln` does not rely on the computation of the gamma function to avoid overflows for large numbers.

Examples

```
gammaln(1000)
  5905.2204
gamma(1000)
  inf
```

See also

`gamma`, `gammainc`, `betaln`

gcd

Greatest common divisor.

Syntax

```
 q = gcd(a, b)
```

Description

`gcd(a,b)` gives the greatest common divisor of integer numbers a and b.

Example

```
 gcd(72, 56)
   8
```

See also

`lcm`

goldenratio

Golden ratio constant.

Syntax

```
 x = goldenratio
```

Description

`goldenratio` is the golden ration $(\sqrt{5}+1)/2$, up to the precision of its floating-point representation.

Example

```
 goldenratio
   1.6180
```

See also

`pi`, `eps`

hypot

Hypotenuse.

Syntax

```
c = hypot(a, b)
```

Description

`hypot(a,b)` gives the square root of the square of `a` and `b`, or of their absolute value if they are complex. The result is always real. `hypot` avoids overflow when the result itself does not overflow.

Examples

```
hypot(3, 4)
  5
hypot([1,2,3+4j,inf], 5)
  5.099  5.3852  5.831  inf
```

See also

`sqrt`, `abs`, `norm`

i j

Imaginary unit.

Syntax

```
i
j
1.23e4i
1.23e4j
```

Description

`i` or `j` are the imaginary unit, i.e. the pure imaginary number whose square is -1. `i` and `j` are equivalent.

Used as a suffix appended without space to a number, `i` or `j` mark an imaginary number. They must follow the fractional part and the exponent, if any; for single-precision numbers, they must precede the `single` suffix.

To obtain a complex number i, you can write either `i` or `1i` (or `j` or `1j`). The second way is safer, because variables `i` and `j` are often used as indices and would hide the meaning of the built-in functions. The expression `1i` is always interpreted as an imaginary constant number.

Imaginary numbers are displayed with `i` or `j` depending on the option set with the `format` command.

Examples

```
i
  1j
format i
2i
  2i
2single + 5jsingle
  2+5i (single)
```

See also

`imag`, `complex`

icdf

Inverse cumulative distribution function.

Syntax

```
x = icdf(distribution,p)
x = icdf(distribution,p,a1)
x = icdf(distribution,p,a1,a2)
```

Description

`icdf(distribution,p)` calculates the value of `x` such that `cdf(distribution,x)` is `p`. The distribution is specified with the first argument, a string; case is ignored ('t' and 'T' are equivalent). Additional arguments must be provided for some distributions. The distributions are given in the table below. Default values for the parameters, when mentioned, mean that the parameter may be omitted.

Distribution	**Name**	**Parameters**
Beta	`beta`	a and b
χ^2	`chi2`	deg. of freedom ν
γ	`gamma`	shape α and scale λ
F	`f`	deg. of freedom ν_1 and ν_2
lognormal	`logn`	mean (0) and st. dev. (1)
normal	`norm`	mean (0) and st. dev. (1)
Student's T	`t`	deg. of freedom ν
uniform	`unif`	limits of the range (0 and 1)

See also

`cdf`, `pdf`

imag

Imaginary part of a complex number.

Syntax

```
im = imag(z)
```

Description

`imag(z)` is the imaginary part of the complex number `z`, or 0 if `z` is real.

Examples

```
imag(1+2j)
  2
imag(1)
  0
```

See also

`real`, `complex`, `i`, `j`

inf

Infinity.

Syntax

```
x = inf
x = Inf
x = inf(n)
x = inf(n1,n2,...)
x = inf([n1,n2,...])
x = inf(..., type)
```

Description

`inf` is the number which represents infinity. Most mathematical functions accept infinity as input argument and yield an infinite result if appropriate. Infinity and minus infinity are two different quantities.

With integer non-negative arguments, `inf` creates arrays whose elements are infinity. Arguments are interpreted the same way as `zeros` and `ones`.

The last argument of `inf` can be a string to specify the type of the result: `'double'` for double-precision (default), or `'single'` for single-precision.

Examples

```
1/inf
  0
-inf
  -inf
```

See also

`isfinite`, `isinf`, `nan`, `zeros`, `ones`

isfinite

Test for finiteness.

Syntax

```
b = isfinite(x)
```

Description

`isfinite(x)` is true if the input argument is a finite number (neither infinite nor nan), and false otherwise. The result is performed on each element of the input argument, and the result has the same size.

Example

```
isfinite([0,1,nan,inf])
  T T F F
```

See also

`isinf`, `isnan`

isfloat

Test for a floating-point object.

Syntax

```
b = isfloat(x)
```

Description

`isfloat(x)` is true if the input argument is a floating-point type (double or single), and false otherwise.

Examples

```
isfloat(2)
  true
isfloat(2int32)
  false
```

See also

`isnumeric`, `isinteger`

isinf

Test for infinity.

Syntax

```
b = isinf(x)
```

Description

`isinf(x)` is true if the input argument is infinite (neither finite nor nan), and false otherwise. The result is performed on each element of the input argument, and the result has the same size.

Example

```
isinf([0,1,nan,inf])
  F F F T
```

See also

`isfinite`, `isnan`, `inf`

isinteger

Test for an integer object.

Syntax

```
b = isinteger(x)
```

Description

`isinteger(x)` is true if the input argument is an integer type (including char and logical), and false otherwise.

Examples

```
isinteger(2int16)
  true
isinteger(false)
  true
isinteger('abc')
  true
isinteger(3)
  false
```

See also

`isnumeric`, `isfloat`

isnan

Test for Not a Number.

Syntax

```
b = isnan(x)
```

Description

`isnan(x)` is true if the input argument is nan (not a number), and false otherwise. The result is performed on each element of the input argument, and the result has the same size.

Example

```
isnan([0,1,nan,inf])
  F F T F
```

See also

`isinf`, `nan`

isnumeric

Test for a numeric object.

Syntax

```
b = isnumeric(x)
```

Description

`isnumeric(x)` is true if the input argument is numeric (real or complex scalar, vector, or array), and false otherwise.

Examples

```
isnumeric(pi)
  true
isnumeric('abc')
  false
```

See also

`ischar`, `isfloat`, `isinteger`, `isscalar`, `isvector`

isprime

Prime number test.

Syntax

```
b = isprime(n)
```

Description

`isprime(n)` returns `true` if `n` is a prime number, or `false` otherwise. If `n` is a matrix, the test is applied to each element and the result is a matrix the same size.

Examples

```
use stdlib
isprime(7)
  true
isprime([0, 2, 10])
  F T F
```

See also

`factor`

isscalar

Test for a scalar number.

Syntax

```
b = isscalar(x)
```

Description

`isscalar(x)` is true if the input argument is scalar (real or complex number of any floating-point or integer type, character or logical value), and false otherwise.

Examples

```
isscalar(2)
  true
isscalar([1, 2, 5])
  false
```

See also

`isnumeric`, `isvector`, `size`

isvector

Test for a vector.

Syntax

```
b = isvector(x)
```

Description

`isvector(x)` is true if the input argument is a row or column vector (real or complex 2-dimension array of any floating-point or integer type, character or logical value with one dimension equal to 1, or empty array), and false otherwise.

Examples

```
isvector([1, 2, 3])
  true
isvector([1; 2])
  true
isvector(7)
  true
isvector([1, 2; 3, 4])
  false
```

See also

`isnumeric`, `isscalar`, `size`, `ndims`, `length`

lcm

Least common multiple.

Syntax

```
q = lcm(a, b)
```

Description

`lcm(a,b)` gives the least common multiple of integer numbers a and b.

Example

```
 lcm(72, 56)
   504
```

See also

`gcd`

log

Natural (base e) logarithm.

Syntax

```
 y = log(x)
```

Description

`log(x)` gives the natural logarithm of `x`. It is the inverse of `exp`. The result is complex if `x` is not real positive.

Example

```
 log([-1,0,1,10,1+2j])
   0+3.1416j inf 0 2.3026 0.8047+1.1071j
```

See also

`log10`, `log2`, `log1p`, `reallog`, `exp`

log10

Decimal logarithm.

Syntax

```
 y = log10(x)
```

Description

`log10(x)` gives the decimal logarithm of `x`, defined by `log10(x) = log(x)/log(10)`. The result is complex if `x` is not real positive.

Example

```
log10([-1,0,1,10,1+2j])
  0+1.3644j inf 0 1 0.3495+0.4808j
```

See also

`log`, `log2`

log1p

Logarithm of x plus one.

Syntax

```
y = log1p(x)
```

Description

`log1p(x)` is `log(1+x)` with improved precision for small x.

Example

```
log1p(1e-15)
  1e-15
log(1 + 1e-15)
  1.1102e-15
```

See also

`log`, `expm1`

log2

Base 2 logarithm.

Syntax

```
y = log2(x)
```

Description

`log2(x)` gives the base 2 logarithm of x, defined as `log2(x)=log(x)/log(2)`. The result is complex if x is not real positive.

Example

```
log2([1, 2, 1024, 2000, -5])
  0  1  10  10.9658  2.3219+4.5324j
```

See also

`log`, `log10`

mod

Modulo.

Syntax

```
m = mod(x, y)
```

Description

`mod(x,y)` gives the modulo of `x` divided by `y`, i.e. a number `m` between 0 and `y` such that `x = q*y+m` with integer `q`. Imaginary parts, if they exist, are ignored.

Examples

```
mod(10,7)
  3
mod(-10,7)
  4
mod(10,-7)
  -4
mod(-10,-7)
  -3
```

See also

`rem`

nan

Not a Number.

Syntax

```
x = nan
x = NaN
x = nan(n)
x = nan(n1,n2,...)
x = nan([n1,n2,...])
x = nan(..., type)
```

Description

NaN (Not a Number) is the result of the primitive floating-point functions or operators called with invalid arguments. For example, 0/0, inf-inf and 0*inf all result in NaN. When used in an expression, NaN propagates to the result. All comparisons involving NaN result in false, except for comparing NaN with any number for inequality, which results in true.

Contrary to built-in functions usually found in the underlying operating system, many functions which would result in NaNs give complex numbers when called with arguments in a certain range.

With integer non-negative arguments, nan creates arrays whose elements are NaN. Arguments are interpreted the same way as `zeros` and `ones`.

The last argument of nan can be a string to specify the type of the result: `'double'` for double-precision (default), or `'single'` for single-precision.

Examples

```
nan
  nan
0*nan
  nan
nan==nan
  false
nan~=nan
  true
log(-1)
  0+3.1416j
```

See also

`inf`, `isnan`, `zeros`, `ones`

nchoosek

Binomial coefficient.

Syntax

```
b = nchoosek(n, k)
```

Description

nchoosek(n,k) gives the number of combinations of n objects taken k at a time. Both n and k must be nonnegative integers with k<n.

Examples

```
nchoosek(10,4)
  210
nchoosek(10,6)
  210
```

See also

factorial, gamma

nthroot

Real nth root.

Syntax

```
y = nthroot(x,n)
```

Description

nthroot(x,n) gives the real nth root of real number x. If x is positive, it is x.^(1./n); if x is negative, it is -abs(x).^(1./n) if n is an odd integer, or NaN otherwise.

Example

```
nthroot([-2,2], 3)
  -1.2599    1.2599
[-2,2] .^ (1/3)
  0.6300+1.0911i  1.2599
```

See also

operator .^, realsqrt, sqrt

pdf

Probability density function.

Syntax

```
y = pdf(distribution,x)
y = pdf(distribution,x,a1)
y = pdf(distribution,x,a1,a2)
```

Description

`pdf(distribution,x)` gives the probability of a density function. The distribution is specified with the first argument, a string; case is ignored ('t' and 'T' are equivalent). Additional arguments must be provided for some distributions. See `cdf` for the list of distributions.

See also

`cdf`

pi

Constant π.

Syntax

```
x = pi
```

Description

`pi` is the number π, up to the precision of its floating-point representation.

Example

```
exp(1j * pi)
  -1
```

See also

`goldenratio`, `i`, `j`, `eps`

real

Real part of a complex number.

Syntax

```
re = real(z)
```

Description

`real(z)` is the real part of the complex number z, or z if z is real.

Examples

```
real(1+2j)
  1
real(1)
  1
```

See also

`imag`, `complex`

reallog

Real natural (base e) logarithm.

Syntax

```
y = reallog(x)
```

Description

`reallog(x)` gives the real natural logarithm of x. It is the inverse of exp for real numbers. The imaginary part of x is ignored. The result is NaN if x is negative.

Example

```
reallog([-1,0,1,10,1+2j])
  nan inf 0 2.3026 0
```

See also

`log`, `realpow`, `realsqrt`, `exp`

realmax realmin

Largest and smallest real numbers.

Syntax

```
x = realmax
x = realmax(n)
x = realmax(n1,n2,...)
x = realmax([n1,n2,...])
x = realmax(..., type)
x = realmin
x = realmin(...)
```

Description

`realmax` gives the largest positive real number in double precision. `realmin` gives the smallest positive real number in double precision which can be represented in normalized form (i.e. with full mantissa precision).

With integer non-negative arguments, `realmax` and `realmin` create arrays whose elements are all set to the respective value. Arguments are interpreted the same way as `zeros` and `ones`.

The last argument of `realmax` and `realmin` can be a string to specify the type of the result: `'double'` for double-precision (default), or `'single'` for single-precision.

Examples

```
realmin
  2.2251e-308
realmin('single')
  1.1755e-38
realmax
  1.7977e308
realmax('single')
  3.4028e38single
realmax + eps(realmax)
  inf
```

See also

`inf`, `ones`, `zeros`, `eps`

realpow

Real power.

Syntax

```
z = realpow(x, y)
```

Description

`realpow(x,y)` gives the real value of x to the power y. The imaginary parts of x and y are ignored. The result is NaN if it is not defined for the input arguments. If the arguments are arrays, their size must match or one of them must be a scalar number; the power is performed element-wise.

See also

operator `.^`, `reallog`, `realsqrt`

realsqrt

Real square root.

Syntax

```
y = realsqrt(x)
```

Description

`realsqrt(x)` gives the real square root of x. The imaginary part of x is ignored. The result is NaN if x is negative.

Example

```
realsqrt([-1,0,1,10,1+2j])
  nan 0 1 3.1623 1
```

See also

`sqrt`, `reallog`, `realpow`, `nthroot`

rem

Remainder of a real division.

Syntax

```
r = rem(x, y)
```

Description

`rem(x,y)` gives the remainder of `x` divided by `y`, i.e. a number `r` between 0 and `sign(x)*abs(y)` such that `x = q*y+r` with integer `q`. Imaginary parts, if they exist, are ignored.

Examples

```
rem(10,7)
  3
rem(-10,7)
  -3
rem(10,-7)
  3
rem(-10,-7)
  -3
```

See also

`mod`

round

Rounding to the nearest integer.

Syntax

```
y = round(x)
```

Description

`round(x)` gives the integer nearest to x. If the argument is a complex number, the real and imaginary parts are handled separately.

Examples

```
round(2.3)
  2
round(2.6)
  3
round(-2.3)
  -2
```

See also

`floor`, `ceil`, `fix`

sign

Sign of a real number or direction of a complex number.

Syntax

```
s = sign(x)
z2 = sign(z1)
```

Description

With a real argument, `sign(x)` is 1 if `x>0`, 0 if `x==0`, or -1 if `x<0`. With a complex argument, `sign(z1)` is a complex value with the same phase as `z1` and whose magnitude is 1.

Examples

```
sign(-2)
  -1
sign(1+1j)
  0.7071+0.7071j
sign([0, 5])
  0 1
```

See also

`abs`, `angle`

sec

Secant.

Syntax

```
y = sec(x)
```

Description

sec(x) gives the secant of x, which is complex if x is.

See also

`asec`, `sech`, `cos`

sech

Hyperbolic secant.

Syntax

```
y = sech(x)
```

Description

acot(x) gives the hyperbolic secant of x, which is complex if x is.

See also

`asech`, `sec`, `cosh`

sin

Sine.

Syntax

```
y = sin(x)
```

Description

`sin(x)` gives the sine of x, which is complex if x is complex.

Example

```
sin(2)
  0.9093
```

See also

`cos`, `asin`, `sinh`

sinc

Sinc.

Syntax

```
y = sinc(x)
```

Description

`sinc(x)` gives the sinc of `x`, i.e. `sin(pi*x)/(pi*x)` if `x~=0` or 1 if `x==0`. The result is complex if `x` is complex.

Example

```
sinc(1.5)
  -0.2122
```

See also

`sin`, `sinh`

single

Conversion to single-precision numbers.

Syntax

```
B = single(A)
```

Description

`single(A)` converts number or array `A` to single precision. `A` can be any kind of numeric value (real, complex, or integer), or a character or logical array.

Single literal numbers can be entered as a floating-point number with the `single` suffix.

Examples

```
single(pi)
  3.1416single
single('AB')
  1x2 single array
    65 66
3.7e4single
  37000single
```

See also

`double`, `uint8` and related functions, operator `+`, `setstr`, `char`, `logical`

sinh

Hyperbolic sine.

Syntax

```
y = sinh(x)
```

Description

`sinh(x)` gives the hyperbolic sine of `x`, which is complex if `x` is complex.

Example

```
sinh(2)
  3.6269
```

See also

`cosh`, `asinh`, `sin`

sqrt

Square root.

Syntax

```
r = sqrt(z)
```

Description

`sqrt(z)` gives the square root of `z`, which is complex if `z` is not real positive.

Examples

```
sqrt(4)
  2
sqrt([1 4 -9 3+4j])
  1 2 3j 2+1j
```

See also

`realsqrt`, `sqrtm`, `chol`

swapbytes

Conversion between big-endian and little-endian representation.

Syntax

```
Y = swapbytes(X)
```

Description

`swapbytes(X)` swaps the bytes representing number `X`. If `X` is an array, each number is swapped separately. The imaginary part, if any, is discarded. `X` can be of any numerical type. `swapbytes` is its own inverse for real numbers.

Example

```
swapbytes(1uint32)
  16777216uint32
```

See also

`typecast`, `cast`

tan

Tangent.

Syntax

```
y = tan(x)
```

Description

`tan(x)` gives the tangent of x, which is complex if x is complex.

Example

```
tan(2)
  -2.185
```

See also

`atan`, `tanh`

tanh

Hyperbolic tangent.

Syntax

```
y = tanh(x)
```

Description

`tanh(x)` gives the hyperbolic tangent of `x`, which is complex if `x` is complex.

Example

```
tanh(2)
  0.964
```

See also

`atanh`, `tan`

typecast

Type conversion with same binary representation.

Syntax

```
Y = typecast(X, type)
```

Description

`typecast(X,type)` changes the numeric array `X` to the type given by string `type`, which can be `'double'`, `'single'`, `'int8'` or any other signed or unsigned integer type, `'char'`, or `'logical'`. The binary representation in memory is preserved. The imaginary part, if any, is discarded. Depending on the conversion, the number of elements is changed, so that the array size in bytes in preserved. The result is a row vector if `X` is a scalar or a row vector, or a column vector otherwise. The result depends on the computer architecture.

Example

```
typecast(1uint32, 'uint8')
  1x4 uint8 array
    0    0   0   1
typecast(pi, 'uint8')
  1x8 uint8 array
    64   9  33 251  84  68  45  24
```

See also

`swapbytes`, `bwrite`, `sread`, `cast`

3.14 Linear Algebra

addpol

Addition of two polynomials.

Syntax

```
p = addpol(p1,p2)
```

Description

`addpol(p1,p2)` adds two polynomials `p1` and `p2`. Each polynomial is given as a vector of coefficients, with the highest power first; e.g., $x^2 + 2x - 3$ is represented by `[1,2,-3]`. Row vectors and column vectors are accepted, as well as matrices made of row vectors or column vectors, provided one matrix is not larger in one dimension and smaller in the other one. `addpol` is equivalent to the plain addition when both arguments have the same size.

Examples

```
addpol([1,2,3], [2,5])
  1 4 8
addpol([1,2,3], -[2,5])  % subtraction
  1 0 -2
addpol([1,2,3;4,5,6], [1;1])
  1 2 4
  4 5 7
```

See also

`conv`, `deconv`, operator +

balance

Diagonal similarity transform for balancing a matrix.

Syntax

```
B = balance(A)
(T, B) = balance(A)
```

Description

`balance(A)` applies a diagonal similarity transform to the square matrix `A` to make the rows and columns as close in norm as possible. Balancing may reduce the 1-norm of the matrix, and improves the accuracy of the computed eigenvalues and/or eigenvectors. To avoid round-off errors, `balance` scales `A` with powers of 2.

`balance` returns the balanced matrix `B` which has the same eigenvalues and singular values as `A`, and optionally the diagonal scaling matrix `T` such that `T\A*T=B`.

Example

```
A = [1,2e6;3e-6,4];
(T,B) = balance(A)
  T =
   16384       0
       0       3.125e-2
  B =
       1       3.8147
       1.5729  4
```

See also

`eig`

care

Continuous-time algebraic Riccati equation.

Syntax

```
(X, L, K) = care(A, B, Q)
(X, L, K) = care(A, B, Q, R)
(X, L, K) = care(A, B, Q, R, S)
(X, L) = care(A, S, Q, true)
```

Description

care(A,B,Q) calculates the stable solution X of the following continuous-time algebraic Riccati equation:

$$A'X + XA - XBB'X + Q = 0$$

All matrices are real; Q and X are symmetric.

With four input arguments, care(A,B,Q,R) (with R real symmetric) solves the following Riccati equation:

$$A'X + XA - XBR^{-1}B'X + Q = 0$$

With five input arguments, care(A,B,Q,R,S) solves the following equation:

$$A'X + XA - (S + XB)R^{-1}(S' + B'X) + Q = 0$$

With two or three output arguments, (X,L,K) = care(...) also returns the gain matrix K defined as

$$K = R^{-1}B'X$$

and the column vector of closed-loop eigenvalues

$$L = \mathrm{eig}(A - BK)$$

care(A,S,Q,true) with up to two output arguments is equivalent to care(A,B,Q) or care(A,B,Q,false) with S=B*B'.

Example

```
A = [-4,2;1,2];
B = [0;1];
C = [2,-1];
Q = C' * C;
R = 5;
(X, L, K) = care(A, B, Q, R)
  X =
      1.07    3.5169
    3.5169   23.2415
  L =
   -4.3488
   -2.2995
  K =
    0.7034    4.6483
A' * X + X * A - X * B / R * B' * X + Q
  1.7319e-14 1.1369e-13
  8.5265e-14 6.2528e-13
```

See also

`dare`

chol

Cholesky decomposition.

Syntax

```
M2 = chol(M1)
```

Description

If a square matrix M1 is symmetric (or hermitian) and positive definite, it can be decomposed into the following product:

$$M_1 = M_2' M_2$$

where M2 is an upper triangular matrix. The Cholesky decomposition can be seen as a kind of square root.

The part of M1 below the main diagonal is not used, because M1 is assumed to be symmetric or hermitian. An error occurs if M1 is not positive definite.

Example

```
M = chol([5,3;3,8])
M =
  2.2361 1.3416
  0      2.4900
M'*M
  5 3
  3 8
```

See also

`inv`, `sqrtm`

cond

Condition number of a matrix.

Syntax

```
x = cond(M)
```

Description

`cond(M)` returns the condition number of matrix `M`, i.e. the ratio of its largest singular value divided by the smallest one, or infinity for singular matrices. The larger the condition number, the more ill-conditioned the inversion of the matrix.

Examples

```
cond([1, 0; 0, 1])
 1
cond([1, 1; 1, 1+1e-3])
 4002.0008
```

See also

`svd`, `rank`

conv

Convolution or polynomial multiplication.

Syntax

```
v = conv(v1,v2)
M = conv(M1,M2)
M = conv(M1,M2,dim)
```

Description

`conv(v1,v2)` convolves the vectors v1 and v2, giving a vector whose length is length(v1)+length(v2)-1. The result is a row vector if both arguments are row vectors, and a column vector if both arguments are column vectors. Otherwise, arguments are considered as matrices.

`conv(M1,M2)` convolves the matrices `M1` and `M2` column by columns. `conv(M1,M2,dim)` convolves along the dimension `dim`, 1 for columns and 2 for rows. If one of the matrices has only one column, or one row, it is repeated to match the size of the other argument.

Example

```
conv([1,2],[1,2,3])
  1 4 7 6
conv([1,2],[1,2,3;4,5,6],2)
  1  4  7  6
  4 13 16 12
```

See also

`deconv`, `filter`, `addpol`, `conv2`

conv2

Two-dimensions convolution of matrices.

Syntax

```
M = conv2(M1,M2)
M = conv2(M1,M2,kind)
```

Description

`conv2(M1,M2)` convolves the matrices `M1` and `M2` along both directions. The optional third argument specifies how to crop the result. Let `(nl1,nc1)=size(M1)` and `(nl2,nc2)=size(M2)`. With `kind='full'` (default value), the result `M` has `nl1+nl2-1` lines and `nc1+nc2-1` columns. With `kind='same'`, the result `M` has `nl1` lines and `nc1` columns; this options is very useful if `M1` represents equidistant samples in a plane (e.g. pixels) to be filtered with the finite-impulse response 2-d filter `M2`. With `kind='valid'`, the result `M` has `nl1-nl2+1` lines and `nc1-nc2+1` columns, or is the empty matrix `[]`; if `M1` represents data filtered by `M2`, the borders where the convolution sum is not totally included in `M1` are removed.

Examples

```
conv2([1,2,3;4,5,6;7,8,9],[1,1,1;1,1,1;1,1,1])
   1  3  6  5  3
   5 12 21 16  9
  12 27 45 33 18
  11 24 39 28 15
   7 15 24 17  9
conv2([1,2,3;4,5,6;7,8,9],[1,1,1;1,1,1;1,1,1],'same')
  12 21 16
  27 45 33
  24 39 28
conv2([1,2,3;4,5,6;7,8,9],[1,1,1;1,1,1;1,1,1],'valid')
  45
```

See also

`conv`

cov

Covariance.

Syntax

```
M = cov(data)
M = cov(data, 0)
M = cov(data, 1)
```

Description

`cov(data)` returns the best unbiased estimate m-by-m covariance matrix of the n-by-m matrix `data` for a normal distribution. Each row of `data` is an observation where n quantities were measured. The covariance matrix is real and symmetric, even if `data` is complex. The diagonal is the variance of each column of `data`. `cov(data,0)` is the same as `cov(data)`.

`cov(data,1)` returns the m-by-m covariance matrix of the n-by-m matrix `data` which contains the whole population.

Example

```
cov([1,2;2,4;3,5])
  1 1.5
  1.5 2.3333
```

See also

`mean`, `var`

cross

Cross product.

Syntax

```
v3 = cross(v1, v2)
v3 = cross(v1, v2, dim)
```

Description

`cross(v1,v2)` gives the cross products of vectors `v1` and `v2`. `v1` and `v2` must be row or columns vectors of three components, or arrays of the same size containing several such vectors. When there is ambiguity, a third argument `dim` may be used to specify the dimension of vectors: 1 for column vectors, 2 for row vectors, and so on.

Examples

```
cross([1; 2; 3], [0; 0; 1])
  2
 -1
  0
cross([1, 2, 3; 7, 1, -3], [4, 0, 0; 0, 2, 0], 2)
  0  12  -8
  6   0  14
```

See also

`dot`, operator `*`, `det`

cumprod

Cumulative products.

Syntax

```
M2 = cumprod(M1)
M2 = cumprod(M1,dim)
```

Description

`cumprod(M1)` returns a matrix `M2` of the same size as `M1`, whose elements `M2(i,j)` are the product of all the elements `M1(k,j)` with `k<=i`. `cumprod(M1,dim)` operates along the dimension `dim` (column-wise if `dim` is 1, row-wise if `dim` is 2).

Examples

```
cumprod([1,2,3;4,5,6])
  1  2  3
  4 10 18
cumprod([1,2,3;4,5,6],2)
  1  2   6
  4 20 120
```

See also

`prod`, `cumsum`

cumsum

Cumulative sums.

Syntax

```
M2 = cumsum(M1)
M2 = cumsum(M1,dim)
```

Description

`cumsum(M1)` returns a matrix `M2` of the same size as `M1`, whose elements `M2(i,j)` are the sum of all the elements `M1(k,j)` with `k<=i`. `cumsum(M1,dim)` operates along the dimension `dim` (column-wise if `dim` is 1, row-wise if `dim` is 2).

Examples

```
cumsum([1,2,3;4,5,6])
  1 2 3
  5 7 9
cumsum([1,2,3;4,5,6],2)
  1 3  6
  4 9 15
```

See also

`sum`, `diff`, `cumprod`

dare

Discrete-time algebraic Riccati equation.

Syntax

```
(X, L, K) = dare(A, B, Q)
(X, L, K) = dare(A, B, Q, R)
```

Description

`dare(A,B,Q)` calculates the stable solution `X` of the following discrete-time algebraic Riccati equation:

$$X = A'XA - A'XB(B'XB + I)^{-1}B'XA + Q$$

All matrices are real; `Q` and `X` are symmetric.

With four input arguments, `dare(A,B,Q,R)` (with R real symmetric) solves the following Riccati equation:

$$X = A'XA - A'XB(B'XB+R)^{-1}B'XA + Q$$

With two or three output arguments, `(X,L,K) = dare(...)` also returns the gain matrix K defined as

$$K = (B'XB+R)^{-1}B'XA$$

and the column vector of closed-loop eigenvalues

$$L = \mathrm{eig}(A - BK)$$

Example

```
A = [-4,2;1,2];
B = [0;1];
C = [2,-1];
Q = C' * C;
R = 5;
(X, L, K) = dare(A, B, Q, R)
  X =
    2327.9552 -1047.113
   -1047.113    496.0624
  L =
     -0.2315
      0.431
  K =
    9.3492   -2.1995
-X + A'*X*A - A'*X*B/(B'*X*B+R)*B'*X*A + Q
    1.0332e-9  -4.6384e-10
   -4.8931e-10  2.2101e-10
```

See also

`care`

deconv

Deconvolution or polynomial division.

Syntax

```
q = deconv(a,b)
(q,r) = deconv(a,b)
```

Description

(q,r)=deconv(a,b) divides the polynomial a by the polynomial b, resulting in the quotient q and the remainder r. All polynomials are given as vectors of coefficients, highest power first. The degree of the remainder is strictly smaller than the degree of b. deconv is the inverse of conv: a = addpol(conv(b,q),r).

Examples

```
[q,r] = deconv([1,2,3,4,5],[1,3,2])
q =
  1 -1 4
r =
  -6 -3
addpol(conv(q,[1,3,2]),r)
  1 2 3 4 5
```

See also

conv, filter, addpol

det

Determinant of a square matrix.

Syntax

```
d = det(M)
```

Description

det(M) is the determinant of the square matrix M, which is 0 (up to the rounding errors) if M is singular. The function rank is a numerically more robust test for singularity.

Examples

```
det([1,2;3,4])
  -2
det([1,2;1,2])
  0
```

See also

poly, rank

diff

Differences.

Syntax

```
dm = diff(A)
dm = diff(A,n)
dm = diff(A,n,dim)
dm = diff(A,[],dim)
```

Description

`diff(A)` calculates the differences between each elements of the columns of matrix `A`, or between each elements of `A` if it is a row vector.

`diff(A,n)` calculates the n:th order differences, i.e. it repeats `n` times the same operation. Up to a scalar factor, the result is an approximation of the n:th order derivative based on equidistant samples.

`diff(A,n,dim)` operates along dimension `dim`. If the second argument n is the empty matrix `[]`, the default value of 1 is assumed.

Examples

```
diff([1,3,5,4,8])
  2 2 -1 4
diff([1,3,5,4,8],2)
  0 -3 5
diff([1,3,5;4,8,2;3,9,8],1,2)
 2  2
 4 -6
 6 -1
```

See also

`cumsum`

dlyap

Discrete-time Lyapunov equation.

Syntax

```
X = dlyap(A, C)
```

Description

`dlyap(A,C)` calculates the solution `X` of the following discrete-time Lyapunov equation:

$$AXA' - X + C = 0$$

All matrices are real.

Example

```
A = [3,1,2;1,3,5;6,2,1];
C = [7,1,2;4,3,5;1,2,1];
X = dlyap(A, C)
  X =
   -1.0505    3.2222   -1.2117
    3.2317   -11.213    4.8234
   -1.4199     5.184   -2.7424
```

See also

`lyap`, `dare`

dot

Scalar product.

Syntax

```
v3 = dot(v1, v2)
v3 = dot(v1, v2, dim)
```

Description

`dot(v1,v2)` gives the scalar products of vectors `v1` and `v2`. `v1` and `v2` must be row or columns vectors of same length, or arrays of the same size; then the scalar product is performed along the first dimension not equal to 1. A third argument `dim` may be used to specify the dimension the scalar product is performed along.

Examples

```
dot([1; 2; 3], [0; 0; 1])
  3
dot([1, 2, 3; 7, 1, -3], [4, 0, 0; 0, 2, 0], 2)
  4
  2
```

See also

`cross`, operator `*`, `det`

eig

Eigenvalues and eigenvectors of a matrix.

Syntax

```
e = eig(M)
(V,D) = eig(M)
```

Description

`eig(M)` returns the vector of eigenvalues of the square matrix `M`.

`(V,D) = eig(M)` returns a diagonal matrix `D` of eigenvalues and a matrix `V` whose columns are the corresponding eigenvectors. They are such that `M*V = V*D`.

Examples

```
eig([1,2;3,4])
  -0.3723
  5.3723
(V,D) = eig([1,2;2,1])
 V =
  0.7071 0.7071
  -0.7071 0.7071
 D =
  -1 0
  0 3
[1,2;2,1] * V
  -0.7071 2.1213
  0.7071 2.1213
V * D
  -0.7071 2.1213
  0.7071 2.1213
```

See also

`schur`, `svd`, `det`, `roots`

expm

Exponential of a square matrix.

Syntax

```
M2 = expm(M1)
```

Description

`expm(M)` is the exponential of the square matrix `M`, which is usually different from the element-wise exponential of `M` given by exp.

Examples

```
expm([1,1;1,1])
  4.1945 3.1945
  3.1945 4.1945
exp([1,1;1,1])
  2.7183 2.7183
  2.7183 2.7183
```

See also

`logm`, operator ^, `exp`

fft

Fast Fourier Transform.

Syntax

```
F = fft(f)
F = fft(f,n)
F = fft(f,n,dim)
```

Description

`fft(f)` returns the discrete Fourier transform (DFT) of the vector `f`, or the DFT's of each columns of the array `f`. With a second argument `n`, the `n` first values are used; if `n` is larger than the length of the data, zeros are added for padding. An optional argument `dim` gives the dimension along which the DFT is performed; it is 1 for calculating the DFT of the columns of `f`, 2 for its rows, and so on. `fft(f,[],dim)` specifies the dimension without resizing the array.

`fft` is based on a mixed-radix Fast Fourier Transform if the data length is non-prime. It can be very slow if the data length has large prime factors or is a prime number.

The coefficients of the DFT are given from the zero frequency to the largest frequency (one point less than the inverse of the sampling period). If the input `f` is real, its DFT has symmetries, and the first half contain all the relevant information.

Examples

```
fft(1:4)
  10 -2+2j -2 -2-2j
fft(1:4, 3)
  6 -1.5+0.866j -1.5-0.866j
```

See also

`ifft`

fft2

2-d Fast Fourier Transform.

Syntax

```
F = fft2(f)
F = fft2(f, size)
F = fft2(f, nr, nc)
F = fft2(f, n)
```

Description

`fft2(f)` returns the 2-d Discrete Fourier Transform (DFT along dimensions 1 and 2) of array `f`.

With two or three input arguments, `fft2` resizes the two first dimensions by cropping or by padding with zeros. `fft2(f,nr,nc)` resizes first dimension to `nr` rows and second dimension to `nc` columns. In `fft2(f,size)`, the new size is given as a two-element vector `[nr,nc]`. `fft2(F,n)` is equivalent to `fft2(F,n,n)`.

If the first argument is an array with more than two dimensions, `fft2` performs the 2-d DFT along dimensions 1 and 2 separately for each plane along remaining dimensions; `fftn` performs an DFT along each dimension.

See also

`ifft2`, `fft`, `fftn`

fftn

n-dimension Fast Fourier Transform.

Syntax

```
F = fftn(f)
F = fftn(f, size)
```

Description

`fftn(f)` returns the n-dimension Discrete Fourier Transform of array `f` (DFT along each dimension of `f`).

With two input arguments, `fftn(f,size)` resizes `f` by cropping or by padding `f` with zeros.

See also

`ifftn`, `fft`, `fft2`

filter

Digital filtering of data.

Syntax

```
y = filter(b,a,u)
y = filter(b,a,u,x0)
y = filter(b,a,u,x0,dim)
(y, xf) = filter(...)
```

Description

`filter(b,a,u)` filters vector `u` with the digital filter whose coefficients are given by polynomials `b` and `a`. The filtered data can also be an array, filtered along the first non-singleton dimension or along the dimension specified with a fifth input argument. The fourth argument, if provided and different than the empty matrix `[]`, is a matrix whose columns contain the initial state of the filter and have `max(length(a),length(b))-1` element. Each column correspond to a signal along the dimension of filtering. The result `y`, which has the same size as the input, can be computed with the following code if `u` is a vector:

```
a = a / a(1);
if length(a) > length(b)
  b = [b, zeros(1, length(a)-length(b))];
else
  a = [a, zeros(1, length(b)-length(a))];
end
n = length(x);
```

```
for i = 1:length(u)
  y(i) = b(1) * u(i) + x(1);
  for j = 1:n-1
    x(j) = b(j + 1) * u(i) + x(j + 1) - a(j + 1) * y(i);
  end
  x(n) = b(n + 1) * u(i) - a(n + 1) * y(i);
end
```

The optional second output argument is set to the final state of the filter.

Examples

```
filter([1,2], [1,2,3], ones(1,10))
  1 1 -2 4 1 -11 22 -8 -47 121

u = [5,6,5,6,5,6,5];
p = 0.8;
filter(1-p, [1,-p], u, p*u(1))
      % low-pass with matching initial state
  5 5.2 5.16 5.328 5.2624 5.4099 5.3279
```

See also

conv, deconv, conv2

funm

Matrix function.

Syntax

```
Y = funm(X, fun)
(Y, err) = funm(X, fun)
```

Description

`funm(X,fun)` returns the matrix function of square matrix `X` specified by function `fun`. `fun` takes a scalar input argument and gives a scalar output. It is either specified by its name or given as an inline function or a function reference.

With a second output argument `err`, `funm` also returns an estimate of the relative error.

Examples

```
funm([1,2;3,4], @sin)
  -0.4656   -0.1484
  -0.2226   -0.6882
X = [1,2;3,4];
funm(X, inline('(1+x)/(2-x)'))
   -0.25  -0.75
  -1.125  -1.375
(eye(2)+X)/(2*eye(2)-X)
   -0.25  -0.75
  -1.125  -1.375
```

See also

`expm`, `logm`, `sqrtm`, `schur`

ifft

Inverse Fast Fourier Transform.

Syntax

```
f = ifft(F)
f = ifft(F, n)
f = ifft(F, n, dim)
```

Description

`ifft` returns the inverse Discrete Fourier Transform (inverse DFT). Up to the sign and a scaling factor, the inverse DFT and the DFT are the same operation: for a vector, `ifft(d) = conj(fft(d))/length(d)`. `ifft` has the same syntax as `fft`.

Examples

```
F = fft([1,2,3,4])
  F =
    10 -2+2j -2 -2-2j
ifft(F)
    1 2 3 4
```

See also

`fft`, `ifft2`, `ifftn`

ifft2

Inverse 2-d Fast Fourier Transform.

Syntax

```
f = ifft2(F)
f = ifft2(F, size)
f = ifft2(F, nr, nc)
f = ifft2(F, n)
```

Description

`ifft2` returns the inverse 2-d Discrete Fourier Transform (inverse DFT along dimensions 1 and 2).

With two or three input arguments, `ifft2` resizes the two first dimensions by cropping or by padding with zeros. `ifft2(F,nr,nc)` resizes first dimension to `nr` rows and second dimension to `nc` columns. In `ifft2(F,size)`, the new size is given as a two-element vector `[nr,nc]`. `ifft2(F,n)` is equivalent to `ifft2(F,n,n)`.

If the first argument is an array with more than two dimensions, `ifft2` performs the inverse 2-d DFT along dimensions 1 and 2 separately for each plane along remaining dimensions; `ifftn` performs an inverse DFT along each dimension.

Up to the sign and a scaling factor, the inverse 2-d DFT and the 2-d DFT are the same operation. `ifft2` has the same syntax as `fft2`.

See also

`fft2`, `ifft`, `ifftn`

ifftn

Inverse n-dimension Fast Fourier Transform.

Syntax

```
f = ifftn(F)
f = ifftn(F, size)
```

Description

`ifftn(F)` returns the inverse n-dimension Discrete Fourier Transform of array F (inverse DFT along each dimension of F).

With two input arguments, `ifftn(F,size)` resizes F by cropping or by padding F with zeros.

Up to the sign and a scaling factor, the inverse n-dimension DFT and the n-dimension DFT are the same operation. `ifftn` has the same syntax as `fftn`.

See also

`fftn`, `ifft`, `ifft2`

hess

Hessenberg reduction.

Syntax

```
(P,H) = hess(A)
H = hess(A)
```

Description

`hess(A)` reduces the square matrix `A` A to the upper Hessenberg form `H` using an orthogonal similarity transformation `P*H*P'=A`. The result `H` is zero below the first subdiagonal and has the same eigenvalues as `A`.

Example

```
(P,H)=hess([1,2,3;4,5,6;7,8,9])
 P =
  1        0       0
  0       -0.4961 -0.8682
  0       -0.8682  0.4961
 H =
  1       -3.597  -0.2481
  -8.0623 14.0462  2.8308
  0        0.8308 -4.6154e-2
P*H*P'
ans =
  1        2       3
  4        5       6
  7        8       9
```

See also

`lu`, `qr`, `schur`

inv

Inverse of a square matrix.

Syntax

```
M2 = inv(M1)
```

Description

`inv(M1)` returns the inverse `M2` of the square matrix `M1`, i.e. a matrix of the same size such that `M2*M1 = M1*M2 = eye(size(M1))`. `M1` must not be singular; otherwise, its elements are infinite.

To solve a set of linear of equations, the operator \ is more efficient.

Example

```
inv([1,2;3,4])
  -2 1
  1.5 -0.5
```

See also

operator `/`, operator \, `pinv`, `lu`, `rank`, eye

kron

Kronecker product.

Syntax

```
M = kron(A, B)
```

Description

`kron(A,B)` returns the Kronecker product of matrices `A` (size m1 by n1) and `B` (size m2 by n2), i.e. an m1*m2-by-n1*n2 matrix made of m1 by n1 submatrices which are the products of each element of `A` with `B`.

Example

```
kron([1,2;3,4],ones(2))
  1  1  2  2
  1  1  2  2
  3  3  4  4
  3  3  4  4
```

See also

`repmat`

kurtosis

Kurtosis of a set of values.

Syntax

```
k = kurtosis(A)
k = kurtosis(A, dim)
```

Description

`kurtosis(A)` gives the kurtosis of the columns of array `A` or of the row vector `A`. The dimension along which `kurtosis` proceeds may be specified with a second argument.

The kurtosis measures how much values are far away from the mean. It is 3 for a normal distribution, and positive for a distribution which has more values far away from the mean.

Example

```
kurtosis(rand(1, 10000))
  1.8055
```

See also

`mean`, `var`, `skewness`, `moment`

linprog

Linear programming.

Syntax

```
x = linprog(c, A, b)
x = linprog(c, A, b, xlb, xub)
```

Description

`linprog(c,A,b)` solves the following linear programming problem:

$$\begin{aligned} &\min c\,x \\ \text{s.t. } Ax &\leq b \end{aligned}$$

The optimum x is either finite, infinite if there is no bounded solution, or not a number if there is no feasible solution.

Additional arguments may be used to constrain x between lower and upper bounds. `linprog(c,A,b,xlb,xub)` solves the following linear programming problem:

$$\begin{aligned} &\min c\,x \\ \text{s.t. } Ax &\leq b \\ x &\geq x_{\text{lb}} \\ x &\leq x_{\text{ub}} \end{aligned}$$

If `xub` is missing, there is no upper bound. `xlb` and `xub` may have less elements than `x`, or contain `-inf` or `+inf`; corresponding elements have no lower and/or upper bounds.

Examples

Maximize $3x + 2y$ subject to $x + y \leq 9$, $3x + y \leq 18$, $x \leq 7$, and $y \leq 6$:

```
c = [-3,-2];
A = [1,1; 3,1; 1,0; 0,1];
b = [9; 18; 7; 6];
x = linprog(c, A, b)
  x =
    4.5
    4.5
```

A more efficient way to solve the problem, with bounds on variables:

```
c = [-3,-2];
A = [1,1; 3,1];
b = [9; 18];
xlb = [];
xub = [7; 6];
```

```
x = linprog(c, A, b, xlb, xub)
  x =
    4.5
    4.5
```

Check that the solution is feasible and bounded:

```
all(isfinite(x))
  true
```

logm

Matrix logarithm.

Syntax

```
Y = logm(X)
(Y, err) = logm(X)
```

Description

`logm(X)` returns the matrix logarithm of `X`, the inverse of the matrix exponential. `X` must be square. The matrix logarithm does not always exist.

With a second output argument `err`, `logm` also returns an estimate of the relative error `norm(expm(logm(X))-X)/norm(X)`.

Example

```
Y = logm([1,2;3,4])
  Y =
   -0.3504 + 2.3911j  0.9294 - 1.0938j
     1.394 - 1.6406j  1.0436 + 0.7505j
expm(Y)
     1 - 5.5511e-16j  2 -7.7716e-16j
     3 - 8.3267e-16j  4
```

See also

`expm`, `sqrtm`, `funm`, `schur`, `log`

lu

LU decomposition.

Syntax

```
(L, U, P) = lu(A)
(L2, U) = lu(A)
Y = lu(A)
```

Description

With three output arguments, `lu(A)` computes the LU decomposition of matrix `A` with partial pivoting, i.e. a lower triangular matrix `L`, an upper triangular matrix `U`, and a permutation matrix `P` such that `P*A=L*U`. If `A` in an m-by-n mytrix, `L` is m-by-min(m,n), `U` is min(m,n)-by-n and `P` is m-by-m. `A` can be rank-deficient.

With two output arguments, `lu(A)` permutes the lower triangular matrix and gives `L2=P'*L`, such that `A=L2*U`.

With a single output argument, `lu` gives `Y=L+U-eye(n)`.

Example

```
X = [1,2,3;4,5,6;7,8,8];
(L,U,P) = lu(X)
L =
 1     0     0
 0.143 1     0
 0.571 0.5   1
U =
 7     8     8
 0     0.857 1.857
 0     0     0.5
P =
 0 0 1
 1 0 0
 0 1 0
P*X-L*U
ans =
 0 0 0
 0 0 0
 0 0 0
```

See also

`inv`, `qr`, `svd`

lyap

Continuous-time Lyapunov equation.

Syntax

```
X = lyap(A, B, C)
X = lyap(A, C)
```

Description

`lyap(A,B,C)` calculates the solution X of the following continuous-time Lyapunov equation:

$$AX + XB + C = 0$$

All matrices are real.

With two input arguments, `lyap(A,C)` solves the following Lyapunov equation:

$$AX + XA' + C = 0$$

Example

```
A = [3,1,2;1,3,5;6,2,1];
B = [2,7;8,3];
C = [2,1;4,5;8,9];
X = lyap(A, B, C)
  X =
    0.1635   -0.1244
   -0.2628    0.1311
   -0.7797   -0.7645
```

See also

`dlyap`, `care`

max

Maximum value of a vector or of two arguments.

Syntax

```
x = max(v)
(v,ind) = max(v)
v = max(M,[],dim)
(v,ind) = max(M,[],dim)
M3 = max(M1,M2)
```

Description

`max(v)` returns the largest number of vector `v`. NaN's are ignored. The optional second output argument is the index of the maximum in `v`; if several elements have the same maximum value, only the first one is obtained. The argument type can be double, single, or integer of any size.

`max(M)` operates on the columns of the matrix `M` and returns a row vector. `max(M,[],dim)` operates along dimension `dim` (1 for columns, 2 for rows).

`max(M1,M2)` returns a matrix whose elements are the maximum between the corresponding elements of the matrices `M1` and `M2`. `M1` and `M2` must have the same size, or be a scalar which can be compared against any matrix.

Examples

```
(mx,ix) = max([1,3,2,5,8,7])
  mx =
    8
  ix =
    5
max([1,3;5,nan], [], 2)
    3
    5
max([1,3;5,nan], 2)
    2 3
    5 2
```

See also

`min`

mean

Arithmetic mean of a vector.

Syntax

```
x = mean(v)
v = mean(M)
v = mean(M,dim)
```

Description

`mean(v)` returns the arithmetic mean of the elements of vector `v`. `mean(M)` returns a row vector whose elements are the means of the corresponding columns of matrix `M`. `mean(M,dim)` returns the mean of matrix `M` along dimension `dim`; the result is a row vector if `dim` is 1, or a column vector if `dim` is 2.

Examples

```
mean(1:5)
  7.5
mean((1:5)')
  7.5
mean([1,2,3;5,6,7])
  3 4 5
mean([1,2,3;5,6,7],1)
  3 4 5
mean([1,2,3;5,6,7],2)
  2
  6
```

See also

`cov`, `std`, `var`, `sum`, `prod`

min

Minimum value of a vector or of two arguments.

Syntax

```
x = min(v)
(v,ind) = min(v)
v = min(M,[],dim)
(v,ind) = min(M,[],dim)
M3 = min(M1,M2)
```

Description

`min(v)` returns the largest number of vector `v`. NaN's are ignored. The optional second smallest argument is the index of the minimum in `v`; if several elements have the same minimum value, only the first one is obtained. The argument type can be double, single, or integer of any size.

`min(M)` operates on the columns of the matrix `M` and returns a row vector. `min(M,[],dim)` operates along dimension `dim` (1 for columns, 2 for rows).

`min(M1,M2)` returns a matrix whose elements are the minimum between the corresponding elements of the matrices `M1` and `M2`. `M1` and

M2 must have the same size, or be a scalar which can be compared against any matrix.

Examples

```
(mx,ix) = min([1,3,2,5,8,7])
  mx =
    1
  ix =
    1
min([1,3;5,nan], [], 2)
    1
    5
min([1,3;5,nan], 2)
    1 2
    2 2
```

See also

max

moment

Central moment of a set of values.

Syntax

```
m = moment(A, order)
m = moment(A, order, dim)
```

Description

moment(A,order) gives the central moment (moment about the mean) of the specified order of the columns of array A or of the row vector A. The dimension along which moment proceeds may be specified with a third argument.

Example

```
moment(randn(1, 10000), 3)
  3.011
```

See also

mean, var, skewness, kurtosis

norm

Norm of a vector or matrix.

Syntax

```
x = norm(v)
x = norm(v,kind)
x = norm(M)
x = norm(M,kind)
```

Description

With one argument, `norm` calculates the 2-norm of a vector or the induced 2-norm of a matrix. The optional second argument specifies the kind of norm.

Kind	**Vector**	**Matrix**
none or 2	sqrt(sum(abs(v).^2))	largest singular value (induced 2-norm)
1	sum(abs(V))	largest column sum of abs
inf or 'inf'	max(abs(v))	largest row sum of abs
-inf	min(abs(v))	largest row sum of abs
p	sum(abs(V).^p)^(1/p)	invalid
'fro'	sqrt(sum(abs(v).^2))	sqrt(sum(diag(M'*M)))

Examples

```
norm([3,4])
  5
norm([2,5;9,3])
  10.2194
norm([2,5;9,3],1)
  11
```

See also

`abs`, `hypot`, `svd`

null

Null space.

Syntax

```
Z = null(A)
```

Description

`null(A)` returns a matrix `Z` whose columns are an orthonormal basis for the null space of m-by-n matrix `A`. `Z` has `n-rank(A)` columns, which are the last right singular values of `A` (that is, those corresponding to the negligible singular values).

Example

```
null([1,2,3;1,2,4;1,2,5])
  -0.8944
  0.4472
  8.0581e-17
```

See also

`svd`, `orth`

orth

Orthogonalization.

Syntax

```
Q = orth(A)
```

Description

`orth(A)` returns a matrix `Q` whose columns are an orthonormal basis for the range of those of matrix `A`. `Q` has `rank(A)` columns, which are the first left singular vectors of `A` (that is, those corresponding to the largest singular values).

Example

```
orth([1,2,3;1,2,4;1,2,5])
  -0.4609 0.788
  -0.5704 8.9369e-2
  -0.6798 -0.6092
```

See also

`svd`, `null`

pinv

Pseudo-inverse of a matrix.

Syntax

```
M2 = pinv(M1)
M2 = pinv(M1,e)
```

Description

`pinv(M1)` returns the pseudo-inverse of matrix `M`. For a nonsingular square matrix, the pseudo-inverse is the same as the inverse. For an arbitrary matrix (possibly nonsquare), the pseudo-inverse `M2` has the following properties: `size(M2) = size(M1')`, `M1*M2*M1 = M1`, `M2*M1*M2 = M2`, and the norm of `M2` is minimum. To pseudo-inverse is based on the singular-value decomposition, where only the singular values larger than some small threshold are considered. This threshold can be specified with an optional second argument.

If `M1` is a full-rank matrix with more rows than columns, `pinv` returns the least-square solution `pinv(M1)*y = (M1'*M1)\M1'*y` of the over-determined system `M1*x = y`.

Examples

```
pinv([1,2;3,4])
    -2    1
     1.5 -0.5
M2 = pinv([1;2])
  M2 =
    0.2 0.4
[1;2] * M2 * [1;2]
    1
    2
M2 * [1;2] * M2
    0.2 0.4
```

See also

`inv`, `svd`

poly

Characteristic polynomial of a square matrix or polynomial coefficients based on its roots.

Syntax

```
pol = poly(M)
pol = poly(r)
```

Description

With a matrix argument, `poly(M)` returns the characteristic polynomial `det(x*eye(size(M))-M)` of the square matrix `M`. The roots of the characteristic polynomial are the eigenvalues of `M`.

With a vector argument, `poly(r)` returns the polynomial whose roots are the elements of the vector `r`. The first coefficient of the polynomial is 1. If the complex roots form conjugate pairs, the result is real.

Examples

```
poly([1,2;3,4]
  1 -5 -2
roots(poly([1,2;3,4]))
  5.3723
 -0.3723
eig([1,2;3,4])
 -0.3723
  5.3723
poly(1:3)
  1 -6 11 -6
```

See also

`roots`, `det`

polyder

Derivative of a polynomial or a polynomial product or ratio.

Syntax

```
A1 = polyder(A)
C1 = polyder(A, B)
(N1, D1) = polyder(N, D)
```

Description

`polyder(A)` returns the polynomial which is the derivative of the polynomial `A`. Both polynomials are given as vectors of their coefficients, highest power first. The result is a row vector.

With a single output argument, `polyder(A,B)` returns the derivative of the product of polynomials `A` and `B`. It is equivalent to `polyder(conv(A,B))`.

With two output arguments, `(N1,D1)=polyder(N,D)` returns the derivative of the polynomial ratio `N/D` as `N1/D1`. Input and output arguments are polynomial coefficients.

Examples

Derivative of $x^3 + 2x^2 + 5x + 2$:

```
polyder([1, 2, 5, 2])
  3 4 5
```

Derivative of $(x^3 + 2x^2 + 5x + 2)/(2x + 3)$:

```
(N, D) = polyder([1, 2, 5, 2], [2, 3])
  N =
    4 13 12 11
  D =
    4 12  9
```

See also

`polyint`, `polyval`, `poly`, `addpol`, `conv`

polyint

Integral of a polynomial.

Syntax

```
pol2 = polyint(pol1)

pol2 = polyint(pol1, c)
```

Description

`polyint(pol1)` returns the polynomial which is the integral of the polynomial `pol1`, whose zero-order coefficient is 0. Both polynomials are given as vectors of their coefficients, highest power first. The result is a row vector. A second input argument can be used to specify the integration constant.

Example

```
Y = polyint([1, 2, 3, 4, 5])
  Y =
    0.2   0.5   1     2     5     0
y = polyder(Y)
  y =
    1     2     3     4     5
Y = polyint([1, 2, 3, 4, 5], 10)
  Y =
    0.2   0.5   1     2     5     10
```

See also

`polyder`, `polyval`, `poly`, `addpol`, `conv`

polyval

Numerical value of a polynomial evaluated at some point.

Syntax

```
y = polyval(pol, x)
```

Description

`polyval(pol,x)` evaluates the polynomial `pol` at `x`, which can be a scalar or a matrix of arbitrary size. The result has the same size as `x`.

Examples

```
polyval([1,3,8], 2)
  18
polyval([1,2], 1:5)
  3 4 5 6 7
```

See also

`polyder`, `polyint`, `poly`, `addpol`, `conv`

prod

Product of the elements of a vector.

Syntax

```
x = prod(v)
v = prod(M)
v = prod(M,dim)
```

Description

`prod(v)` returns the product of the elements of vector `v`. `prod(M)` returns a row vector whose elements are the products of the corresponding columns of matrix `M`. `prod(M,dim)` returns the product of matrix `M` along dimension `dim`; the result is a row vector if `dim` is 1, or a column vector if `dim` is 2.

Examples

```
prod(1:5)
  120
prod((1:5)')
  120
prod([1,2,3;5,6,7])
  5 12 21
prod([1,2,3;5,6,7],1)
  5 12 21
prod([1,2,3;5,6,7],2)
  6
  210
```

See also

`sum`, mean, operator `*`

qr

QR decomposition.

Syntax

```
(Q, R, E) = qr(A)
(Q, R) = qr(A)
(Qe, Re, e) = qr(A, false)
(Qe, Re) = qr(A, false)
```

Description

With three output arguments, `qr(A)` computes the QR decomposition of matrix `A` with column pivoting, i.e. a square unitary matrix `Q` and an upper triangular matrix `R` such that `A*E=Q*R`. With two output arguments, `qr(A)` computes the QR decomposition without pivoting, such that `A=Q*R`.

With a second input argument with the value `false`, if `A` has `m` rows and `n` columns with `m>n`, `qr` produces an m-by-n `Q` and an n-by-n `R`. Bottom rows of zeros of `R`, and the corresponding columns of `Q`, are discarded. With column pivoting, the third output argument `e` is a permutation vector: `A(:,e)=Q*R`.

Example

```
(Q,R) = qr([1,2;3,4;5,6])
Q =
   -0.169     0.8971   0.4082
   -0.5071    0.276   -0.8165
   -0.8452   -0.345    0.4082
R =
   -5.9161   -7.4374
         0    0.8281
         0         0
(Q,R) = qr([1,2;3,4;5,6],false)
  Q =
    0.169     0.8971
    0.5071    0.276
    0.8452   -0.345
  R =
    5.9161    7.4374
    0         0.8281
```

See also

`lu`, `schur`, `hess`, `svd`

rank

Rank of a matrix.

Syntax

```
x = rank(M)
x = rank(M,e)
```

Description

`rank(M)` returns the rank of matrix `M`, i.e. the number of lines or columns linearly independent. To obtain it, the singular values are computed and the number of values significantly larger than 0 is counted. The value below which they are considered to be 0 can be specified with the optional second argument.

Examples

```
rank([1,1;0,0])
 1
rank([1,1;0,1j])
 2
```

See also

`svd`, `cond`, `pinv`, `det`

roots

Roots of a polynomial.

Syntax

```
r = roots(pol)
r = roots(M)
r = roots(M,dim)
```

Description

`roots(pol)` calculates the roots of the polynomial `pol`. The polynomial is given by the vector of its coefficients, highest power first, while the result is a column vector.

With a matrix as argument, `roots(M)` calculates the roots of the polynomials corresponding to each column of `M`. An optional second argument is used to specify in which dimension `roots` operates (1 for columns, 2 for rows). The roots of the i:th polynomial are in the i:th column of the result, whatever the value of `dim` is.

Examples

```
roots([1, 0, -1])
  1
 -1
roots([1, 0, -1]’)
```

```
   1
  -1
 roots([1, 1; 0, 5; -1, 6])
   1 -2
  -1 -3
 roots([1, 0, -1]’, 2)
   []
```

See also

`poly`, `eig`

schur

Schur factorization.

Syntax

```
 (U,T) = schur(A)
 T = schur(A)
 (U,T) = schur(A, ’c’)
 T = schur(A, ’c’)
```

Description

`schur(A)` computes the Schur factorization of square matrix `A`, i.e. a unitary matrix `U` and a square matrix `T` (the *Schur matrix*) such that `A=U*T*U’`. If `A` is complex, the Schur matrix is upper triangular, and its diagonal contains the eigenvalues of `A`; if `A` is real, the Schur matrix is real upper triangular, except that there may be 2-by-2 blocks on the main diagonal which correspond to the complex eigenvalues of `A`. To force a complex Schur factorization with an upper triangular matrix `T`, `schur` is given a second input argument `’c’` or `’complex’`.

Example

```
 (U,T) = schur([1,2;3,4])
   U =
    -0.8246   -0.5658
     0.5658   -0.8246
   T =
    -0.3723   -1
          0    5.3723
 eig([1,2;3,4])
   ans =
    -0.3723
     5.3723
```

```
T = schur([1,0,0;0,1,2;0,-3,1])
  T =
     1     0     0
     0     1     2
     0    -3     1
T = schur([1,0,0;0,1,2;0,-3,1],'c')
  T =
     1             0             0
     0             1 + 2.4495j   1
     0             0             1 - 2.4495j
```

See also

`lu`, `hess`, `qr`, `eig`

skewness

Skewness of a set of values.

Syntax

```
s = skewness(A)
s = skewness(A, dim)
```

Description

`skewness(A)` gives the skewness of the columns of array `A` or of the row vector `A`. The dimension along which `skewness` proceeds may be specified with a second argument.

The skewness measures how asymmetric a distribution is. It is 0 for a symmetric distribution, and positive for a distribution which has more values much larger than the mean.

Example

```
skewness(randn(1, 10000).^2)
  2.6833
```

See also

`mean`, `var`, `kurtosis`, `moment`

sqrtm

Matrix square root.

Syntax

```
Y = sqrtm(X)
(Y, err) = sqrtm(X)
```

Description

`sqrtm(X)` returns the matrix square root of `X`, such that `sqrtm(X)^2=X`. `X` must be square. The matrix square root does not always exist.

With a second output argument `err`, `sqrtm` also returns an estimate of the relative error `norm(sqrtm(X)^2-X)/norm(X)`.

Example

```
Y = sqrtm([1,2;3,4])
  Y =
    0.5537 + 0.4644j   0.807 - 0.2124j
    1.2104 - 0.3186j  1.7641 + 0.1458j
Y^2
    1   2
    3   4
```

See also

`expm`, `logm`, `funm`, `schur`, `chol`, `sqrt`

std

Standard deviation.

Syntax

```
x = std(v)
x = std(v, p)
v = std(M)
v = std(M, p)
v = std(M, p, dim)
```

Description

`std(v)` gives the standard deviation of vector `v`, normalized by `length(v)-1`. With a second argument, `std(v,p)` normalizes by `length(v)-1` if `p` is true, or by `length(v)` if `p` is false.

`std(M)` gives a row vector which contains the standard deviation of the columns of `M`. With a third argument, `std(M,p,dim)` operates along dimension `dim`.

Example

```
std([1, 2, 5, 6, 10, 12])
  4.3359
```

See also

mean, var, cov

sum

Sum of the elements of a vector.

Syntax

```
x = sum(v)
v = sum(M)
v = sum(M,dim)
```

Description

`sum(v)` returns the sum of the elements of vector `v`. `sum(M)` returns a row vector whose elements are the sums of the corresponding columns of matrix `M`. `sum(M,dim)` returns the sum of matrix `M` along dimension `dim`; the result is a row vector if `dim` is `1`, or a column vector if `dim` is `2`.

Examples

```
sum(1:5)
  15
sum((1:5)')
  15
sum([1,2,3;5,6,7])
  6 8 10
sum([1,2,3;5,6,7],1)
  6 8 10
sum([1,2,3;5,6,7],2)
  6
  18
```

See also

prod, mean, operator +

svd

Singular value decomposition.

Syntax

```
s = svd(M)
(U,S,V) = svd(M)
(U,S,V) = svd(M,false)
```

Description

The singular value decomposition `(U,S,V) = svd(M)` decomposes the m-by-n matrix `M` such that `M = U*S*V'`, where `S` is an m-by-n diagonal matrix with decreasing positive diagonal elements (the singular values of `M`), `U` is an m-by-m unitary matrix, and `V` is an n-by-n unitary matrix. The number of non-zero diagonal elements of `S` (up to rounding errors) gives the rank of `M`.

When `M` is rectangular, in expression `U*S*V'`, some columns of `U` or `V` are multiplied by rows or columns of zeros in `S`, respectively. `(U,S,V) = svd(M,false)` produces `U`, `S` and `V` where these columns or rows are discarded (relationship `M = U*S*V'` still holds):

Size of `A`	**Size of** `U`	**Size of** `S`	**Size of** `V`
m by n, m <= n	m by m	m by m	n by m
m by n, m > n	m by n	n by n	n by n

`svd(M,true)` produces the same result as `svd(M)`.

With one output argument, `s = svd(M)` returns the vector of singular values `s=diag(S)`.

The singular values of `M` can also be computed with `s = sqrt(eig(M'*M))`, but `svd` is faster and more robust.

Examples

```
(U,S,V)=svd([1,2;3,4])
 U =
  0.4046 0.9145
  0.9145 -0.4046
 S =
  5.465 0
  0 0.366
 V =
  0.576 -0.8174
  0.8174 0.576
U*S*V'
  1 2
  3 4
 svd([1,2;1,2])
   3.1623
   3.4697e-19
```

See also

`eig`, `pinv`, `rank`, `cond`, `norm`

trace

Trace of a matrix.

Syntax

```
 tr = trace(M)
```

Description

`trace(M)` returns the trace of the matrix `M`, i.e. the sum of its diagonal elements.

Example

```
 trace([1,2;3,4])
   5
```

See also

`norm`, `diag`

var

Variance of a set of values.

Syntax

```
 s2 = var(A)
 s2 = var(A, p)
 s2 = var(A, p, dim)
```

Description

`var(A)` gives the variance of the columns of array `A` or of the row vector `A`. The variance is normalized with the number of observations minus 1, or by the number of observations if a second argument is true. The dimension along which `var` proceeds may be specified with a third argument.

See also

`mean`, `std`, `cov`, `kurtosis`, `skewness`, `moment`

3.15 Array Functions

cat

Array concatenation.

Syntax

```
 cat(dim, A1, A2, ...)
```

Description

`cat(dim,A1,A2,...)` concatenates arrays `A1`, `A2`, etc. along dimension `dim`. Other dimensions must match. `cat` is a generalization of the comma and the semicolon inside brackets.

Examples

```
 cat(2, [1,2;3,4], [5,6;7,8])
   1  2  5  6
   3  4  7  8
 cat(3, [1,2;3,4], [5,6;7,8])
   2x2x2 array
     (:,:,1) =
       1  2
       3  4
     (:,:,2) =
       5  6
       7  8
```

See also

operator `[]`, operator `;`, operator `,`

cell

Cell array of empty arrays.

Syntax

```
C = cell(n)
C = cell(n1,n2,...)
C = cell([n1,n2,...])
```

Description

`cell` builds a cell array whose elements are empty arrays `[]`. The size of the cell array is specified by one integer for a square array, or several integers (either as separate arguments or in a vector) for a cell array of any size.

Example

```
cell(2, 3)
  2x3 cell array
```

See also

`zeros`, operator `{}`, `iscell`

cellfun

Function evaluation for each cell of a cell array.

Syntax

```
A = cellfun(fun, C)
A = cell(fun, C, ...)
```

Description

`cellfun(fun,C)` evaluates function `fun` for each cell of cell array `C`. Each evaluation must give a scalar result of numeric, logical, or character type; results are returned as a non-cell array the same size as `C`. First argument is a function reference, an inline function, or the name of a function as a string.

With more than two input arguments, `cellfun` calls function `fun` as `feval(fun,C{i},other)`, where `C{i}` is each cell of `C` in turn, and `other` stands for the remaining arguments of `cellfun`.

`cellfun` differs from `map` in two ways: the result is a non-cell array, and remaining arguments of `cellfun` are provided directly to `fun`.

Examples

```
cellfun(@isempty, {1, ''; {}, ones(5)})
  F T
  T F
map(@isempty, {1, ''; {}, ones(5)})
  2x2 cell array
cellfun(@size, {1, ''; {}, ones(5)}, 2)
  1 0
  0 5
```

See also

`map`

diag

Creation of a diagonal matrix or extraction of the diagonal elements of a matrix.

Syntax

```
M = diag(v)
M = diag(v,k)
v = diag(M)
v = diag(M,k)
```

Description

With a vector input argument, `diag(v)` creates a square diagonal matrix whose main diagonal is given by `v`. With a second argument, the diagonal is moved by that amount in the upper right direction for positive values, and in the lower left direction for negative values.

With a matrix input argument, the main diagonal is extracted and returned as a column vector. A second argument can be used to specify another diagonal.

Examples

```
diag(1:3)
  1 0 0
  0 2 0
  0 0 3
```

```
diag(1:3,1)
  0 1 0 0
  0 0 2 0
  0 0 0 3
  0 0 0 0
M = magic(3)
M =
  8 1 6
  3 5 7
  4 9 2
diag(M)
  8
  5
  2
diag(M,1)
  1
  7
```

See also

`tril`, `triu`, eye, `trace`

eye

Identity matrix.

Syntax

```
M = eye(n)
M = eye(m,n)
M = eye([m,n])
M = eye(..., type)
```

Description

eye builds a matrix whose diagonal elements are 1 and other elements 0. The size of the matrix is specified by one integer for a square matrix, or two integers (either as two arguments or in a vector of two elements) for a rectangular matrix.

An additional input argument can be used to specify the type of the result. It must be the string `’double’`, `’single’`, `’int8’`, `’int16’`, `’int32’`, `’int64’`, `’uint8’`, `’uint16’`, `’uint32’`, or `’uint64’` (64-bit arrays are not supported on all platforms).

Examples

```
eye(3)
  1 0 0
  0 1 0
  0 0 1
eye(2, 3)
  1 0 0
  0 1 0
eye(2, 'int8')
  2x2 int8 array
    1 0
    0 1
```

See also

`ones`, `zeros`, `diag`

find

Find the indices of the non-null elements of an array.

Syntax

```
ix = find(v)
[s1,s2] = find(M)
[s1,s2,x] = find(M)
... = find(..., n)
... = find(..., n, dir)
```

Description

With one output argument, `find(v)` returns a vector containing the indices of the nonzero elements of `v`. `v` can be an array of any dimension; the indices correspond to the internal storage ordering and can be used to access the elements with a single subscript.

With two output arguments, `find(M)` returns two vectors containing the subscripts (row in the first output argument, column in the second output argument) of the nonzero elements of 2-dim array `M`. To obtain subscripts for an array of higher dimension, you can convert the single output argument of `find` to subscripts with `ind2sub`.

With three output arguments, `find(M)` returns in addition the nonzero values themselves in the third output argument.

With a second input argument `n`, `find` limits the maximum number of elements found. It searches forward by default; with a third input argument `dir`, `find` gives the `n` first nonzero values if `dir` is `'first'` or `'f'`, and the `n` last nonzero values if `dir` is `'last'` or `'l'`.

Examples

```
ix = find([1.2,0;0,3.6])
ix =
  1
  4
[s1,s2] = find([1.2,0;0,3.6])
s1 =
  1
  2
s2 =
  1
  2
[s1,s2,x] = find([1.2,0;0,3.6])
s1 =
  1
  2
s2 =
  1
  2
x =
  1.2
  3.6
A = rand(3)
  A =
    0.5599    0.3074    0.5275
    0.3309    0.8077    0.3666
    0.7981    0.6424    0.6023
find(A > 0.7, 2, 'last')
  7
  5
```

See also

`nnz`, `sort`

flipdim

Flip an array along any dimension.

Syntax

```
B = flipdim(A, dim)
```

Description

`flipdim(A,dim)` gives an array which has the same size as `A`, but where indices of dimension `dim` are reversed.

Examples

```
flipdim(cat(3, [1,2;3,4], [5,6;7,8]), 3)
  2x2x2 array
    (:,:,1) =
      5  6
      7  8
  (:,:,2) =
      1  2
      3  4
```

See also

`fliplr`, `flipud`, `rot90`, `reshape`

fliplr

Flip an array or a list around its vertical axis.

Syntax

```
A2 = fliplr(A1)
list2 = fliplr(list1)
```

Description

`fliplr(A1)` gives an array `A2` which has the same size as `A1`, but where all columns are placed in reverse order.

`fliplr(list1)` gives a list `list2` which has the same length as `list1`, but where all top-level elements are placed in reverse order. Elements themselves are left unchanged.

Examples

```
fliplr([1,2;3,4])
  2 1
  4 3
fliplr({1, 'x', {1,2,3}})
  {{1,2,3}, 'x', 1}
```

See also

`flipud`, `flipdim`, `rot90`, `reshape`

flipud

Flip an array upside-down.

Syntax

```
A2 = flipud(A1)
```

Description

`flipud(A1)` gives an array `A2` which has the same size as `A1`, but where all lines are placed in reverse order.

Example

```
flipud([1,2;3,4])
  3 4
  1 2
```

See also

`fliplr`, `flipdim`, `rot90`, `reshape`

ind2sub

Conversion from single index to row/column subscripts.

Syntax

```
(i, j, ...) = ind2sub(size, ind)
```

Description

`ind2sub(size,ind)` gives the subscripts of the element which would be retrieved from an array whose size is specified by `size` by the single index `ind`. `size` must be either a scalar for square matrices or a vector of two elements or more for arrays. `ind` can be an array; the result is calculated separately for each element and has the same size.

Example

```
M = [3, 6; 8, 9];
M(3)
  8
(i, j) = ind2sub(size(M), 3)
  i =
    2
  j =
    1
M(i, j)
  8
```

See also

`sub2ind`, `size`

interp1

1D interpolation.

Syntax

```
yi = interp1(x, y, xi)
yi = interp1(x, y, xi, xi, method)
yi = interp1(y, xi, xi)
yi = interp1(y, xi, xi, method)
yi = interp1(..., method, extraval)
```

Description

`interp1(x,y,xi)` interpolates data along one dimension. Input data are defined by vector `y`, where element `y(i)` corresponds to coordinates `x(i)`. Interpolation is performed at points defined in vector `xi`; the result is a vector of the same site as `xi`.

If `y` is an array, interpolation is performed along dimension 1 (i.e. along its columns), and `size(y,1)` must be equal to `length(x)`. Then if `xi` is a vector, interpolation is performed at the same points for each remaining dimensions of `y`, and the result is an array of size `[length(xi),size(y)(2:end)]`; if `xi` is an array, all sizes must match `y` except for the first one.

The default interpolation method is linear. An additional input argument can be provided to specify it with a string (only the first character is considered):

Argument	**Meaning**
`'0'` or `'nearest'`	nearest value
`'<'`	lower coordinate
`'>'`	higher coordinate
`'1'` or `'linear'`	linear

With vectors, `interp1` produces the same result as `interpn`; vector orientations do not have to match, though.

When the method is followed by a scalar number `extraval`, that value is assigned to all values outside the range defined by `x` (i.e. extrapolated values). The default is NaN.

Examples

One-dimension interpolation:

```
interp1([1, 2, 5, 8], [0.1, 0.2, 0.5, 1], [0, 2, 3, 7])
  nan   0.2000   0.3000   0.8333
interp1([1, 2, 5, 8], [0.1, 0.2, 0.5, 1], [0, 2, 3, 7], '0')
  nan   0.2000   0.2000   1.0000
```

Interpolation of multiple values:

```
t = 0:10;
y = [sin(t'), cos(t')];
tnew = 0:0.4:8;
ynew = interp1(t, y, tnew)
  ynew =
    0.0000  1.0000
    0.3366  0.8161
    ...
    0.8564  0.2143
    0.9894 -0.1455
```

See also

interpn

interpn

Multidimensional interpolation.

Syntax

```
Vi = interpn(x1, ..., xn, V, xi1, ..., xin)
Vi = interpn(x1, ..., xn, V, xi1, ..., xin, method)
Vi = interpn(..., method, extraval)
```

Description

interpn(x1,...,xn,V,xi1,...,xin) interpolates data in a space of n dimensions. Input data are defined by array V, where element V(i,j,...) corresponds to coordinates x1(i), x2(j), etc. Interpolation is performed for each coordinates defined by arrays xi1, xi2, etc., which must all have the same size; the result is an array of the same size.

Length of vectors x1, x2, ... must match the size of V along the corresponding dimension. Vectors x1, x2, ... must be sorted (monotonically increasing or decreasing), but they do not have to be spaced uniformly. Interpolated points outside the input volume are set to nan. Input and output data can be complex. Imaginary parts of coordinates are ignored.

The default interpolation method is multilinear. An additional input argument can be provided to specify it with a string (only the first character is considered):

Argument	**Meaning**
`'0'` or `'nearest'`	nearest value
`'<'`	lower coordinates
`'>'`	higher coordinates
`'1'` or `'linear'`	multilinear

Method `'<'` takes the sample where each coordinate has its index as large as possible, lower or equal to the interpolated value, and smaller than the last coordinate. Method `'>'` takes the sample where each coordinate has its index greater or equal to the interpolated value.

When the method is followed by a scalar number `extraval`, that value is assigned to all values outside the input volume (i.e. extrapolated values). The default is NaN.

Examples

One-dimension interpolation:

```
interpn([1, 2, 5, 8], [0.1, 0.2, 0.5, 1], [0, 2, 3, 7])
  nan   0.2000   0.3000   0.8333
interpn([1, 2, 5, 8], [0.1, 0.2, 0.5, 1], [0, 2, 3, 7], '0')
  nan   0.2000   0.2000   1.0000
```

Three-dimension interpolation:

```
D = cat(3,[0,1;2,3],[4,5;6,7]);
interpn([0,1], [0,1], [0,1], D, 0.2, 0.7, 0.5)
  3.1000
```

Image rotation (we define original coordinates between -0.5 and 0.5 in vector c and arrays X and Y, and the image as a linear gradient between 0 and 1):

```
c = -0.5:0.01:0.5;
X = repmat(c, 101, 1);
Y = X';
phi = 0.2;
Xi = cos(phi) * X - sin(phi) * Y;
Yi = sin(phi) * X + cos(phi) * Y;
D = 0.5 + X;
E = interpn(c, c, D, Xi, Yi);
E(isnan(E)) = 0.5;
```

See also

`interp1`

intersect

Set intersection.

Syntax

```
c = intersect(a, b)
(c, ia, ib) = intersect(a, b)
```

Description

`intersect(a,b)` gives the intersection of sets a and b, i.e. it gives the set of members of both sets a and b. Sets are any type of numerical, character or logical arrays, or lists or cell arrays of character strings. Multiple elements of input arguments are considered as single members; the result is always sorted and has unique elements.

The optional second and third output arguments are vectors of indices such that if `(c,ia,ib)=intersect(a,b)`, then c is `a(ia)` as well as `b(ib)`.

Example

```
a = {'a','bc','bbb','de'};
b = {'z','bc','aa','bbb'};
(c, ia, ib) = intersect(a, b)
  c =
    {'bbb','bc'}
  ia =
    3 2
  ib =
    4 2
a(ia)
  {'bbb','bc'}
b(ib)
  {'bbb','bc'}
```

Set exclusive or can also be computed as the union of a and b minus the intersection of a and b:

```
setdiff(union(a, b), intersect(a, b))
  {'a','aa','de','z'}
```

See also

`unique`, `union`, `setdiff`, `setxor`, `ismember`

ipermute

Inverse permutation of the dimensions of an array.

Syntax

```
B = ipermute(A, perm)
```

Description

`ipermute(A,perm)` returns an array with the same elements as `A`, but where dimensions are permuted according to the vector of dimensions `perm`. It performs the inverse permutation of `permute`. `perm` must contain integers from `1` to `n`; dimension `i` in `A` becomes dimension `perm(i)` in the result.

Example

```
size(ipermute(rand(3,4,5), [2,3,1]))
  5 3 4
```

See also

`permute`, `ndims`, `squeeze`

isempty

Test for empty matrices or empty lists.

Syntax

```
b = isempty(M)
b = isempty(list)
```

Description

`isempty(obj)` gives true if `obj` is the empty array `[]`, the empty string `''`, or the empty list `{}`, and false otherwise.

Examples

```
isempty([])
  true
isempty(0)
  false
isempty('')
```

```
  true
isempty({})
  true
isempty({{}})
  false
```

See also

`size`, `length`

iscell

Test for cell arrays.

Syntax

```
b = iscell(X)
```

Description

`iscell(X)` gives true if `X` is a cell array or a list, and false otherwise.

Examples

```
iscell({1;2})
  true
iscell({1,2})
  true
islist({1;2})
  false
```

See also

`islist`

ismember

Test for set membership.

Syntax

```
b = ismember(m, s)
```

Description

`ismember(m,s)` tests if elements of array `m` are members of set `s`. The result is a logical array the same size as `m`; each element is `true` if the corresponding element of `m` is a member of `s`, or false otherwise. `m` must be a numerical array or a cell array, matching type of set `s`.

Example

```
s = {'a','bc','bbb','de'};
m = {'d','a','x';'de','a','z'};
b = ismember(m, s)
  b =
    F T F
    T T F
```

See also

`intersect`, `union`, `setdiff`, `setxor`

length

Length of a vector or a list.

Syntax

```
n = length(v)
n = length(list)
```

Description

`length(v)` gives the length of vector `v`. `length(A)` gives the number of elements along the largest dimension of array `A`. `length(list)` gives the number of elements in a list.

Examples

```
length(1:5)
  5
length((1:5)')
  5
length(ones(2,3))
  3
length({1, 1:6, 'abc'})
  3
length({{}})
  1
```

See also

`size`, `numel`, `end`

magic

Magic square.

Syntax

```
M = magic(n)
```

Description

A magic square is a square array of size n-by-n which contains each integer between 1 and n^2, and whose sum of each column and of each line is equal. `magic(n)` returns magic square of size n-by-n.

There is no 2-by-2 magic square. If the size is 2, the matrix [1,3;4,2] is returned instead.

Example

```
magic(3)
  8 1 6
  3 5 7
  4 9 2
```

See also

`zeros`, `ones`, `eye`, `rand`, `randn`

meshgrid

Arrays of X-Y coordinates.

Syntax

```
(X, Y) = meshgrid(x, y)
(X, Y) = meshgrid(x)
```

Description

`meshgrid(x,y)` produces two arrays of `x` and `y` coordinates suitable for the evaluation of a function of two variables. The input argument `x` is copied to the rows of the first output argument, and the input argument `y` is copied to the columns of the second output argument, so that both arrays have the same size. `meshgrid(x)` is equivalent to `meshgrid(x,x)`.

Example

```
(X, Y) = meshgrid(1:5, 2:4)
  X =
    1  2  3  4  5
    1  2  3  4  5
    1  2  3  4  5
  Y =
    2  2  2  2  2
    3  3  3  3  3
    4  4  4  4  4
Z = atan2(X, Y)
  Z =
    0.4636    0.7854    0.9828    1.1071    1.1903
    0.3218    0.5880    0.7854    0.9273    1.0304
    0.2450    0.4636    0.6435    0.7854    0.8961
```

See also

`ndgrid`, `repmat`

ndgrid

Arrays of N-dimension coordinates.

Syntax

```
(X1, ..., Xn) = ndgrid(x1, ..., xn)
(X1, ..., Xn) = ndgrid(x)
```

Description

`ndgrid(x1,...,xn)` produces `n` arrays of `n` dimensions. Array `i` is obtained by reshaping input argument `i` as a vector along dimension `i` and replicating it along all other dimensions to match the length of other input vectors. All output arguments have the same size.

With one input argument, `ndgrid` reuses it to match the number of output arguments.

`(Y,X)=ndgrid(y,x)` is equivalent to `(X,Y)=meshgrid(x,y)`.

Example

```
(X1, X2) = ndgrid(1:3)
  X1 =
    1   1   1
    2   2   2
    3   3   3
  X2 =
    1   2   3
    1   2   3
    1   2   3
```

See also

`meshgrid`, `repmat`

ndims

Number of dimensions of an array.

Syntax

```
n = ndims(A)
```

Description

`ndims(A)` returns the number of dimensions of array `A`, which is at least 2. Scalars, row and column vectors, and matrices have 2 dimensions.

Examples

```
ndims(magic(3))
  2
ndims(rand(3,4,5))
  3
```

See also

`size`, `squeeze`, `permute`, `ipermute`

nnz

Number of nonzero elements.

Syntax

```
n = nnz(A)
```

Description

`nnz(A)` returns the number of nonzero elements of array `A`.

See also

`find`

num2cell

Conversion from numeric array to cell array.

Syntax

```
C = num2cell(A)
C = num2cell(A, dims)
```

Description

`num2cell(A)` creates a cell array the same size as numeric array `A`. The value of each cell is the corresponding elements of `A`.

`num2cell(A,dims)` cuts array `A` along dimensions `dims` and creates a cell array with the result. Dimensions of cell array are the same as dimensions of `A` for dimensions not in `dims`, and `1` for dimensions in `dims`; dimensions of cells are the same as dimensions of `A` for dimensions in `dims`, and `1` for dimensions not in `dims`.

Argument `A` can be a numerical array of any dimension and class, a logical array, or a char array.

Examples

```
num2cell([1, 2; 3, 4])
  {1, 2; 3, 4}
num2cell([1, 2; 3, 4], 1)
  {[1; 3], [2; 4]}
num2cell([1, 2; 3, 4], 2)
  {[1, 2]; [3, 4]}
```

See also

`num2list`, `permute`

numel

Number of elements of an array.

Syntax

```
n = numel(A)
```

Description

`numel(A)` gives the number of elements of array `A`. It is equivalent to `prod(size(A))`.

Examples

```
numel(1:5)
  5
numel(ones(2, 3))
  6
numel({1, 1:6; ’abc’, []})
  4
numel({2, ’vwxyz’})
  2
```

See also

`size`, `length`

ones

Array of ones.

Syntax

```
A = ones(n)
A = ones(n1, n2, ...)
A = ones([n1, n2, ...])
A = ones(..., type)
```

Description

`ones` builds an array whose elements are 1. The size of the array is specified by one integer for a square matrix, or several integers (either as separate arguments or in a vector) for an array of any size.

An additional input argument can be used to specify the type of the result. It must be the string `’double’`, `’single’`, `’int8’`, `’int16’`, 'int32', 'int64', 'uint8', 'uint16', 'uint32', or 'uint64' (64-bit arrays are not supported on all platforms).

Example

```
ones(2,3)
  1 1 1
  1 1 1
ones(2, 'int32')
  2x2 int32 array
    1 1
    1 1
```

See also

`zeros`, `eye`, `rand`, `randn`, `repmat`

permute

Permutation of the dimensions of an array.

Syntax

```
B = permute(A, perm)
```

Description

`permute(A,perm)` returns an array with the same elements as `A`, but where dimensions are permuted according to the vector of dimensions `perm`. It is a generalization of the matrix transpose operator. `perm` must contain integers from `1` to `n`; dimension `perm(i)` in `A` becomes dimension `i` in the result.

Example

```
size(permute(rand(3,4,5), [2,3,1]))
  4 5 3
```

See also

`ndims`, `squeeze`, `ipermute`, `num2cell`

rand

Uniformly-distributed random number.

Syntax

```
x = rand
M = rand(n)
M = rand(n1, n2, ...)
M = rand([n1, n2, ...])
rand('seed', s);
```

Description

`rand` builds a scalar pseudo-random number uniformly distributed between 0 and 1. The lower bound 0 may be reached, but the upper bound 1 is never. The current implementation is based on a scalar 64-bit seed, which theoretically allows 2ˆ64 different numbers. This seed can be set with the arguments `rand('seed', s)`, where `s` is a scalar or a vector of two components. `rand('seed', s)` returns the empty array [] as output argument. To discard it, the statement should be followed by a semicolon.

`rand(n)`, `rand(n1,n2,...)` and `rand([n1,n2,...])` return an n-by-n square matrix or an array of arbitrary size whose elements are pseudo-random numbers uniformly distributed between 0 and 1.

Examples

```
rand
  0.2361
rand(1, 3)
  0.6679 0.8195 0.2786
rand('seed',0);
rand
  0.2361
```

See also

`randn`

randn

Normally-distributed random number

Syntax

```
x = randn
M = randn(n)
M = randn(n1, n2, ...)
M = randn([n1, n2, ...])
randn('seed', s);
```

Description

randn builds a scalar pseudo-random number chosen from a normal distribution with zero mean and unit variance. The current implementation is based on a scalar 64-bit seed, which theoretically allows 2ˆ64 different numbers. This seed can be set with the arguments `randn('seed', s)`, where s is a scalar or a vector of two components. The seed is not the same as the seed of rand. `randn('seed', s)` returns the empty array [] as output argument. To discard it, the statement should be followed by a semicolon.

`randn(n)`, `randn(n1,n2,...)` and `randn([n1,n2,...])` return an n-by-n square matrix or an array of arbitrary size whose elements are pseudo-random numbers chosen from a normal distribution.

Examples

```
randn
  1.5927
randn(1, 3)
  0.7856 0.6489 -0.8141
randn('seed',0);
randn
  1.5927
```

See also

rand

repmat

Replicate an array.

Syntax

```
A2 = repmat(A1, n)
A2 = repmat(A1, m, n)
A2 = repmat(A1, [n1,...])
```

Description

`repmat` creates an array with multiple copies of its first argument. It can be seen as an extended version of `ones`, where `1` is replaced by an arbitrary array. The number of copies is `m` in the vertical direction, and `n` in the horizontal direction. The type of the first argument (number, character or logical value) is preserved. With a vector as second argument, the array can be replicated along more than two dimensions.

Examples

```
repmat([1,2;3,4],1,2)
  1 2 1 2
  3 4 3 4
repmat('abc',3)
  abcabcabc
  abcabcabc
  abcabcabc
```

See also

`zeros`, `ones`, operator `:`, `kron`, `replist`

reshape

Rearrange the elements of an array to change its shape.

Syntax

```
A2 = reshape(A1)
A2 = reshape(A1, n1, n2, ...)
A2 = reshape(A1, [n1, n2, ...])
```

Description

`reshape(A1)` gives a column vector with all the elements of array `A1`, which is read row-wise. If `A1` is a variable, `reshape(A1)` is the same as `A1(:)`.

`reshape(A1,n1,n2,...)` or `reshape(A1,[n1,n2,...])` changes the dimensions of array `A1` so that the result has `m` rows and `n` columns. `A1` must have `n1*n2*...` elements; read line-wise, both `A1` and the result have the same elements.

When dimensions are given as separate elements, one of them can be replaced with the empty array `[]`; it is replaced by the value such that the number of elements of the result matches the size of input array.

Example

```
reshape([1,2,3;10,20,30], 3, 2)
  1  2
  3  10
  20 30
reshape(1:12, 3, [])
  1  2  3  4
```

```
   5  6  7  8
   9 10 11 12
```

See also

operator ()

rot90

Array rotation.

Syntax

```
A2 = rot90(A1)
A2 = rot90(A1, k)
```

Description

`rot90(A1)` rotates array `A1` 90 degrees counter-clockwise; the top left element of `A1` becomes the bottom left element of `A2`. If `A1` is an array with more than two dimensions, each plane corresponding to the first two dimensions is rotated.

In `rot90(A1,k)`, the second argument is the number of times the array is rotated 90 degrees counter-clockwise. With `k = 2`, the array is rotated by 180 degrees; with `k = 3` or `k = -1`, the array is rotated by 90 degrees clockwise.

Examples

```
rot90([1,2,3;4,5,6])
  3 6
  2 5
  1 4
rot90([1,2,3;4,5,6], -1)
  4 1
  5 2
  6 3
rot90([1,2,3;4,5,6], -1)
  6 5 4
  3 2 1
fliplr(flipud([1,2,3;4,5,6]))
  6 5 4
  3 2 1
```

See also

`fliplr`, `flipud`, `reshape`

setdiff

Set difference.

Syntax

```
c = setdiff(a, b)
(c, ia) = setdiff(a, b)
```

Description

setdiff(a,b) gives the difference between sets a and b, i.e. the set of members of set a which do not belong to b. Sets are any type of numerical, character or logical arrays, or lists or cell arrays of character strings. Multiple elements of input arguments are considered as single members; the result is always sorted and has unique elements.

The optional second output argument is a vector of indices such that if (c,ia)=setdiff(a,b), then c is a(ia).

Example

```
a = {'a','bc','bbb','de'};
b = {'z','bc','aa','bbb'};
(c, ia) = setdiff(a, b)
  c =
    {'a','de'}
  ia =
    1 4
a(ia)
  {'a','de'}
```

See also

unique, union, intersect, setxor, ismember

setxor

Set exclusive or.

Syntax

```
c = setxor(a, b)
(c, ia, ib) = setxor(a, b)
```

Description

`setxor(a,b)` performs an exclusive or operation between sets a and b, i.e. it gives the set of members of sets a and b which are not members of the intersection of a and b. Sets are any type of numerical, character or logical arrays, or lists or cell arrays of character strings. Multiple elements of input arguments are considered as single members; the result is always sorted and has unique elements.

The optional second and third output arguments are vectors of indices such that if `(c,ia,ib)=setxor(a,b)`, then `c` is the union of `a(ia)` and `b(ib)`.

Example

```
a = {'a','bc','bbb','de'};
b = {'z','bc','aa','bbb'};
(c, ia, ib) = setxor(a, b)
  c =
    {'a','aa','de','z'}
  ia =
    1 4
  ib =
    3 1
union(a(ia),b(ib))
  {'a','aa','de','z'}
```

Set exclusive or can also be computed as the union of a and b minus the intersection of a and b:

```
setdiff(union(a, b), intersect(a, b))
  {'a','aa','de','z'}
```

See also

`unique`, `union`, `intersect`, `setdiff`, `ismember`

size

Size of an array.

Syntax

```
v = size(A)
(m, n) = size(A)
m = size(A, i)
```

Description

`size(A)` returns the number of rows and the number of elements along each dimension of array `A`, either in a row vector or as scalars if there are two output arguments or more.

`size(A,i)` gives the number of elements in array `A` along dimension `i`: `size(A,1)` gives the number of rows and `size(A,2)` the number of columns.

Examples

```
M = ones(3, 5);
size(M)
  3 5
(m, n) = size(M)
  m =
    3
  n =
    5
size(M, 1)
  3
size(M, 2)
  5
```

See also

`length`, `numel`, `ndims`, `end`

sort

Array sort.

Syntax

```
(A_sorted, ix) = sort(A)
(A_sorted, ix) = sort(A, dim)
(A_sorted, ix) = sort(A, dir)
(A_sorted, ix) = sort(A, dim, dir)
(list_sorted, ix) = sort(list)
(list_sorted, ix) = sort(list, dir)
```

Description

`sort(A)` sorts separately the elements of each column of array `A`, or the elements of `A` if it is a row vector. The result has the same size as `A`. Elements are sorted in ascending order, with NaNs at the end. For complex arrays, numbers are sorted by magnitude.

The optional second output argument gives the permutation array which transforms `A` into the sorted array. It can be used to reorder elements in another array or to sort the rows of a matrix with respect to one of its columns, as shown in the last example below. Order of consecutive identical elements is preserved.

If a second numeric argument `dim` is provided, the sort is performed along dimension `dim` (columns if `dim` is 1, rows if 2, etc.)

An additional argument can specify the ordering direction. It must be the string `'ascending'` (or `'a'`) for ascending order, or `'descending'` (or `'d'`) for descending order. In both cases, NaNs are moved to the end.

`sort(list)` sorts the elements of a list, which must be strings. Cell arrays are sorted like lists, not column-wise like numeric arrays. The second output argument is a row vector. The direction can be specified with a second input argument.

Examples

```
sort([3,6,2,3,9,1,2])
  1 2 2 3 3 6 9
sort([2,5,3;nan,4,2;6,1,1])
  2   1   1
  6   4   2
  nan 5   3
sort([2,5,3;nan,4,2;6,1,1], 'd')
  6   5   3
  2   4   2
  nan 1   1
sort({'def', 'abcd', 'abc'})
  {'abc', 'abcd', 'def'}
```

To sort the rows of an array after the first column, one can obtain the permutation vector by sorting the first column, and use it as subscripts on the array rows:

```
M = [2,4; 5,1; 3,9; 4,0]
  2 4
  5 1
  3 9
  4 0
(Ms, ix) = sort(M(:,1));
M(ix,:)
  2 4
  3 9
  4 0
  5 1
```

Algorithm

Shell sort.

See also

`unique`

squeeze

Suppression of singleton dimensions of an array.

Syntax

```
B = squeeze(A)
```

Description

`squeeze(A)` returns an array with the same elements as `A`, but where dimensions equal to 1 are removed. The result has at least 2 dimensions; row and column vectors keep their dimensions.

Examples

```
size(squeeze(rand(1,2,3,1,4)))
  2 3 4
size(squeeze(1:5))
  1 5
```

See also

`permute`, `ndims`

sub2ind

Conversion from row/column subscripts to single index.

Syntax

```
ind = sub2ind(size, i, j)
```

Description

`sub2ind(size,i,j)` gives the single index which can be used to retrieve the element corresponding to the `i`:th row and the `j`:th column of an array whose size is specified by `size`. `size` must be either a scalar for square matrices or a vector of two elements or more for other arrays. If `i` and `j` are arrays, they must have the same size: the result is calculated separately for each element and has the same size.

Example

```
M = [3, 6; 8, 9];
M(2, 1)
  8
sub2ind(size(M), 2, 1)
  7
M(3)
  8
```

See also

`ind2sub`, `size`

tril

Extraction of the lower triangular part of a matrix.

Syntax

```
L = tril(M)
L = tril(M,k)
```

Description

`tril(M)` extracts the lower triangular part of a matrix; the result is a matrix of the same size where all the elements above the main diagonal are set to zero. A second argument can be used to specify another diagonal: 0 is the main diagonal, positive values are above and negative values below.

Examples

```
M = magic(3)
M =
  8 1 6
```

```
   3 5 7
   4 9 2
 tril(M)
   8 0 0
   3 5 0
   4 9 2
 tril(M,1)
   8 1 0
   3 5 7
   4 9 2
```

See also

`triu`, `diag`

triu

Extraction of the upper triangular part of a matrix.

Syntax

```
 U = triu(M)
 U = triu(M,k)
```

Description

`tril(M)` extracts the upper triangular part of a matrix; the result is a matrix of the same size where all the elements below the main diagonal are set to zero. A second argument can be used to specify another diagonal; 0 is the main diagonal, positive values are above and negative values below.

Examples

```
 M = magic(3)
 M =
   8 1 6
   3 5 7
   4 9 2
 triu(M)
   8 1 6
   0 5 7
   0 0 2
 triu(M,1)
   0 1 6
   0 0 7
   0 0 0
```

See also

`tril`, `diag`

union

Set union.

Syntax

```
c = union(a, b)
(c, ia, ib) = union(a, b)
```

Description

`union(a,b)` gives the union of sets `a` and `b`, i.e. it gives the set of members of sets a or `b` or both. Sets are any type of numerical, character or logical arrays, or lists or cell arrays of character strings. Multiple elements of input arguments are considered as single members; the result is always sorted and has unique elements.

The optional second and third output arguments are vectors of indices such that if `(c,ia,ib)=union(a,b)`, then elements of `c` are the elements of `a(ia)` or `b(ib)`; the intersection of `a(ia)` and `b(ib)` is empty.

Example

```
a = {'a','bc','bbb','de'};
b = {'z','bc','aa','bbb'};
(c, ia, ib) = union(a, b)
  c =
    {'a','aa','bbb','bc','de','z'}
  ia =
    1 3 2 4
  ib =
    3 1
a(ia)
  {'a','bbb','bc','de'}
b(ib)
  {'aa','z'}
```

Set exclusive or can also be computed as the union of `a` and `b` minus the intersection of `a` and `b`:

```
setdiff(union(a, b), intersect(a, b))
  {'a','aa','de','z'}
```

See also

`unique`, `intersect`, `setdiff`, `setxor`, `ismember`

unique

Keep unique elements.

Syntax

```
v2 = unique(v1)
list2 = unique(list1)
(b, ia, ib) = unique(a)
```

Description

With an array argument, `unique(v1)` sorts its elements and removes duplicate elements. Unless `v1` is a row vector, `v1` is considered as a column vector.

With an argument which is a list of strings, `unique(list)` sorts its elements and removes duplicate elements.

The optional second output argument is set to a vector of indices such that if `(b,ia)=unique(a)`, then `b` is `a(ia)`.

The optional third output argument is set to a vector of indices such that if `(b,ia,ib)=unique(a)`, then `a` is `b(ib)`.

Examples

```
(b,ia,ib) = unique([4,7,3,8,7,1,3])
  b =
    1 3 4 7 8
  ia =
    6 3 1 2 4
  ib =
    3 4 2 5 4 1 2
unique({'def', 'ab', 'def', 'abc'})
  {'ab', 'abc', 'def'}
```

See also

`sort`, `union`, `intersect`, `setdiff`, `setxor`, `ismember`

zeros

Null array.

Syntax

```
A = zeros(n)
A = zeros(n1,n2,...)
A = zeros([n1,n2,...])
A = zeros(..., type)
```

Description

`zeros` builds an array whose elements are 0. The size of the array is specified by one integer for a square matrix, or several integers (either as separate arguments or in a vector) for an array of any size.

An additional input argument can be used to specify the type of the result. It must be the string `'double'`, `'single'`, `'int8'`, `'int16'`, `'int32'`, `'int64'`, `'uint8'`, `'uint16'`, `'uint32'`, or `'uint64'` (64-bit arrays are not supported on all platforms).

Examples

```
zeros([2,3])
  0 0 0
  0 0 0
zeros(2)
  0 0
  0 0
zeros(1, 5, 'uint16')
  1x5 uint16 array
    0 0 0 0 0
```

See also

`ones`, `cell`, `eye`, `rand`, `randn`, `repmat`

3.16 Triangulation Functions

delaunay

2-d Delaunay triangulation.

Syntax

```
t = delaunay(x, y)
(t, e) = delaunay(x, y)
```

Description

`delaunay(x,y)` calculates the Delaunay triangulation of 2-d points given by arrays `x` and `y`. Both arrays must have the same number of values, `m`. The result is an array of three columns. Each row corresponds to a triangle; values are indices in `x` and `y`.

The second output argument, if requested, is a logical vector of size `m`-by-`1`; elements are true if the corresponding point in x and y belongs to the convex hull of the set of points.

The Delaunay triangulation is a net of triangles which link all the starting points in such a way that no point is included in the circumscribed circle of any other triangle. Triangles are "as equilateral" as possible.

Example

Delaunay triangulation of 20 random points:

```
x = rand(20, 1);
y = rand(20, 1);
(t, e) = delaunay(x, y);
```

With Sysquake graphical functions, points belonging to the convex hull are displayed as crosses and interior points as circles:

```
clf;
scale equal;
plot(x(e), y(e), 'x');
plot(x(~e), y(~e), 'o');
```

Array of vertex indices is modified to have closed triangles:

```
t = [t, t(:, 1)];
```

Triangles are displayed:

```
plot(x(t), y(t));
```

See also

`delaunayn`, `voronoi`

delaunayn

N-d Delaunay triangulation.

Syntax

```
t = delaunayn(x)
(t, e) = delaunayn(x)
```

Description

`delaunayn(x)` calculates the Delaunay triangulation of points given by the rows of array `x` in a space of dimension `size(x,2)`. The result is an array with one more column. Each row corresponds to a simplex; values are row indices in `x` and give the vertices of each polyhedron.

The second output argument, if requested, is a logical vector with as many elements as rows in `x`; elements are true if the corresponding point in `x` belongs to the convex hull of the set of points.

See also

`delaunay`, `tsearchn`, `voronoin`

griddata

Data interpolation in 2-d plane.

Syntax

```
vi = griddata(x, y, v, xi, yi)
vi = griddata(x, y, v, xi, yi, method)
```

Description

`griddata(x,y,v,xi,yi)` interpolates values at coordinates given by the corresponding elements of arrays `xi` and `yi` in a 2-dimension plane. Original data are defined by corresponding elements of arrays `x`, `y`, and `v` (which must have the same size), such that the value at coordinate `[x(i);y(i)]` is `v(i)`. The result is an array with the same size as `xi` and `yi` where `vi(j)` is the value interpolated at `[xi(j);yi(j)]`.

All coordinates are real (imaginary components are ignored). Values `v` and `vi` can be real or complex. The result for coordinates outside the convex hull defined by `x` and `y` is NaN.

`griddata` is based on Delaunay triangulation. The interpolation method used in each triangle is linear by default, or can be specified with an additional input argument, a string:

Argument	**Meaning**
`'0'` or `'nearest'`	nearest value
`'1'` or `'linear'`	linear

See also

`delaunay`, `tsearch`, `griddatan`, `interpn`

griddatan

Data interpolation in N-d space.

Syntax

```
vi = griddatan(x, v, xi)
vi = griddatan(x, v, xi, method)
```

Description

`griddatan(x,v,xi)` interpolates values at coordinates given by the `p` rows of `p`-by-`n` array `xi` in an `n`-dimension space. Original data are defined by `m`-by-`n` array `x` and `m`-by-1 column vector `v`, such that the value at coordinate `x(i,:)'` is `v(i)`. The result is a `p`-by-1 column vector `vi` where `vi(j)` is the value interpolated at `xi(j,:)'`.

Coordinates `x` and `xi` are real (imaginary components are ignored). Values `v` and `vi` can be real or complex. The result for coordinates outside the convex hull defined by `x` is NaN.

`griddatan` is based on Delaunay triangulation. The interpolation method used in each simplex is linear by default, or can be specified with an additional input argument, a string:

Argument	**Meaning**
`'0'` or `'nearest'`	nearest value
`'1'` or `'linear'`	linear

See also

`delaunayn`, `tsearchn`, `griddata`, `interpn`

tsearch

Search of points in triangles.

Syntax

```
ix = tsearch(x, y, t, xi, yi)
```

Description

`tsearch(x,y,t,xi,yi)` searches in which triangle is located each point given by the corresponding elements of arrays `xi` and `yi`. Corresponding elements of arrays `x` and `y` represent the vertices of the triangles, and rows of array `t` represent their indices in `x` and `y`; array `t` is usually the result of `delaunay`. Dimensions of `x` and `y`, and of `xi` and `yi`, must be equal. The result is an array with the same size as `xi` and `yi` where each element is the row index in `t` of the first triangle which contains the point, or NaN if the point is outside all triangles (i.e. outside the convex hull of points defined by `x` and `y` if `t` is a proper triangulation such as the one computed with `delaunay`).

Example

Search for triangles containing points [0,0] and [0,1] corresponding to Delauny triangulation of 20 random points:

```
x = randn(20, 1);
y = randn(20, 1);
t = delaunay(x, y);
xi = [0, 0];
yi = [0, 1];
ix = tsearch(x, y, t, xi, yi);
```

See also

`tsearchn`, `delaunay`, `voronoi`

tsearchn

Search of points in triangulation simplices.

Syntax

```
ix = tsearchn(x, t, xi)
```

Description

`tsearchn(x,t,xi)` searches in which simplex each point given by the rows of array `xi` is located. Rows of array `x` represent the vertices of the simplices, and rows of array `t` represent their indices in `x`; array `t` is usually the result of `delaunayn`. Dimensions must match: in a space of n dimensions, `x` and `xi` have n columns, and `t` has n+1 columns. The result is a column vector with one element for each row of `xi`, which is the row index in `t` of the first simplex which contains the point, or NaN if the point is outside all simplices (i.e. outside the convex hull of points `x` if `t` is a proper triangulation of `x` such as the one computed with `delaunayn`).

Example

Search for simplices containing points [0,0] and [0,1] corresponding to Delauny triangulation of 20 random points:

```
x = randn(20, 2);
t = delaunayn(x);
xi = [0, 0; 0, 1];
ix = tsearchn(x, t, xi);
```

See also

`delaunayn`, `voronoin`

voronoi

2-d Voronoi tessalation.

Syntax

```
(v, p) = voronoi(x, y)
```

Description

`voronoi(x,y)` calculates the Voronoi tessalation of the set of 2-d points given by arrays `x` and `y`. Both arrays must have the same number of values, `m`. The first output argument `v` is an array of two columns which contains the coordinates of the vertices of the Voronoi cells, one row per vertex. The first row contains infinity and is used as a marker for unbounded Voronoi cells. The second output argument `p` is a list of vectors of row indices in `v`; each element describes the Voronoi cell corresponding to a point in `x`. In each cell, vertices are sorted counterclockwise.

Voronoi tessalation is a tessalation (a partition of the plane) such that each region is the set of points closer to one of the initial point than to any other one. Two regions are in contact if and only if their initial points are linked in the corresponding Delaunay triangulation.

Example

Voronoi tessalation of 20 random points:

```
x = rand(20, 1);
y = rand(20, 1);
(v, p) = voronoi(x, y);
```

These points are displayed as crosses with Sysquake graphical functions. The scale is fixed, because Voronoi polygons can have vertices which are far away from the points.

```
clf;
scale('equal', [0,1,0,1]);
plot(x, y, 'x');
```

Voronoi polygons are displayed in a loop, skipping unbounded polygons. The first vertex is repeated to have closed polygons. Since `plot` expects row vectors, vertex coordinates are transposed.

```
for p1 = p
  if ~any(p1 == 1)
    p1 = [p1, p1(1)];
    plot(v(p1,1)', v(p1,2)');
  end
end
```

See also

`voronoin`, `delaunay`

voronoin

N-d Voronoi tessalation.

Syntax

```
(v, p) = voronoin(x)
```

Description

`voronoin(x)` calculates the Voronoi tessalation of the set of points given by the rows of arrays `x` in a space of dimension `n=size(x,2)`. The first output argument `v` is an array of `n` columns which contains the coordinates of the vertices of the Voronoi cells, one row per vertex. The first row contains infinity and is used as a marker for unbounded Voronoi cells. The second output argument `p` is a list of vectors of row indices in `v`; each element describes the Voronoi cell corresponding to a point in `x`. In each cell, vertices are sorted by index.

See also

`voronoi`, `delaunayn`

3.17 Integer Functions

uint8 uint16 uint32 uint64 int8 int16 int32 int64

Conversion to integer types.

Syntax

```
B = uint8(A)
B = uint16(A)
B = uint32(A)
B = uint64(A)
B = int8(A)
B = int16(A)
B = int32(A)
B = int64(A)
```

Description

The functions convert a number or an array to unsigned or signed integers. The name contains the size of the integer in bits.

To avoid a conversion from double to integer, constant literal numbers should be written with a type suffix, such as `12int32`. This is the only way to specify large 64-bit numbers, because double-precision floating-point numbers have a mantissa of 56 bits.

`uint64` and `int64` are not supported on platforms with tight memory constraints.

Examples

```
uint8(3)
  3uint8
3uint8
  3uint8
uint8([50:50:400])
  1x8 uint8 array
    50 100 150 200 250  44  94 144
int8([50:50:400])
  1x8 int8 array
    50  100 -106  -56   -6   44   94 -112
```

See also

`double`, `single`, `char`, `logical`, `map2int`

intmax

Largest integer.

Syntax

```
i = intmax
i = intmax(type)
```

Description

Without input argument, `intmax` gives the largest signed 32-bit integer. `intmax(type)` gives the largest integer of the type specified by string `type`, which can be `'uint8'`, `'uint16'`, `'uint32'`, `'uint64'`, `'int8'`, `'int16'`, `'int32'`, or `'int64'` (64-bit integers are not supported on all platforms). The result has the corresponding integer type.

Examples

```
intmax
  2147483647int32
intmax('uint16')
  65535uint16
```

See also

`intmin`, `realmax`, `uint8` and related functions, `map2int`

intmin

Smallest integer.

Syntax

```
i = intmin
i = intmin(type)
```

Description

Without input argument, `intmin` gives the smallest signed 32-bit integer. `intmin(type)` gives the largest integer of the type specified by string `type`, which can be `'uint8'`, `'uint16'`, `'uint32'`, `'uint64'`, `'int8'`, `'int16'`, `'int32'`, or `'int64'` (64-bit integers are not supported on all platforms). The result has the corresponding integer type.

Examples

```
intmin
  -2147483648int32
intmin('uint16')
  0uint16
```

See also

`intmax`, `realmin`, `uint8` and related functions, `map2int`

map2int

Mapping of a real interval to an integer type.

Syntax

```
B = map2int(A)
B = map2int(A, vmin, vmax)
B = map2int(A, vmin, vmax, type)
```

Description

`map2int(A,vmin,vmax)` converts number or array `A` to 8-bit unsigned integers. Values between `vmin` and `vmax` in `A` are mapped linearly to values 0 to 255. With a single input argument, the default input interval is 0 to 1.

`map2int(A,vmin,vmax,type)` converts `A` to the specified type, which can be any integer type given as a string: `'uint8'`, `'uint16'`, `'uint32'`, `'uint64'`, `'int8'`, `'int16'`, `'int32'`, or `'int64'` (64-bit integers are not supported on all platforms). The input interval is mapped to its full range.

In all cases, input values outside the interval are clipped to the minimum or maximum values.

Examples

```
map2int(-0.2:0.2:1.2)
  1x5 uint8 array
    0   0  51 102 153 204 255 255
map2int([1,3,7], 0, 10, 'uint16')
  1x3 uint16 array
    6553 19660 45875
map2int([1,3,7], 0, 10, 'int16')
  1x3 int16 array
    -26214 -13107  13107
```

See also

`uint8` and related functions.

3.18 Non-Linear Numerical Functions

fminbnd

Minimum of a function.

Syntax

```
(x, y) = fminbnd(fun, x0)
(x, y) = fminbnd(fun, [xlow,xhigh])
(x, y) = fminbnd(..., options)
(x, y) = fminbnd(..., options, ...)
(x, y, didConverge) = fminbnd(...)
```

Description

`fminbnd(fun,...)` finds numerically a local minimum of function `fun`. `fun` is either specified by its name or given as an anonymous or inline function or a function reference. It has at least one input argument `x`, and it returns one output argument, also a real number. `fminbnd` finds the value `x` such that `fun(x)` is minimized.

Second argument tells where to search; it can be either a starting point or a pair of values which must bracket the minimum.

The optional third argument may contain options. It is either the empty array `[]` for default options, or the result of `optimset`.

Remaining input arguments of `fminbnd`, if any, are given as additional input arguments to function `fun`. They permit to parameterize the function. For example `fminbnd('fun',x0,[],2,5)` calls `fun` as `fun(x,2,5)` and minimizes its value with respect to `x`.

The first output argument of fminbnd is the value of x at optimum. The second output argument, if it exists, is the value of fun(x) at optimum. The third output argument, if it exists, is set to true if fminbnd has converged to an optimum, or to false if it has not; in that case, other output arguments are set to the best value obtained. With one or two output arguments, fminbnd throws an error if it does not converge.

Examples

Minimum of a sine near 2, displayed with 15 digits:

```
fprintf('%.15g\n', fminbnd(@sin, 2));
  4.712389014989218
```

To find the minimum of $ce^x - \sin x$ between -1 and 10 with $c = 0.1$, the expression is written as an inline function stored in variable fun:

```
fun = inline('c*exp(x)-sin(x)', 'x', 'c');
```

Then fminbnd is used, with the value of c passed as an additional argument:

```
x = fminbnd(fun,[-1,10],[],0.1)
  x =
    1.2239
```

With an anonymous function, this becomes

```
c = 0.1;
fun = @(x) c*exp(x)-sin(x);
x = fminbnd(fun,[-1,10])
  x =
    1.2239
```

Attempt to find the minimum of an unbounded function:

```
(x,y,didConverge) = fminbnd(@exp,10)
  x =
    -inf
  y =
    0
  didConverge =
    false
```

See also

optimset, fminsearch, fzero, inline, operator @

fminsearch

Minimum of a function in Rˆn.

Syntax

```
x = fminsearch(fun, x0)
x = fminsearch(..., options)
x = fminsearch(..., options, ...)
(x, y, didConverge) = fminsearch(...)
```

Description

`fminsearch(fun,x0,...)` finds numerically a local minimum of function `fun`. `fun` is either specified by its name or given as an anonymous or inline function or a function reference. It has at least one input argument `x`, a real scalar, vector or array, and it returns one output argument, a scalar real number. `fminsearch` finds the value `x` such that `fun(x)` is minimized, starting from point `x0`.

The optional third input argument may contain options. It is either the empty array `[]` for default options, or the result of `optimset`.

Remaining input arguments of `fminsearch`, if any, are given as additional input arguments to function `fun`. They permit to parameterize the function. For example `fminsearch('fun',x0,[],2,5)` calls `fun` as `fun(x,2,5)` and minimizes its value with respect to `x`.

The first output argument of `fminsearch` is the value of `x` at optimum. The second output argument, if it exists, is the value of `fun(x)` at optimum. The third output argument, if it exists, is set to true if `fminsearch` has converged to an optimum, or to false if it has not; in that case, other output arguments are set to the best value obtained. With one or two output arguments, `fminsearch` throws an error if it does not converge.

Algorithm

`fminsearch` implements the Nelder-Mead simplex method. It starts from a polyhedron centered around `x0` (the "simplex"). Then at each iteration, either vertex `x_i` with the maximum value `fun(x_i)` is moved to decrease it with a reflexion-expansion, a reflexion, or a contraction; or the simplex is shrinked around the vertex with minimum value. Iterations stop when the simplex is smaller than the tolerance, or when the maximum number of iterations or function evaluations is reached (then an error is thrown).

Examples

Minimum of a sine near 2, displayed with 15 digits:

```
fprintf('%.15g\n', fminsearch(@sin, 2));
  4.712388977408411
```

Maximum of $xe^{-x^2y^2}xy - 0.1x^2$ The function if defined as an anonymous function stored in variable `fun`:

```
fun = @(x,y) x.*exp(-(x.*y).^2).*x.*y-0.1*x.^2;
```

In Sysquake, the contour plot can be displayed with the following commands:

```
[X,Y] = meshgrid(0:0.02:3, 0:0.02:3);
contour(feval(fun, X, Y), [0,3,0,3], 0.1:0.05:0.5);
```

The maximum is obtained by minimizing the opposite of the function, rewritten to use as input a single variable in R^2:

```
mfun = @(X) -(X(1)*exp(-(X(1)*X(2))^2)*X(1)*X(2)-0.1*X(1)^2);
fminsearch(mfun, [1, 2])
  2.1444  0.3297
```

For the same function with a constraint $x < 1$, the objective function can be modified to return $+\infty$ for inputs outside the feasible region (note that we can start on the constraint boundary, but starting from the infeasible region would probably fail):

```
mfunc = @(X) ...
  X(1) < 1 ...
    ? -(X(1)*exp(-(X(1)*X(2))^2)*X(1)*X(2) - 0.1*X(1)^2) ...
    : inf;
fminsearch(mfunc, [1, 2])
  1    0.7071
```

See also

`optimset`, `fminbnd`, `fzero`, `inline`, operator `@`

fzero

Zero of a function.

Syntax

```
x = fzero(fun,x0)
x = fzero(fun,[xlow,xhigh])
x = fzero(...,options)
x = fzero(...,options,...)
```

Description

`fzero(fun,...)` finds numerically a zero of function `fun`. `fun` is either specified by its name or given as an anonymous or inline function or a function reference. It has at least one input argument `x`, and it returns one output argument, also a real number. `fzero` finds the value `x` such that `fun(x)==0`, up to some tolerance.

Second argument tells where to search; it can be either a starting point or a pair of values `xlow` and `xhigh` which must bracket the zero, such that `fun(xlow)` and `fun(xhigh)` have opposite sign.

The optional third argument may contain options. It is either the empty array `[]` for the default options, or the result of `optimset`.

Additional input arguments of `fzero` are given as additional input arguments to the function specified by `fun`. They permit to parameterize the function.

Examples

Zero of a sine near 3, displayed with 15 digits:

```
fprintf('%.15g\n', fzero(@sin, 3));
  3.141592653589793
```

To find the solution of $e^x = c + \sqrt{x}$ between 0 and 100 with $c = 10$, a function `f` whose zero gives the desired solution is written:

```
function y = f(x,c)
  y = exp(x) - c - sqrt(x);
```

Then `fsolve` is used, with the value of c passed as an additional argument:

```
x = fzero(@f,[0,100],[],10)
  x =
    2.4479
f(x,10)
  1.9984e-15
```

An anonymous function can be used to avoid passing `10` as an additional argument, which can be error-prone since a dummy empty option arguments has to be inserted.

```
x = fzero(@(x) f(x,10), [0,100])
  x =
    2.4479
```

See also

`optimset`, `fminsearch`, `inline`, operator `@`, `roots`

ode23 ode45

Ordinary differential equation integration.

Syntax

```
(t,y) = ode23(fun,[t0,tend],y0)
(t,y) = ode23(fun,[t0,tend],y0,options)
(t,y) = ode23(fun,[t0,tend],y0,options,...)
(t,y,te,ye,ie) = ode23(...)
(t,y) = ode45(fun,[t0,tend],y0)
(t,y) = ode45(fun,[t0,tend],y0,options)
(t,y) = ode45(fun,[t0,tend],y0,options,...)
(t,y,te,ye,ie) = ode45(...)
```

Description

`ode23(fun,[t0,tend],y0)` and `ode45(fun,[t0,tend],y0)` integrate numerically an ordinary differential equation (ODE). Both functions are based on a Runge-Kutta algorithm with adaptive time step; `ode23` is low-order and `ode45` high-order. In most cases for non-stiff equations, `ode45` is the best method. The function to be integrated is either specified by its name or given as an anonymous or inline function or a function reference. It should have at least two input arguments and exactly one output argument:

```
function yp = f(t,y)
```

The function calculates the derivative `yp` of the state vector `y` at time `t`.

Integration is performed over the time range specified by the second argument `[t0,tend]`, starting from the initial state `y0`. It may stop before reaching `tend` if the integration step cannot be reduced enough to obtain the required tolerance. If the function is continuous, you can try to reduce `MinStep` in the options argument (see below).

The optional fourth argument may contain options. It is either the empty array `[]` for the default options, or the result of `odeset` (the use of a vector of option values is deprecated.)

Events generated by options `Events` or `EventTime` can be obtained by three additional output arguments: `(t,y,te,ye,ie)=...` returns event times in `te`, the corresponding states in `ye` and the corresponding event identifiers in `ie`.

Additional input arguments of `ode45` are given as additional input arguments to the function specified by `fun`. They permit to parameterize the ODE.

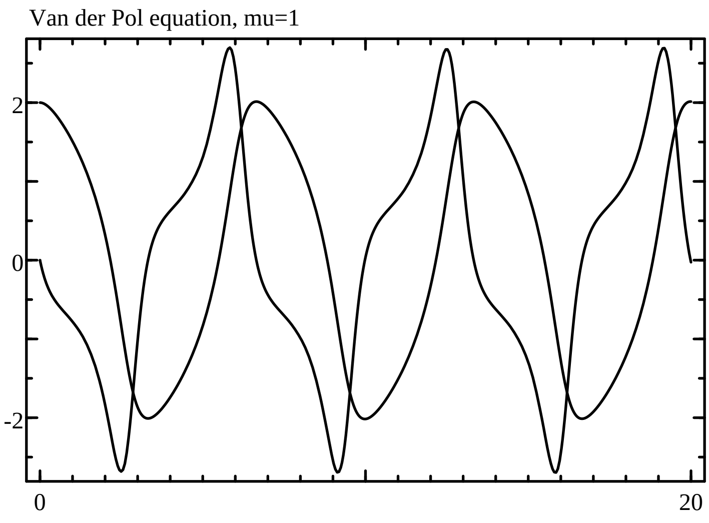


Figure 3.1 Van der Pol equation with $\mu = 1$ integrated with ode45

Example

Let us integrate the following ordinary differential equation (Van Der Pol equation), parameterized by μ:

$$x'' = \mu\left(1 - x^2\right)x' - x$$

Let $y_1 = x$ and $y_2 = x'$; their derivatives are

$$\begin{aligned} y_1' &= y_2 \\ y_2' &= \mu\left(1 - y_1^2\right)y_2 - y_1 \end{aligned}$$

and can be computed by the following function:

```
function yp = f(t,y,mu)
yp = [y(2); mu*(1-y(1)^2)*y(2)-y(1)];
```

The following ode45 call integrates the Van Der Pol equation from 0 to 10 with the default options, starting from $x(0) = 2$ and $x'(0) = 0$, with $\mu = 1$ (see Fig. 3.1):

```
(t,y)=ode45(@f,[0,10],[2;0],[],1);
```

The `plot` command expects traces along the second dimension; consequently, the result of ode45 should be transposed.

```
plot(t', y');
```

See also

odeset, quad, inline, operator @, expm

odeset

Options for ordinary differential equation integration.

Syntax

```
options = odeset
options = odeset(name1, value1, ...)
options = odeset(options0, name1, value1, ...)
```

Description

odeset(name1,value1,...) creates the option argument used by ode23 and ode45. Options are specified with name/value pairs, where the name is a string which must match exactly the names in the table below. Case is significant. Options which are not specified have a default value. The result is a structure whose fields correspond to each option. Without any input argument, odeset creates a structure with all the default options. Note that ode23 and ode45 also interpret the lack of an option argument, or the empty array [], as a request to use the default values.

When its first input argument is a structure, odeset adds or changes fields which correspond to the name/value pairs which follow.

Here is the list of permissible options (empty arrays mean "automatic"):

Name	Default	Meaning
AbsTol	1e-6	maximum absolute error
Events	[] (none)	state-based event function
EventTime	[] (none)	time-based event function
InitialStep	[] (10*MinStep)	initial time step
MaxStep	[] (time range/10)	maximum time step
MinStep	[] (time range/1e6)	minimum time step
NormControl	false	error control on state norm
OnEvent	[] (none)	event function
OutputFcn	[] (none)	output function
Past	false	provide past times and states
PreArg	{}	list of prepended input arguments
Refine	[] (1, 4 for ode45)	refinement factor
RelTol	1e-3	maximum relative error
Stats	false	statistics display

Time steps and output

Several options control how the time step is tuned during the numerical integration. Error is calculated separately on each element of y if NormControl is false, or on norm(y) if it is true; time steps are chosen so that it remains under AbsTol or RelTol times the state, whichever is larger. If this cannot be achieved, for instance if the system is stiff and requires an integration step smaller than MinStep, integration is aborted.

'Refine' specifies how many points are added to the result for each integration step. When it is larger than 1, additional points are interpolated, which is much faster than reducing MaxStep.

The output function OutputFcn, if defined, is called after each step. It is a function name in a string, a function reference, or an anonymous or inline function, which can be defined as

```
function stop = outfun(tn, yn)
```

where tn is the time of the new samples, yn their values, and stop a logical value which is false to continue integrating or true to stop. The number of new samples is given by the value of Refine; when multiple values are provided, tn is a row vector and yn is a matrix whose columns are the corresponding states. The output function can be used for incremental plots, for animations, or for managing large amounts of output data without storing them in variables.

Events

Events are additional time steps at controlled time, to change instantaneously the states, and to base the termination condition on the states. Time instants where events occur are either given explicitly by EventTime, or implicitly by Events. There can be multiple streams of events, which are checked independently and are identified by a positive integer for Events, or a negative integer for EventTime. For instance, for a ball which bounces between several walls, the intersection between each wall and the ball trajectory would be a different event stream.

For events which occur at regular times, EventTime is an n-by-two matrix: for each row, the first column gives the time step ts, and the second column gives the offset to. Non-repeating events are specified with an infinite time step ts. Events occur at time t=to+k*ts, where k is an integer.

When event time is varying, EventTime is a function which can be defined as

```
function eventTime = eventtimefun(t, y, ...)
```

where t is the current time, y the current state, and the ellipsis stand for additional arguments passed to ode∗. The function returns a (column) vector whose elements are the times where the next event occurs. In both cases, each row corresponds to a different event stream.

For events which are based on the state, the value of a function which depends on the time and the states is checked; the event occurs when its sign changes. Events is a function which can be defined as

```
function (value, isterminal, direction) ...
         = eventsfun(t, y, ...)
```

Input arguments are the same as for EventTime. Output arguments are (column) vectors where each element i corresponds to an event stream. An event occurs when value(i) crosses zero, in either direction if direction(i)==0, from negative to nonnegative if direction(i)>0, or from positive to nonpositive if direction(i)<0. The event terminates integration if isterminal(i) is true. The Events function is evaluated for each state obtained by integration; intermediate time steps obtained by interpolation when Refine is larger than 1 are not considered. When an event occurs, the integration time step is reset to the initial value, and new events are disabled during the next integration step to avoid shattering. MaxStep should be used if events are missed when the result of Events is not monotonous between events.

When an event occurs, function OnEvent is called if it exists. It can be defined as

```
function yn = onevent(t, y, i, ...)
```

where i identifies the event stream (positive for events produced by Events or negative for events produced by EventTime); and the output yn is the new value of the state, immediately after the event.

The primary goal of ode∗ functions is to integrate states. However, there are systems where some states are constant between events, and are changed only when an event occurs. For instance, in a relay with hysteresis, the output is constant except when the input overshoots some value. In the general case, ni states are integrated and n-ni states are kept constant between events. The total number of states n is given by the length of the initial state vector y0, and the number of integrated states ni is given by the size of the output of the integrated function. Function OnEvent can produce a vector of size n to replace all the states, of size n-ni to replace the non-integrated states, or empty to replace no state (this can be used to display results or to store them in a file, for instance).

Event times are computed after an integration step has been accepted. If an event occurs before the end of the integration step, the step is shortened; event information is stored in the output arguments of ode∗ te, ie and ye; and the OnEvent function is called. The output arguments t and y of ode∗ contain two rows with the same time and the state right before the event and right after it. The time step used for integration is not modified by events.

Additional arguments

Past is a logical value which, if it is true, specifies that the time and state values computed until now (what will eventually be the result of ode23 or ode45) are passed as additional input arguments to functions called during intergration. This is especially useful for delay differential equations (DDE), where the state at some time point in the past can be interpolated from the integration results accumulated until now with interp1. Assuming no additional parameters or PreArg (see below), functions must be defined as

```
function yp = f(t,y,tpast,ypast)
function stop = outfun(tn,yn,tpast,ypast)
function eventTime = eventtimefun(t,y,tpast,ypast)
function (value, isterminal, direction) ...
          = eventsfun(t,y,tpast,ypast)
function yn = onevent(t,y,tpast,ypast,i)
```

PreArg is a list of additional input arguments for all functions called during integration; they are placed before normal arguments. For example, if its value is {1,'abc'}, the integrated function is called with fun(1,'abc',t,y), the output function as outfun(1,'abc',tn,yn), and so on.

Examples

Default options

```
odeset
  AbsTol: 1e-6
  Events: []
  EventTime: []
  InitialStep: []
  MaxStep: []
  MinStep: []
  NormControl: false
  OnEvent: []
  OutputFcn: []
  PreArg: {}
  Refine: []
  RelTol: 1e-3
  Stats: false
```

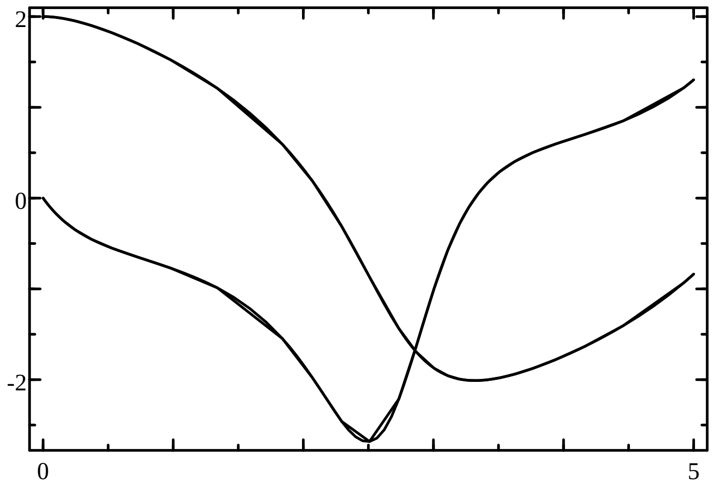


Figure 3.2 Van der Pol equation with `Refine` set to 1 and 4

Option `'refine'`

ode45 is typically able to use large time steps to achieve the requested tolerance. When plotting the output, however, interpolating it with straight lines produces visual artifacts. This is why ode45 inserts 3 interpolated points for each calculated point, based on the fifth-order approximation calculated for the integration (`Refine` is 4 by default). In the following code, curves with and without interpolation are compared (see Fig. 3.2). Note that the numbers of evaluations of the function being integrated are the same.

```
mu = 1;
fun = @(t,y) [y(2); mu*(1-y(1)^2)*y(2)-y(1)];
(t, y) = ode45(fun, [0,5], [2;0], ...
               odeset('Refine',1,'Stats',true));
  Number of function evaluations: 289
  Successful steps: 42
  Failed steps (error too large): 6
size(y)
  43  2
(ti, yi) = ode45(fun, [0,5], [2;0], ...
                 odeset('Stats',true));
  Number of function evaluations: 289
  Successful steps: 42
  Failed steps (error too large): 6
size(yi)
  169  2
```

```
plot(ti', yi', 'g');
plot(t', y');
```

State-based events

For simulating a ball bouncing on the ground, an event is generated every time the ball hits the ground, and its speed is changed instantaneously. Let `y(1)` be the height of the ball above the ground, and `y(2)` its speed (SI units are used). The state-space model is

```
y' = [y(2); -9.81];
```

An event occurs when the ball hits the ground:

```
value = y(1);
isterminal = false;
direction = -1;
```

When the event occurs, a new state is computed:

```
yn = [0; -damping*y(2)];
```

To integrate this, the following functions are defined:

```
function yp = ballfun(t, y, damping)
  yp = [y(2); -9.81];
function (v, te, d) = ballevents(t, y, damping)
  v = y(1);    // event when the height becomes negative
  te = false;  // do not terminate
  d = -1;      // only for negative speeds
function yn = ballonevent(t, y, i, damping)
  yn = [0; -damping*y(2)];
```

Ball state is integrated during 5 s (see Fig. 3.3) with

```
opt = odeset('Events', @ballevents, ...
             'OnEvent', @ballonevent);
(t, y) = ode45(@ballfun, [0, 5], [2; 0], opt, 1);
plot(t', y');
```

Time events with discontinuous function

If the function being integrated has discontinuities at known time instants, option `EventTime` can be used to insure an accurate switching time. Consider a first-order filter with input $u(t)$, where $u(t) = 0$ for $t < 1$ and $u(t) = 1$ for $t \geq 1$. The following function is defined for the state derivative:

```
function yp = filterfun(t, y)
  yp = -y + (t <= 1 ? 0 : 1);
```

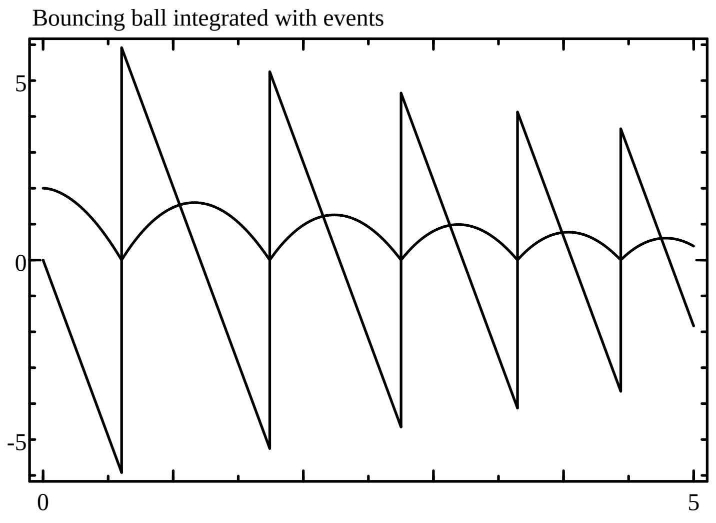


Figure 3.3 Bouncing ball integrated with events

A single time event is generated at $t = 1$:

```
opt = odeset('EventTime', [inf, 1]);
(t, y) = ode45(@filterfun, [0, 5], 0, opt);
plot(t', y');
```

Function `filterfun` is integrated in the normal way until $t = 1$ inclusive, with $u = 0$. This is why the conditional expression in `filterfun` is *less than or equal to* and not *less than*. Then the event occurs, and integration continues from $t = 1 + \epsilon$ with $u = 0$.

Non-integrated state

For the last example, we will consider a system made of an integrator and a relay with hysteresis in a loop. Let `y(1)` be the output of the integrator and `y(2)` the output of the relay. Only `y(1)` is integrated:

```
yi' = y(2);
```

An event occurs when the integrator is larger or smaller than the hysteresis:

```
value = y(1) - y(2);
isTerminal = false;
direction = sign(y(2));
```

When the event occurs, a new value is computed for the 2nd state:

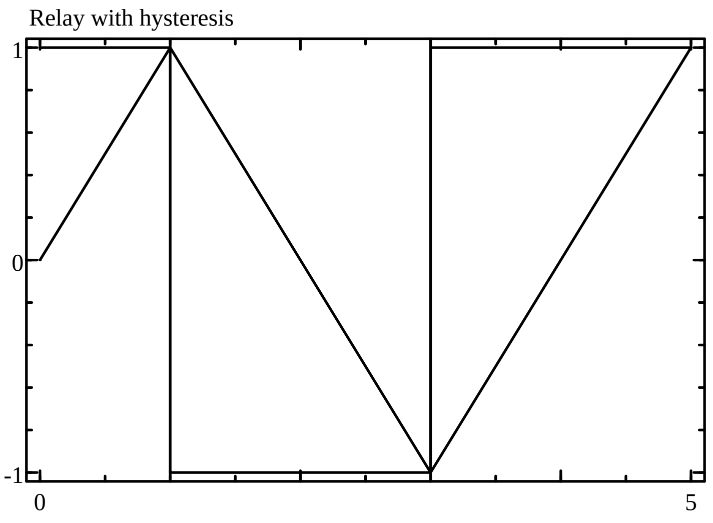


Figure 3.4 Relay with hysteresis integrated with events

```
yn = -y(2);
```

To integrate this, the following functions are defined:

```
function yp = relayfun(t, y)
  yp = y(2);
function (v, te, d) = relayevents(t, y)
  v = y(1) - y(2);
  te = false;
  d = sign(y(2));
function yn = relayonevent(t, y, i)
  yn = -y(2);
```

The initial state is `[0;1]`; 0 for the integrator, and 1 for the output of the relay. State is integrated during 5 s (see Fig. 3.4) with

```
(t, y) = ode45(@relayfun, [0, 5], [0; 1], ...
 odeset('Events', @relayevents, 'OnEvent', @relayonevent));
plot(t', y');
```

Delay differential equation

A system whose Laplace transform is $Y(s)/U(s) = e^{-ds}/(s^2 + s)$ (first order + integrator + delay d) is simulated with unit negative feedback. The reference signal is 1 for $t > 0$. First, the open-loop system is converted from transfer function to state-space, such that $x'(t) = Ax(t) +$

$Bu(t)$ and $y(t) = Cx(t-d)$. The closed-loop state-space model is obtained by setting $u(t) = 1 - y(t)$, which gives $x'(t) = Ax(t) + BCx(t-d)$.

Delayed state is interpolated from past results with `interp1`. Note that values for $t < 0$ (extrapolated) are set to 0, and that values more recent than the last result are interpolated with the state passed to `f` for current `t`.

```
(A,B,C) = tf2ss(1,[1,1,0]);
d = 0.1;
x0 = zeros(length(A),1);
tmax = 10;
f = @(t,x,tpast,xpast) ...
     A*x+B*(1-C*interp1([tpast;t],[xpast;x.'],t-d,'1',0).');
(t,x) = ode45(f, [0,tmax], x0, odeset('Past',true));
```

Output y can be computed from the state:

```
y = C * interp1(t,x,t-d,'1',0).';
```

See also

`ode23`, `ode45`, `optimset`, `interp1`

optimset

Options for minimization and zero finding.

Syntax

```
options = optimset
options = optimset(name1, value1, ...)
options = optimset(options0, name1, value1, ...)
```

Description

`optimset(name1,value1,...)` creates the option argument used by `fminbnd`, `fminsearch`, and `fzero`. Options are specified with name/value pairs, where the name is a string which must match exactly the names in the table below. Case is significant. Options which are not specified have a default value. The result is a structure whose fields correspond to each option. Without any input argument, `optimset` creates a structure with all the default options. Note that `fminbnd`, `fminsearch`, and `fzero` also interpret the lack of an option argument, or the empty array `[]`, as a request to use the default values.

When its first input argument is a structure, `optimset` adds or changes fields which correspond to the name/value pairs which follow.

Here is the list of permissible options (empty arrays mean "automatic"):

Name	**Default**	**Meaning**
`Display`	`false`	detailed display
`MaxFunEvals`	`1000`	maximum number of evaluations
`MaxIter`	`500`	maximum number of iterations
`TolX`	`[]`	maximum relative error

The default value of `TolX` is `eps` for `fzero` and `sqrt(eps)` for `fminbnd` and `fminsearch`.

Examples

Default options:

```
optimset
  Display: false
  MaxFunEvals: 1000
  MaxIter: 500
  TolX: []
```

Display of the steps performed to find the zero of $\cos x$ between 1 and 2:

```
fzero(@cos, [1,2], optimset('Display',true))
  Checking lower bound
  Checking upper bound
  Inverse quadratic interpolation 2,1.5649,1
  Inverse quadratic interpolation 1.5649,1.571,2
  Inverse quadratic interpolation 1.571,1.5708,1.5649
  Inverse quadratic interpolation 1.5708,1.5708,1.571
  Inverse quadratic interpolation 1.5708,1.5708,1.571
ans =
  1.5708
```

See also

`fzero`, `fminbnd`, `fminsearch`, `odeset`

quad

Numerical integration.

Syntax

```
y = quad(fun, a, b)
y = quad(fun, a, b, tol)
y = quad(fun, a, b, tol, trace)
y = quad(fun, a, b, tol, trace, ...)
```

Description

`quad(fun,a,b)` integrates numerically function `fun` between a and `b`. `fun` is either specified by its name or given as an anonymous or inline function or a function reference.

The optional fourth argument is the requested relative tolerance of the result. It is either a positive real scalar number or the empty matrix (or missing argument) for the default value, which is `sqrt(eps)`. The optional fifth argument, if true or nonzero, makes `quad` displays information at each step.

Additional input arguments of `quad` are given as additional input arguments to function `fun`. They permit to parameterize the function.

Example

$$\int_0^2 te^{-t}\mathrm{d}t$$

```
quad(@(t) t*exp(-t), 0, 2)
  0.5940
```

See also

`sum`, `ode45`, `inline`, operator `@`

3.19 String Functions

base64decode

Decode base64-encoded data.

Syntax

```
strb = base64decode(strt)
```

Description

`base64decode(strt)` decodes the contents of string `strt` which represents data encoded with base64. Characters which are not 'A'-'Z', 'a'-'z', '0'-'9', '+', '/', or '=' are ignored. Decoding stops at the end of the string or when '=' is reached.

See also

`base64encode`

base64encode

Encode data using base64.

Syntax

```
strt = base64encode(strb)
```

Description

`base64encode(strb)` encodes the contents of string `strb` which represents binary data. The result contains only characters 'A'-'Z', 'a'-'z', '0'-'9', '+', '/', and '='; it is suitable for transmission or storage on media which accept only text.

Each character of encoded data represents 6 bits of binary data; i.e. one needs four characters for three bytes. The six bits represent 64 different values, encoded with the characters 'A' to 'Z', 'a' to 'z', '0' to '9', '+', and '/' in this order. When the binary data have a length which is not a multiple of 3, encoded data are padded with one or two characters '=' to have a multiple of 4.

Base64 encoding is an Internet standard described in RFC 1521.

Example

```
s = base64encode(char(0:10))
  s =
    AAECAwQFBgcICQo=
double(base64decode(s))
  0  1  2  3  4  5  6  7  8  9 10
```

See also

`base64decode`

char

Convert an array to a character array (string).

Syntax

```
s = char(A)
S = char(s1, s2, ...)
```

Description

`char(A)` converts the elements of matrix `A` to characters, resulting in a string of the same size. Characters are stored in unsigned 16-bit words. The shape of `A` is preserved. Even if most functions ignore the string shape, you can force a row vector with `char(A(:).')`.

`char(s1,s2,...)` concatenates vertically the arrays given as arguments to produce a string matrix. If the strings do not have the same number of columns, blanks are added to the right.

Examples

```
char(65:70)
  ABCDEF
char([65, 66; 67, 68](:).')
  ABCD
char('ab','cde')
  ab
  cde
char('abc',['de';'fg'])
  abc
  de
  fg
```

See also

`setstr`, uint16, operator :, operator .', `ischar`, `logical`, `double`, `single`

deblank

Remove trailing blank characters from a string.

Syntax

```
s2 = deblank(s1)
```

Description

`deblank(s1)` removes the trailing blank characters from string `s1`. Blank characters are spaces (code 32), tabulators (code 9), carriage returns (code 13), line feeds (code 10), and null characters (code 0).

Example

```
double(' \tAB  CD\r\n\0')
  32  9 65 66 32 32 67 68 13 10 0
double(deblank(' \tAB  CD\n\r\0'))
  32  9 65 66 32 32 67 68
```

See also

`strtrim`

findstr

Find a substring in a string.

Syntax

```
pos = findstr(str, sub)
```

Description

`findstr(str,sub)` finds occurrences of string `sub` in string `str` and returns a vector of the positions of all occurrences, or the empty vector `[]` if there is none. Occurrences may overlap.

Examples

```
findstr('ababcdbaaab','ab')
  1 3 10
findstr('ababcdbaaab','ac')
  []
findstr('aaaaaa','aaa')
  1 2 3
```

See also

`find`, `strcmp`, `strmatch`, `strtok`

ischar

Test for a string object.

Syntax

```
 b = ischar(obj)
```

Description

`ischar(obj)` is true if the object `obj` is a character string, false otherwise. Strings can have more than one line.

Examples

```
 ischar('abc')
   true
 ischar(0)
   false
 ischar([])
   false
 ischar('')
   true
 ischar(['abc';'def'])
   true
```

See also

`isletter`, `isspace`, `isnumeric`, `islogical`, `isinteger`, `islist`, `isstruct`, `setstr`, `char`

isdigit

Test for decimal digit characters.

Syntax

```
 b = isdigit(s)
```

Description

For each character of string `s`, `isdigit(s)` is true if it is a digit (`'0'` to `'9'`) and false otherwise.

Examples

```
isdigit('a123bAB12* ')
  F T T T F F F T T F F
```

See also

`isletter`, `isspace`, `lower`, `upper`, `ischar`

isletter

Test for letter characters.

Syntax

```
b = isletter(s)
```

Description

For each character of string `s`, `isletter(s)` is true if it is a letter and false otherwise. Letters with diacritical signs are not considered as letters.

Examples

```
isletter('abAB12* ')
  T T T T F F F F
```

See also

`isdigit`, `isspace`, `lower`, `upper`, `ischar`

isspace

Test for space characters.

Syntax

```
b = isspace(s)
```

Description

For each character of string `s`, `isspace(s)` is true if it is a space, a tabulator, a carriage return or a line feed, and false otherwise.

Example

```
isspace('a\tb c\nd')
  0 1 0 1 0 1 0
```

See also

`isletter`, `isdigit`, `ischar`

lower

Convert all uppercase letters to lowercase.

Syntax

```
s2 = lower(s1)
```

Description

`lower(s1)` converts all the uppercase letters of string `s1` to lowercase. Currently, only ASCII letters (without diacritic) are converted.

Example

```
lower('abcABC123')
  abcabc123
```

See also

`upper`, `isletter`

md5

Calculate MD5 digest.

Syntax

```
digest = md5(strb)
digest = md5(fd)
```

Description

`md5(strb)` calculates the MD5 digest of `strb` which represents binary data. `strb` can be a string (only the least-significant byte of each character is considered) or an array of bytes of class `uint8` or `int8`. The result is a string of 32 hexadecimal digits. It is believed to be hard to create the input to get a given digest, or to create two inputs with the same digest.

`md5(fd)` calculates the MD5 digest of the bytes read from file descriptor `fd` until the end of the file. The file is left open.

MD5 digest is an Internet standard described in RFC 1321.

Examples

MD5 of the three characters ’a’, ’b’, and ’c’:

```
md5('abc')
  900150983cd24fb0d6963f7d28e17f72
```

This can be compared to the result of the command tool `md5` found on many unix systems:

```
$ echo -n abc | md5
900150983cd24fb0d6963f7d28e17f72
```

The following statements calculate the digest of the file `'somefile'`:

```
fd = fopen('somefile');
digest = md5(fd);
fclose(fd);
```

See also

`sha1`

setstr

Conversion of an array to a string.

Syntax

```
str = setstr(A)
```

Description

`setstr(A)` converts the elements of array `A` to characters, resulting in a string of the same size. Characters are stored in unsigned 16-bit words.

Example

```
setstr(65:75)
  ABCDEFGHIJK
```

See also

`char`, `uint16`, `logical`, `double`

sha1

Calculate SHA1 digest.

Syntax

```
digest = sha1(strb)
digest = sha1(fd)
```

Description

`sha1(strb)` calculates the SHA1 digest of `strb` which represents binary data. `strb` can be a string (only the least-significant byte of each character is considered) or an array of bytes of class `uint8` or `int8`. The result is a string of 40 hexadecimal digits. It is believed to be hard to create the input to get a given digest, or to create two inputs with the same digest.

`sha1(fd)` calculates the SHA1 digest of the bytes read from file descriptor `fd` until the end of the file. The file is left open.

SHA1 digest is an Internet standard described in RFC 3174.

Example

SHA1 digest of the three characters ’a’, ’b’, and ’c’:

```
sha1('abc')
  a9993e364706816aba3e25717850c26c9cd0d89d
```

See also

`md5`

strcmp

String comparison.

Syntax

```
b = strcmp(s1, s2)
b = strcmp(s1, s2, n)
```

Description

`strcmp(s1, s2)` is true if the strings `s1` and `s2` are equal (i.e. same length and corresponding characters are equal). `strcmp(s1, s2, n)` compares the strings up to the n:th character. Note that this function does not return the same result as the `strcmp` function of the standard C library.

Examples

```
strcmp('abc','abc')
  true
strcmp('abc','def')
  false
strcmp('abc','abd',2)
  true
strcmp('abc','abc',5)
  false
```

See also

`strcmpi`, operator ===, operator ~==, operator ==, `findstr`, `strmatch`

strcmpi

String comparison with ignoring letter case.

Syntax

```
b = strcmpi(s1, s2)
b = strcmpi(s1, s2, n)
```

Description

`strcmpi` compares strings for equality, ignoring letter case. In every other respect, it behaves like `strcmp`.

Examples

```
strcmpi('abc','aBc')
  true
strcmpi('Abc','abd',2)
  true
```

See also

`strcmp`, operator ===, operator ~==, operator ==, `findstr`, `strmatch`

strmatch

String match.

Syntax

```
i = strmatch(str, strMatrix)
i = strmatch(str, strList)
i = strmatch(..., 'exact')
```

Description

`strmatch(str,strMatrix)` compares string `str` with each row of the character matrix `strMatrix`; it returns the index of the first row whose beginning is equal to `str`, or 0 if no match is found. Case is significant.

`strmatch(str,strList)` compares string `str` with each element of list `strList`, which must be strings.

With a third argument, which must be the string `'exact'`, `str` must match the complete row or element of the second argument, not only the beginning.

Examples

```
strmatch('abc',['axyz';'uabc';'abcd';'efgh'])
  3
strmatch('abc',['axyz';'uabc';'abcd';'efgh'],'exact')
  0
strmatch('abc',{'ABC','axyz','abcdefg','ab','abcd'})
  3
```

See also

`strcmp`, `findstr`

strtok

Token search in string.

Syntax

```
(token, remainder) = strtok(str)
(token, remainder) = strtok(str, separators)
```

Description

`strtok(str)` gives the first token in string `str`. A token is defined as a substring delimited by separators or by the beginning or end of the string; by default, separators are spaces, tabulators, carriage returns and line feeds. If no token is found (i.e. if `str` is empty or contains only separator characters), the result is the empty string.

The optional second output is set to what follows immediately the token, including separators. If no token is found, it is the same as `str`.

An optional second input argument contains the separators in a string.

Examples

Strings are displayed with quotes to show clearly the separators.

```
strtok(' ab cde ')
  'ab'
(t, r) = strtok(' ab cde ')
  t =
    'ab'
  r =
    ' cde '
(t, r) = strtok('2, 5, 3')
  t =
    '2'
  r =
    ', 5, 3'
```

See also

`strmatch`, `findstr`, `strtrim`

strtrim

Remove leading and trailing blank characters from a string.

Syntax

```
s2 = strtrim(s1)
```

Description

`strtrim(s1)` removes the leading and trailing blank characters from string s1. Blank characters are spaces (code 32), tabulators (code 9), carriage returns (code 13), line feeds (code 10), and null characters (code 0).

Example

```
double(' \tAB  CD\r\n\0')
  32  9 65 66 32 32 67 68 13 10 0
double(strtrim(' \tAB  CD\n\r\0'))
  65 66 32 32 67 68
```

See also

`deblank`, `strtok`

upper

Convert all lowercase letters to lowercase.

Syntax

```
s2 = upper(s1)
```

Description

`upper(s1)` converts all the lowercase letters of string `s1` to uppercase. Currently, only ASCII letters (without diacritic) are converted.

Example

```
upper('abcABC123')
  ABCABC123
```

See also

`lower`, `isletter`

utf8decode

Decode Unicode characters encoded with UTF-8.

Syntax

```
str = utf8decode(b)
```

Description

`utf8decode(b)` decodes the contents of uint8 or int8 array `b` which represents Unicode characters encoded with UTF-8. Each Unicode character corresponds to one, two, or three bytes of UTF-8 code. The result is a standard character array with a single row. Invalid codes (for example when the beginning of the decoded data does not correspond to a character boundary) are ignored.

See also

`utf8encode`

utf8encode

Encode a string of Unicode characters using UTF-8.

Syntax

```
b = utf8encode(str)
```

Description

`utf8encode(b)` encodes the contents of character array `str` using UTF-8. Each Unicode character in `str` corresponds to one, two, or three bytes of UTF-8 code. The result is an array of unsigned 8-bit integers.

If the input string does not contain Unicode characters, the output is invalid.

Example

```
b = utf8encode(['abc', 200, 2000, 20000])
  b =
    1x10 uint8 array
      97  98  99 195 136 223 144 228 184 160
str = utf8decode(b);
+str
```

```
   1x6 uint16 array
     97    98    99   200  2000 20000
```

See also

`utf8decode`

3.20 List Functions

apply

Function evaluation with arguments in lists.

Syntax

```
 listout = apply(fun, listin)
 listout = apply(fun, listin, nargout)
```

Description

`listout=apply(fun,listin)` evaluates function `fun` with input arguments taken from the elements of list `listin`. Output arguments are grouped in list `listout`. Function `fun` is specified either by its name as a string or by an inline function.

The number of expected output arguments can be specified with an optional third input argument `nargout`. By default, the maximum number of output arguments is requested, up to 256; this limit exists to prevent functions with an unlimited number of output arguments, such as `deal`, from filling memory.

Examples

```
 apply('min', {5, 7})
   {5}
 apply('size',{magic(3)},2)
   {3, 3}
 apply(inline('2*x+3*y','x','y'), {5, 10})
   {40}
```

See also

`map`, `feval`, `inline`, operator @

join

List concatenation.

Syntax

```
list = join(l1, l2, ...)
```

Description

`join(l1,l2,...)` joins elements of lists `l1`, `l2`, etc. to make a larger list.

Examples

```
join({1,'a',2:5}, {4,2}, {{'xxx'}})
  {1,'a',[2,3,4,5],4,2,{'xxx'}}
```

See also

operator `,`, operator `;`, `replist`

islist

Test for a list object.

Syntax

```
b = islist(obj)
```

Description

`islist(obj)` is true if the object `obj` is a list, false otherwise.

Examples

```
islist({1, 2, 'x'})
  true
islist({})
  true
islist([])
  false
ischar('')
  false
```

See also

`isstruct`, `isnumeric`, `ischar`, `islogical`, `isempty`

list2num

Conversion from list to numeric array.

Syntax

```
A = list2num(list)
```

Description

`list2num(list)` takes the elements of `list`, which must be numbers or arrays, and concatenates them on a row (along second dimension) as if they were placed inside brackets and separated with commas. Element sizes must be compatible.

Example

```
list2num({1, 2+3j, 4:6})
  1  2+3j  4  5  6
```

See also

`num2list`, operator `[]`, operator `,`

map

Function evaluation for each element of a list

Syntax

```
(listout1,...) = map(fun, listin1, ...)
```

Description

`map(fun,listin1,...)` evaluates function `fun` successively for each corresponding elements of the remaining arguments, which must be lists or cell arrays. It returns the result(s) of the evaluation as list(s) or cell array(s) with the same size as inputs. Input lists which contain a single element are repeated to match other arguments if necessary. `fun` is the name of a function as a string, a function reference, or an inline function.

Examples

```
map('max', {[2,6,4], [7,-1], 1:100})
  {6, 7, 100}
map(inline('x+10'), {3,7,16})
  {13, 17, 26}
(nr, nc) = map(@size, {1,'abc',[4,7;3,4]})
  nr =
    {1,1,2}
  nc =
    {1,3,2}
s = map(@size, {1,'abc',[4,7;3,4]})
  s =
    {[1,1], [1,3], [2,2]}
map(@disp, {'hello', 'lme'})
  hello
  lme
map(@atan2, {1}, {2,3})
  {0.4636,0.3218}
```

See also

`apply`, `cellfun`, `for`, `inline`, operator @

num2list

Conversion from array to list.

Syntax

```
list = num2list(A)
list = num2list(A, dim)
```

Description

`num2list(A)` creates a list with the elements of non-cell array `A`.

`num2list(A,dim)` cuts array `A` along dimension `dim` and creates a list with the result.

Examples

```
num2list(1:5)
  {1, 2, 3, 4, 5}
num2list([1,2;3,4])
  {1, 2, 3, 4}
num2list([1, 2; 3, 4], 1)
  {[1, 2], [3, 4]}
```

```
num2list([1, 2; 3, 4], 2)
  {[1; 3], [2; 4]}
```

See also

`list2num`, `num2cell`

replist

Replicate a list.

Syntax

```
listout = replist(listin, n)
```

Description

`replist(listin,n)` makes a new list by concatenating `n` copies of list `listin`.

Example

```
replist({1, 'abc'}, 3)
  {1,'abc',1,'abc',1,'abc'}
```

See also

`join`, `repmat`

3.21 Structure Functions

cell2struct

Convert a cell array to a structure array.

Syntax

```
SA = cell2struct(CA, fields)
SA = cell2struct(CA, fields, dim)
```

Description

`cell2struct(CA,fields)` converts a cell array to a structure array. The size of the result is `size(SA)(2:end)`, where `nf` is the number of fields. Field `SA(i1,i2,...).f` of the result contains cell `CA{j,i1,i2,...}`, where `f` is field `field{j}`. Argument `fields` contains the field names as strings.

With a third input argument, `cell2struct(CA,fields,dim)` picks fields of each element along dimension `dim`. The size of the result is the size of `CA` where dimension `dim` is removed.

Examples

```
SA = cell2struct({1, 'ab'; 2, 'cde'}, {'a', 'b'});
SA = cell2struct({1, 2; 'ab', 'cde'}, {'a', 'b'}, 2);
```

See also

`struct2cell`

fieldnames

List of fields of a structure.

Syntax

```
fields = fieldnames(strct)
```

Description

`fieldnames(strct)` returns the field names of structure `strct` as a list of strings.

Example

```
fieldnames(struct('a', 1, 'b', 1:5))
  {'a', 'b'}
```

See also

`struct`, `isfield`, `orderfields`, `rmfield`

getfield

Value of a field in a structure.

Syntax

```
value = getfield(strct, name)
```

Description

`getfield(strct,name)` gets the value of field `name` in structure `strct`. It is an error if the field does not exist. `getfield(s,'f')` gives the same value as `s.f`. `getfield` is especially useful when the field name is not fixed, but is stored in a variable or is the result of an expression.

See also

operator `.`, `struct`, `setfield`, `rmfield`

isfield

Test for the existence of a field in a structure.

Syntax

```
b = isfield(strct, name)
```

Description

`isfield(strct, name)` is true if the structure `strct` has a field whose name is the string name, false otherwise.

Examples

```
isfield(struct('a', 1:3, 'x', 'abc'), 'x')
  true
isfield(struct('a', 1:3, 'x', 'abc'), 'X')
  false
```

See also

`isstruct`, `struct`

isstruct

Test for a structure object.

Syntax

```
b = isstruct(obj)
```

Description

`isstruct(obj)` is true if its argument `obj` is a structure or structure array, false otherwise.

Examples

```
isstruct(struct('a', 123))
  true
isstruct({1, 2, 'x'})
  false
a.f = 3;
isstruct(a)
  true
```

See also

`struct`, `isfield`, `isa`, `islist`, `ischar`, `isobject`, `islogical`

orderfields

Reorders the fields of a structure.

Syntax

```
strctout = orderfields(strctin)
strctout = orderfields(strctin, structref)
strctout = orderfields(strctin, names)
strctout = orderfields(strctin, perm)
(strctout, perm) = orderfields(...)
```

Description

With a single input argument, `orderfields(strctin)` reorders structure fields by sorting them by field names.

With two input arguments, `orderfields` reorders the fields of the first argument after the second argument. Second argument can be a permutation vector containing integers from 1 to `length(strctin)`, another structure with the same field names, or a list of names. In the last cases, all the fields of the structure must be present in the second argument.

The (first) output argument is a structure with the same fields and the same value as the first input argument; the only difference is the field order. An optional second output argument is set to the permutation vector.

Examples

```
s = struct('a',123,'c',1:3,'b','123')
  s =
    a: 123
    c: real 1x3
    b: 'abcde'
(t, p) = orderfields(s)
  t =
    a: 123
    b: 'abcde'
    c: real 1x3
  p =
    1
    3
    2
t = orderfields(s, {'c', 'b', 'a'})
  t =
    c: real 1x3
    b: 'abcde'
    a: 123
```

See also

`struct`, `fieldnames`

rmfield

Deletion of a field in a structure.

Syntax

```
strctout = rmfield(strctin, name)
```

Description

`strctout=rmfield(strctin,name)` makes a structure `strctout` with the same fields as `strctin`, except for field named name which is removed. If field name does not exist, `strctout` is the same as `strctin`.

Example

```
x = rmfield(struct('a', 1:3, 'b', 'abc'), 'a');
fieldnames(x)
  b
```

See also

`struct`, `setfield`, `getfield`, `orderfields`

setfield

Assignment to a field in a structure.

Syntax

```
strctout = setfield(strctin, name, value)
```

Description

`strctout=setfield(strctin,name,value)` makes a structure `strctout` with the same fields as `strctin`, except that field named `name` is added if it does not exist yet and is set to `value`. `s=setfield(s,'f',v)` has the same effect as `s.f=v`; `s=setfield(s,str,v)` has the same effect as `s.(str)=v`.

See also

operator `.`, `struct`, `getfield`, `rmfield`

struct

Creation of a structure

Syntax

```
strct = struct(fieldname1, value1, fieldname2, value2, ...)
```

Description

`struct` builds a new structure. Input arguments are used by pairs to create the fields; for each pair, the first argument is the field name, provided as a string, and the second one is the field value.

Example

```
x = struct('a', 1, 'b', 2:5);
x.a
  1
x.b
  2 3 4 5
```

See also

`structarray`, `isstruct`, `isfield`, `rmfield`, `fieldnames`, operator {}

struct2cell

Convert a structure array to a cell array.

Syntax

```
CA = struct2cell(SA)
```

Description

`struct2cell(SA)` converts a structure or structure array to a cell array. The size of the result is `[nf,size(SA)]`, where `nf` is the number of fields. Cell `CA{j,i1,i2,...}` of the result contains field `SA(i1,i2,...).f`, where `f` is the j:th field.

Example

```
SA = cell2struct({1, 'ab'; 2, 'cde'}, {'a', 'b'});
CA = struct2cell(SA);
```

See also

`cell2struct`

structarray

Create a structure array.

Syntax

```
SA = structarray(fieldname1, A1, fieldname2, A2, ...)
```

Description

`structarray` builds a new structure array. Input arguments are used by pairs to create the fields; for each pair, the first argument is the field name, provided as a string, and the second one is the field values as a cell array. All cell arrays must have the same size; the resulting structure array has the same size.

Example

```
SA = structarray('a', {1,2;3,4}, 'b', {'a', 1:3; 'def', true});
```

See also

`struct`, `cell2struct`

3.22 Object Functions

class

Object creation.

Syntax

```
object = class(strct, 'classname')
object = class(strct, 'classname', parent1, ...)
str = class(object)
```

Description

`class(strct,'classname')` makes an object of the specified class with the data of structure `strct`. Object fields can be accessed only from methods of that class, i.e. functions whose name is `classname::methodname`. Objects must be created by the class constructor `classname::classname`.

`class(strct,'classname',parent1,...)` makes an object of the specified class which inherits fields and methods from one or several other object(s) `parent1`, ... Parent objects are inserted as additional fields in the object, with the same name as the class. Fields of parent objects cannot be directly accessed by the new object's methods, only by the parent's methods.

`class(object)` gives the class of `object` as a string. The table below gives the name of native types.

Class	**Native type**
`double`	real, complex, or logical scalar or array
`char`	character or character array
`list`	list or structure
`inline`	inline function
`funref`	function reference

Examples

```
o1 = class(struct('fld1', 1, 'fld2', rand(4)), 'c1');
o2 = class(struct('fld3', 'abc'), 'c2', o1);
class(o2)
  c2
```

See also

`map`, `isa`, `isobject`, `methods`

isa

Test for an object of a given class.

Syntax

```
b = isa(object,'classname')
```

Description

`isa(object,'classname')` returns true of `object` is an object of class `class`, directly or by inheritance.

Example

```
isa(pi,'double')
  true
```

See also

`class`, `isobject`, `methods`

isobject

Test for an object.

Syntax

```
b = isobject(a)
```

Description

`object(a)` returns true if a is an object created with `class`.

See also

`class`, `isa`, `isstruct`

methods

List of methods for a class.

Syntax

```
methods classname
list = methods('classname')
```

Description

`methods classname` displays the list of methods defined for class `classname`. Inherited methods and private methods are ignored. With an output argument, `methods` gives produces a list of strings.

See also

`class`, `info`

3.23 Logical Functions

all

Check whether all the elements are true.

Syntax

```
v = all(A)
v = all(A,dim)
b = all(v)
```

Description

`all(A)` performs a logical AND on the elements of the columns of array `A`, or the elements of a vector. If a second argument `dim` is provided, the operation is performed along that dimension.

`all` can be omitted if its result is used by `if` or `while`, because these statements consider an array to be true if all its elements are nonzero.

Examples

```
all([1,2,3] == 2)
  false
all([1,2,3] > 0)
  true
```

See also

any, operator &, `bitall`

any

Check whether any element is true.

Syntax

```
v = any(A)
v = any(A,dim)
b = any(v)
```

Description

`any(A)` performs a logical OR on the elements of the columns of array `A`, or the elements of a vector. If a second argument `dim` is provided, the operation is performed along that dimension.

Examples

```
any([1,2,3] == 2)
  true
any([1,2,3] > 5)
  false
```

See also

`all`, operator |, `bitany`

bitall

Check whether all the corresponding bits are true.

Syntax

```
v = bitall(A)
v = bitall(A,dim)
b = bitall(v)
```

Description

`bitall(A)` performs a bitwise AND on the elements of the columns of array `A`, or the elements of a vector. If a second argument `dim` is provided, the operation is performed along that dimension. `A` can be a double or an integer array. For double arrays, `bitall` uses the 32 least-significant bits.

Examples

```
bitall([5, 3])
  1
bitall([7uint8, 6uint8; 3uint8, 6uint8], 2)
  2x1 uint8 array
    6
    2
```

See also

`bitany`, `all`, `bitand`

bitand

Bitwise AND.

Syntax

```
c = bitand(a, b)
```

Description

Each bit of the result is the binary AND of the corresponding bits of the inputs.

The inputs can be scalar, arrays of the same size, or a scalar and an array. If the input arguments are of type double, so is the result, and the operation is performed on 32 bits.

Examples

```
bitand(1,3)
  1
bitand(1:6,1)
  1 0 1 0 1 0
bitand(7uint8, 1234int16)
  2int16
```

See also

`bitor`, `bitxor`, `bitall`, `bitget`

bitany

Check whether any of the corresponding bits is true.

Syntax

```
v = bitany(A)
v = bitany(A,dim)
b = bitany(v)
```

Description

`bitany(A)` performs a bitwise OR on the elements of the columns of array `A`, or the elements of a vector. If a second argument `dim` is provided, the operation is performed along that dimension. `A` can be a double or an integer array. For double arrays, `bitany` uses the 32 least-significant bits.

Examples

```
bitany([5, 3])
  7
bitany([0uint8, 6uint8; 3uint8, 6uint8], 2)
  2x1 uint8 array
    6
    7
```

See also

`bitall`, any, `bitor`

bitcmp

Bit complement (bitwise NOT).

Syntax

```
b = bitcmp(i)
b = bitcmp(a, n)
```

Description

`bitcmp(i)` gives the 1-complement (bitwise NOT) of the integer `i`.

`bitcmp(a,n)`, where `a` is an integer or a double, gives the 1-complement of the `n` least-significant bits. The result has the same type as `a`.

The inputs can be scalar, arrays of the same size, or a scalar and an array. If a is of type double, so is the result, and the operation is performed on at most 32 bits.

Examples

```
bitcmp(1,4)
  14
bitcmp(0, 1:8)
  1 3 7 15 31 63 127 255
bitcmp([0uint8, 1uint8, 255uint8])
  1x3 uint8 array
  255 254   0
```

See also

`bitxor`, operator ~

bitget

Bit extraction.

Syntax

```
b = bitget(a, n)
```

Description

`bitget(a, n)` gives the `n`:th bit of integer `a`. `a` can be an integer or a double. The result has the same type as `a`. `n=1` corresponds to the least significant bit.

The inputs can be scalar, arrays of the same size, or a scalar and an array. If a is of type double, so is the result, and `n` is limited to 32.

Examples

```
bitget(123,5)
  1
bitget(7, 1:8)
  1 1 1 0 0 0 0 0
bitget(5uint8, 2)
  0uint8
```

See also

`bitset`, `bitand`, `bitshift`

bitor

Bitwise OR.

Syntax

```
c = bitor(a, b)
```

Description

The input arguments are converted to 32-bit unsigned integers; each bit of the result is the binary OR of the corresponding bits of the inputs.

The inputs can be scalar, arrays of the same size, or a scalar and an array. If the input arguments are of type double, so is the result, and the operation is performed on 32 bits.

Examples

```
bitor(1,2)
  3
bitor(1:6,1)
  1 3 3 5 5 7
bitor(7uint8, 1234int16)
  1239int16
```

See also

`bitand`, `bitxor`, `bitany`, `bitget`

bitset

Bit assignment.

Syntax

```
b = bitset(a, n)
b = bitset(a, n, v)
```

Description

`bitset(a,n)` sets the n:th bit of integer a to 1. a can be an integer or a double. The result has the same type as a. n=1 corresponds to the least significant bit. With 3 input arguments, `bitset(a,n,v)` sets the bit to 1 if v is nonzero, or clears it if v is zero.

The inputs can be scalar, arrays of the same size, or a mix of them. If a is of type double, so is the result, and n is limited to 32.

Examples

```
bitset(123,10)
  635
bitset(123, 1, 0)
  122
bitset(7uint8, 1:8)
  1x8 uint8 array
    7   7   7  15  23  39  71 135
```

See also

`bitget`, `bitand`, `bitor`, `bitxor`, `bitshift`

bitshift

Bit shift.

Syntax

```
b = bitshift(a, shift)

b = bitshift(a, shift, n)
```

Description

The first input argument is converted to a 32-bit unsigned integer, and shifted by `shift` bits, to the left if `shift` is positive or to the right if it is negative. With a third argument n, only n bits are retained.

The inputs can be scalar, arrays of the same size, or a mix of both.

Examples

```
 bitshift(1,3)
   8
 bitshift(8, -2:2)
   2 4 8 16 32
 bitshift(15, 0:3, 4)
   15 14 12 8
```

See also

`bitget`

bitxor

Bitwise exclusive OR.

Syntax

```
 c = bitxor(a, b)
```

Description

The input arguments are converted to 32-bit unsigned integers; each bit of the result is the binary exclusive OR of the corresponding bits of the inputs.

The inputs can be scalar, arrays of the same size, or a scalar and an array.

Examples

```
 bitxor(1,3)
   2
 bitxor(1:6,1)
   0 3 2 5 4 7
 bitxor(7uint8, 1234int16)
   1237int16
```

See also

`bitcmp`, `bitand`, `bitor`, `bitget`

false

Boolean constant *false*.

Syntax

```
b = false
B = false(n)
B = false(n1, n2, ...)
B = false([n1, n2, ...])
```

Description

The boolean constant false can be used to set the value of a variable. It is equivalent to `logical(0)`. The constant 0 is equivalent in many cases; indices (to get or set the elements of an array) are an important exception.

With input arguments, `false` builds a logical array whose elements are false. The size of the array is specified by one integer for a square matrix, or several integers (either as separate arguments or in a vector) for an array of any size.

Examples

```
false
  false
islogical(false)
  true
false(2,3)
  F F F
  F F F
```

See also

`true`, `logical`, `zeros`

graycode

Conversion to Gray code.

Syntax

```
g = graycode(n)
```

Description

`graycode(n)` converts the integer number n to Gray code. The argument n can be an integer number of class double (converted to an unsigned integer) or any integer type. If it is an array, conversion is performed on each element. The result has the same type and size as the input.

Gray code is an encoding which maps each integer of `s` bits to another integer of `s` bits, such that two consecutive codes (i.e. `graycode(n)` and `graycode(n+1)` for any `n`) have only one bit which differs.

Example

```
graycode(0:7)
  0 1 3 2 6 7 5 4
```

See also

`igraycode`

igraycode

Conversion from Gray code.

Syntax

```
n = igraycode(g)
```

Description

`igraycode(n)` converts the Gray code `g` to the corresponding integer. It is the inverse of `graycode`. The argument `n` can be an integer number of class double (converted to an unsigned integer) or any integer type. If it is an array, conversion is performed on each element. The result has the same type and size as the input.

Example

```
igraycode(graycode(0:7))
  0 1 2 3 4 5 6 7
```

See also

`graycode`

islogical

Test for a boolean object.

Syntax

```
b = islogical(obj)
```

Description

`islogical(obj)` is true if `obj` is a logical value, and false otherwise. The result is always a scalar, even if `obj` is an array. Logical values are obtained with comparison operators, logical operators, test functions, and the function `logical`.

Examples

```
islogical(eye(10))
  false
islogical(~eye(10))
  true
```

See also

`logical`, `isnumeric`, `isinteger`, `ischar`

logical

Transform a number into a boolean.

Syntax

```
B = logical(A)
```

Description

`logical(x)` converts array or number `A` to logical (boolean) type. All nonzero elements of `A` are converted to true, and zero elements to false.

Logical values are stored as `0` for false or `1` for true in unsigned 8-bit integers. They differ from the `uint8` type when they are used to select the elements of an array or list.

Examples

```
a=1:3; a([1,0,1])
Index out of range
a=1:3; a(logical([1,0,1]))
  1 3
```

See also

islogical, uint8, double, char, setstr, operator ()

true

Boolean constant *true*.

Syntax

```
b = true
B = true(n)
B = true(n1, n2, ...)
B = true([n1, n2, ...])
```

Description

The boolean constant `true` can be used to set the value of a variable. It is equivalent to `logical(1)`. The constant `1` is equivalent in many cases; indices (to get or set the elements of an array) are an important exception.

With input arguments, `true` builds a logical array whose elements are true. The size of the array is specified by one integer for a square matrix, or several integers (either as separate arguments or in a vector) for an array of any size.

Examples

```
true
  true
islogical(true)
  true
true(2)
  T T
  T T
```

See also

false, logical, ones

xor

Exclusive or.

Syntax

```
b3 = xor(b1,b2)
```

Description

`xor(b1,b2)` performs the exclusive or operation between the corresponding elements of `b1` and `b2`. `b1` and `b2` must have the same size or one of them must be a scalar.

Examples

```
xor([false false true true],[false true false true])
  F T T F
xor(pi,8)
  false
```

See also

operator &, operator |

3.24 Dynamical System Functions

This section describes functions related to linear time-invariant dynamical systems.

c2dm

Continuous-to-discrete-time conversion.

Syntax

```
(numd,dend) = c2dm(numc,denc,Ts)
dend = c2dm(numc,denc,Ts)
(numd,dend) = c2dm(numc,denc,Ts,method)
dend = c2dm(numc,denc,Ts,method)
(Ad,Bd,Cd,Dd) = c2dm(Ac,Bc,Cc,Dc,Ts,method)
```

Description

`(numd,dend) = c2dm(numc,denc,Ts)` converts the continuous-time transfer function `numc/denc` to a discrete-time transfer function `numd/dend` with sampling period `Ts`. The continuous-time transfer function is given by two polynomials in s, and the discrete-time transfer function is given by two polynomials in z, all as vectors of coefficients with highest powers first.

`c2dm(numc,denc,Ts,method)` uses the specified conversion method. `method` is one of

`'zoh'` or `'z'`	zero-order hold (default)
`'foh'` or `'f'`	first-order hold
`'tustin'` or `'t'`	Tustin (bilinear transformation)
`'matched'` or `'m'`	Matched zeros, poles and gain

The input and output arguments `numc`, `denc`, `numd`, and `dend` can also be matrices; in that case, the conversion is applied separately on each row with the same sampling period `Ts`.

`c2dm(Ac,Bc,Cc,Dc,Ts,method)` performs the conversion from continuous-time state-space model (Ac,Bc,Cc,Dc) to discrete-time state-space model (Ad,Bd,Cd,Dd), defined by

$$\begin{aligned}\frac{\mathrm{d}x}{\mathrm{d}t}(t) &= A_c x(t) + B_c u(t)\\ y(t) &= C_c x(t) + D_c u(t)\end{aligned}$$

and

$$\begin{aligned}x(k+1) &= A_d x(k) + B_d u(k)\\ y(k) &= C_d x(k) + D_d u(k)\end{aligned}$$

Method `'matched'` is not supported for state-space models.

Examples

```
(numd, dend) = c2dm(1, [1, 1], 0.1)
  numd =
    0.0952
  dend =
    1 -0.9048
(numd, dend) = c2dm(1, [1, 1], 0.1, 'foh')
  numd =
    0.0484
  dend =
    1 -0.9048
(numd, dend) = c2dm(1, [1, 1], 0.1, 'tustin')
  numd =
    0.0476 0.0476
  dend =
    1 -0.9048
```

See also

`d2cm`

d2cm

Discrete-to-continuous-time conversion.

Syntax

```
(numc,denc) = d2cm(numd,dend,Ts)
denc = d2cm(numd,dend,Ts)
(numc,denc) = d2cm(numd,dend,Ts,method)
denc = d2cm(numd,dend,Ts,method)
```

Description

`(numc,denc) = d2cm(numd,dend,Ts,method)` converts the discrete-time transfer function numd/dend with sampling period Ts to a continuous-time transfer function numc/denc. The continuous-time transfer function is given by two polynomials in s, and the discrete-time transfer function is given by two polynomials in z, all as vectors of coefficients with highest powers first.

Method is

`tustin` or `'t'`	Tustin (bilinear transformation) (default)

The input and output arguments numc, denc, numd, and dend can also be matrices; in that case, the conversion is applied separately on each row with the same sampling period Ts.

`d2cm(Ad,Bd,Cd,Dd,Ts,method)` performs the conversion from discrete-time state-space model (Ad,Bd,Cd,Dd) to continuous-time state-space model (Ac,Bc,Cc,Dc), defined by

$$\begin{aligned} x(k+1) &= A_d x(k) + B_d u(k) \\ y(k) &= C_d x(k) + D_d u(k) \end{aligned}$$

and

$$\begin{aligned} \frac{\mathrm{d}x}{\mathrm{d}t}(t) &= A_c x(t) + B_c u(t) \\ y(t) &= C_c x(t) + D_c u(t) \end{aligned}$$

Example

```
(numd, dend) = c2dm(1, [1, 1], 5, 't')
  numd =
    0.7143 0.7143
  dend =
    1 0.4286
(numc, denc) = d2cm(numd, dend)
  numc =
    -3.8858e-17 1
  denc =
    1 1
```

See also

c2dm

dmargin

Robustness margins of a discrete-time system.

Syntax

```
(gm,psi,wc,wx) = dmargin(num,den,Ts)
(gm,psi,wc,wx) = dmargin(num,den)
```

Description

The open-loop discrete-time transfer function is given by the two polynomials num and den, with sampling period Ts (default value is 1). If the closed-loop system (with negative feedback) is unstable, all output arguments are set to an empty matrix. Otherwise, dmargin calculates the gain margins gm, which give the interval of gain for which the closed-loop system remains stable; the phase margin psi, always positive if it exists, which defines the symmetric range of phases which can be added to the open-loop system while keeping the closed-loop system stable; the critical frequency associated to the gain margins, where the open-loop frequency response intersects the real axis around -1; and the cross-over frequency associated to the phase margin, where the open-loop frequency response has a unit magnitude. If the Nyquist diagram does not cross the unit circle, psi and wx are empty.

Examples

Stable closed-loop, Nyquist inside unit circle:

```
(gm,psi,wc,wx) = dmargin(0.005,poly([0.9,0.9]))
  gm = [-2, 38]
  psi = []
  wc = [0, 0.4510]
  wx = []
```

Stable closed-loop, Nyquist crosses unit circle:

```
(gm,psi,wc,wx) = dmargin(0.05,poly([0.9,0.9]))
  gm = [-0.2, 3.8]
  psi = 0.7105
  wc = [0, 0.4510]
  wx = 0.2112
```

Unstable closed-loop:

```
(gm,psi,wc,wx) = dmargin(1,poly([0.9,0.9]))
  gm = []
  psi = []
  wc = []
  wx = []
```

Caveats

Contrary to many functions, `dmargin` cannot be used with several transfer functions simultaneously, because not all of them may correspond simultaneously to either stable or unstable closed-loop systems.

See also

`margin`

margin

Robustness margins of a continuous-time system.

Syntax

```
(gm,psi,wc,wx) = margin(num,den)
```

Description

The open-loop continuous-time transfer function is given by the two polynomials `num` and `den`. If the closed-loop system (with negative feedback) is unstable, all output arguments are set to an empty matrix. Otherwise, `margin` calculates the gain margins `gm`, which give the interval of gain for which the closed-loop system remains stable; the phase margin psi, always positive if it exists, which defines the symmetric range of phases which can be added to the open-loop system while keeping the closed-loop system stable; the critical frequency associated to the gain margins, where the open-loop frequency response intersects the real axis around -1; and the cross-over frequency associated to the phase margin, where the open-loop frequency response has a unit magnitude. If the Nyquist diagram does not cross the unit circle, psi and wx are empty.

Examples

Stable closed-loop, Nyquist inside unit circle:

```
(gm,psi,wc,wx) = margin(0.5,poly([-1,-1,-1]))
  gm = [-2, 16]
  psi = []
  wc = [0, 1.7321]
  wx = []
```

Stable closed-loop, Nyquist crosses unit circle:

```
(gm,psi,wc,wx) = margin(4,poly([-1,-1,-1]))
  gm = [-0.25 2]
  psi = 0.4737
  wc = [0, 1.7321]
  wx = 1.2328
```

Unstable closed-loop:

```
(gm,psi,wc,wx) = margin(10,poly([-1,-1,-1]))
  gm = []
  psi = []
  wc = []
  wx = []
```

Caveats

Contrary to many functions, margin cannot be used with several transfer functions simultaneously, because not all of them may correspond simultaneously to either stable or unstable closed-loop systems.

See also

dmargin

ss2tf

Conversion from state space to transfer function.

Syntax

```
(num,den) = ss2tf(A,B,C,D)
den = ss2tf(A,B,C,D)
(num,den) = ss2tf(A,B,C,D,iu)
den = ss2tf(A,B,C,D,iu)
```

Description

A continuous-time linear time-invariant system can be represented by the state-space model

$$\begin{aligned}\frac{\mathrm{d}x}{\mathrm{d}t}(t) &= Ax(t)+Bu(t)\\ y(t) &= Cx(t)+Du(t)\end{aligned}$$

where $x(t)$ is the state, $u(t)$ the input, $y(t)$ the output, and $ABCD$ four constant matrices which characterize the model. If it is a single-input single-output system, it can also be represented by its transfer function *num/den*. `(num,den) = ss2tf(A,B,C,D)` converts the model from state space to transfer function. If the state-space model has multiple outputs, `num` is a matrix whose lines correspond to each output (the denominator is the same for all outputs). If the state-space model has multiple inputs, a fifth input argument is required and specifies which one to consider.

For a sampled-time model, exactly the same function can be used. The derivative is replaced by a forward shift, and the variable s of the Laplace transform is replaced by the variable z of the z transform. But as long as coefficients are concerned, the conversion is the same.

The degree of the denominator is equal to the number of states, i.e. the size of A. The degree of the numerator is equal to the number of states if D is not null, and one less if D is null.

Example

```
(num, den) = ss2tf(-1, 1, 1, 0)
  num =
    1
  den =
    1 1
```

See also

`tf2ss`

tf2ss

Conversion from transfer function to state space.

Syntax

```
(A,B,C,D) = tf2ss(num,den)
```

Description

`tf2ss(num,den)` returns the state-space representation of the transfer function num/den, which is given as two polynomials. The transfer function must be causal, i.e. `num` must not have more columns than den. Systems with several outputs are specified by a `num` having one row per output; the denominator den must be the same for all the outputs.

`tf2ss` applies to continuous-time systems (Laplace transform) as well as to discrete-time systems (z transform or delta transform).

Example

```
(A,B,C,D) = tf2ss([2,5],[2,3,8])
  A =
    -1.5 -4
    1 0
  B =
    1
    0
  C =
    1 2.5
  D =
    0
```

See also

`ss2tf`

3.25 Input/Output Functions

bwrite

Store data in an array of bytes.

Syntax

```
s = bwrite(data)
s = bwrite(data, precision)
```

Description

`bwrite(data)` stores the contents of the matrix `data` into an array of class `uint8`. The second parameter is the precision, whose meaning is the same as for `fread`. Its default value is 'uint8'.

Examples

```
bwrite(12345, 'uint32;l')
  1x4 uint8 array
    57  48   0   0
bwrite(12345, 'uint32;b')
  1x4 uint8 array
     0   0  48  57
```

See also

swrite, sread, fwrite, sprintf

clc

Clear the text window or panel.

Syntax

```
clc
clc(fd)
```

Description

`clc` (clear console) clears the contents of the command-line window or panel.

`clc(fd)` clears the contents of the window or panel associated with file descriptor `fd`.

disp

Simple display on the standard output.

Syntax

```
disp(obj)
```

Description

`disp(obj)` displays the object `obj`. Command `format` may be used to control how numbers are formatted.

Example

```
disp('hello')
hello
```

See also

`format`, `fprintf`

fclose

Close a file.

Syntax

```
fclose(fd)
fclose('all')
```

Description

`fclose(fd)` closes the file descriptor `fd` which was obtained with functions such as `fopen`. Then `fd` should not be used anymore. `fclose('all')` closes all the open file descriptors.

feof

Check end-of-file status.

Syntax

```
b = feof(fd)
```

Description

`feof(fd)` is false if more data can be read from file descriptor `fd`, and true if the end of the file has been reached.

Example

Count the number of lines and characters in a file (`fopen` and `fclose` are not available in all LME applications):

```
fd = fopen('data.txt');
lines = 0;
characters = 0;
while ~feof(fd)
  str = fgets(fd);
  lines = lines + 1;
  characters = characters + length(str);
end
fclose(fd);
```

See also

`ftell`

fflush

Flush the input and output buffers.

Syntax

```
fflush(fd)
```

Description

`fflush(fd)` discards all the data in the input buffer and forces data out of the output buffer, when the device and their driver permits it. `fflush` can be useful to recover from errors.

fgetl

Reading of a single line.

Syntax

```
line = fgetl(fd)
line = fgetl(fd, n)
```

Description

A single line (of at most `n` characters) is read from a text file. The end of line character is discarded. Upon end of file, `fgetl` gives an empty string.

See also

`fgets`, `fscanf`

fgets

Reading of a single line.

Syntax

```
line = fgets(fd)
line = fgets(fd, n)
```

Description

A single line (of at most `n` characters) is read from a text file. Unless the end of file is encountered before, the end of line (always a single line feed) is preserved. Upon end of file, `fgets` gives an empty string.

See also

`fgetl`, `fscanf`

format

Default output format.

Syntax

```
format
format short
format short e
format short eng
format short g
format long
format long e
format long eng
format long g
format int
format int d
format int u
format int x
format int o
format int b
format bank
format ’+’
format i
format j
format loose
format compact
```

Description

`format` changes the format used by command `disp` and for output produced with expressions which do not end with a semicolon. The following arguments are recognized:

Arguments	**Meaning**
(none)	fixed format with 0 or 4 digits, loose spacing
`short`	fixed format with 0 or 4 digits
`short e`	exponential format with 4 digits
`short eng`	engineering format with 4 digits
`short g`	general format with up to 4 digits
`long`	fixed format with 0 or 15 digits
`long e`	exponential format with 15 digits
`long eng`	engineering format with 15 digits
`long g`	general format with up to 15 digits
`int`	signed decimal integer
`int d`	signed decimal integer
`int u`	unsigned decimal integer
`int x`	hexadecimal integer
`int o`	octal integer
`int b`	binary integer
`bank`	fixed format with 2 digits (for currencies)
`+`	'+', '-' or 'I' for nonzero, space for zero
`i`	symbol `i` to represent the imaginary unit
`j`	symbol `j` to represent the imaginary unit
`loose`	empty lines to improve readability
`compact`	no empty line

Format for numbers, for imaginary unit symbol and for spacing is set separately. Format `'+'` displays compactly numeric and boolean arrays: positive numbers and complex numbers with a positive real part are displayed as `+`, negative numbers or complex numbers with a negative real part as `-`, pure imaginary nonzero numbers as `I`, and zeros as spaces. The default format is `format short g`, `format j`, and `format compact`.

See also

`disp`, `fprintf`

fprintf

Formatted output.

Syntax

```
n = fprintf(fd,format,a,b,...)
n = fprintf(format,a,b,...)
```

Description

`fprintf(format,a,b,...)` converts its arguments to a string and writes it to the standard output. `fprintf(fd,format,a,b,...)` specifies the output file descriptor. See `sprintf` for a description of the conversion process.

Example

```
fprintf('%d %.2f %.3E %g\n',1:3,pi)
1 2.00 3.000E0 3.1416
  22
```

Caveat

Same limitations as `sprintf`

See also

`sprintf`, `fwrite`

fread

Raw input.

Syntax

```
(a, count) = fread(fd)
(a, count) = fread(fd, size)
(a, count) = fread(fd, size, precision)
```

Description

`fread(fd)` reads signed bytes from the file descriptor `fd` until it reaches the end of file. It returns a column vector whose elements are signed bytes (between -128 and 127), and optionally in the second output argument the number of bytes it has read.

`fread(fd,size)` reads the number of bytes specified by `size`. If `size` is a scalar, that many bytes are read and result in a column vector. If `size` is a vector of two elements `[m,n]`, `m*n` elements are read row by row and stored in an m-by-n matrix. If the end of the file is reached before the specified number of elements have been read, the number of rows is reduced without throwing an error. The optional second output argument always gives the number of elements in the result.

With a third argument, `fread(fd, size, precision)` reads integer words of 1, 2, or 4 bytes, or IEEE floating-point numbers of 4 bytes (single precision) or 8 bytes (double precision). The meaning of the string `precision` is described in the table below.

precision	**meaning**
`int8`	signed 8-bit integer ($-128 \le x \le 127$)
`char`	signed 8-bit integer ($-128 \le x \le 127$)
`int16`	signed 16-bit integer ($-32768 \le x \le 32767$)
`int32`	signed 32-bit integer ($-2147483648 \le x \le 2147483647$)
`int64`	signed 64-bit integer ($-9.223372e18 \le x \le 9.223372e18$)
`uint8`	unsigned 8-bit integer ($0 \le x \le 255$)
`uchar`	unsigned 8-bit integer ($0 \le x \le 255$)
`uint16`	unsigned 16-bit integer ($0 \le x \le 65535$)
`uint32`	unsigned 32-bit integer ($0 \le x \le 4294967295$)
`uint64`	unsigned 64-bit integer ($0 \le x \le 18.446744e18$)
`single`	32-bit IEEE floating-point
`double`	64-bit IEEE floating-point

By default, multibyte words are encoded with the least significant byte first (little endian). The characters `';b'` can be appended to specify that they are encoded with the most significant byte first (big endian) (for symmetry, `';l'` is accepted and ignored).

By default, the output is a double array. To get an output which has the same type as what is specified by `precision`, the character `*` can be inserted at the beginning. For instance `'*uint8'` reads bytes and stores them in an array of class `uint8`, `'*int32;b'` reads signed 32-bit words and stores them in an array of class `int32` after performing byte swapping if necessary, and `'*char'` reads bytes and stores them in a character row vector (i.e. a plain string).

See also

fwrite, sread

fscanf

Reading of formatted numbers.

Syntax

```
r = fscanf(fd, format)
(r, count) = fscanf(fd, format)
```

Description

A single line is read from a text file, and numbers, characters and strings are decoded according to the format string. The format string follows the same rules as sscanf.

The optional second output argument is set to the number of elements decoded successfully (may be different than the length of the first argument if decoding strings).

Example

Read a number from a file (fopen and fclose are not available in all LME applications):

```
fd = fopen('test.txt', 'rt');
fscanf(fd, '%f')
  2.3
fclose(fd);
```

See also

sscanf

fseek

Change the current read or write position in a file.

Syntax

```
status = fseek(fd, position)
status = fseek(fd, position, mode)
```

Description

`fseek(fd,position,mode)` changes the position in an open file where the next input/output commands will read or write data. The first argument `fd` is the file descriptor returned by `fopen` or similar functions (`fopen` is not available in all LME applications). The second argument is the new position. The third argument `mode` specifies how the position is used:

b	absolute position from the beginning of the file
c	relative position from the current position
e	offset from the end of the file (must be ≤ 0)

The default value is `'b'`. Only the first character is checked, so `'beginning'` is a valid alternative for `'b'`. `fseek` returns 0 if successful or -1 if the position is outside the limits of the file contents.

See also

`ftell`

ftell

Get the current read or write position in a file.

Syntax

```
position = ftell(fd)
```

Description

`ftell(fd)` gives the current file position associated with file descriptor `fd`. The file position is the offset (with respect to the beginning of the file) at which the next input function will read or the next output function will write. The offset is expressed in bytes. With text files, `ftell` may not always correspond to the number of characters read or written.

See also

`fseek`, `feof`

fwrite

Raw output.

Syntax

```
count = fwrite(fd, data)
count = fwrite(fd, data, precision)
```

Description

`fwrite(fd, data)` writes the contents of the matrix `data` to the output referenced by the file descriptor `fd`. The third parameter is the precision, whose meaning is the same as for `fread`. Its default value is `'uint8'`.

See also

`fread`, `swrite`, `bwrite`

redirect

Redirect or copy standard output or error to another file descriptor.

Syntax

```
redirect(fd, fdTarget)
redirect(fd, fdTarget, copy)
redirect(fd)
R = redirect(fd)
redirect
R = redirect
```

Description

`redirect(fd,fdTarget)` redirects output from file descriptor `fd` to `fdTarget`. `fd` must be 1 for standard output or 2 for standard error. If `fdTarget==fd`, the normal behavior is restored.

`redirect(fd,fdTarget,copy)` copies output to both `fd` and `fdTarget` if `copy` is true, instead of redirecting it only to `fdTarget`. If `copy` is false, the result is the same as with two input arguments.

With zero or one input argument and without output argument, `redirect` displays the current redirection for the specified file descriptor (1 or 2) or for both of them. Note that the redirection itself may alter where the result is displayed.

With an output argument, `redirect` returns a 1-by-2 row vector if the file descriptor is specified, or a 2-by-2 matrix otherwise. The first column contains the target file descriptor and the second column, 1 for copy mode and 0 for pure redirection mode.

Examples

Create a new file `diary.txt` and copy to it both standard output and error:

```
fd = fopen('diary.txt', 'w');
redirect(1, fd, true);
redirect(2, fd, true);
```

Stop copying standard output and error and close file:

```
redirect(1, 1);
redirect(2, 2);
fclose(fd);
```

Redirect standard error to standard output and get the redirection state:

```
redirect(2, 1)
redirect
  stdout (fd=1) -> fd=1
  stderr (fd=2) -> fd=1
redirect(2)
  stderr (fd=2) -> fd=1
R = redirect
  R =
    1 0
    1 0
R = redirect(2)
  R =
    1 0
```

sprintf

Formatted conversion of objects into a string.

Syntax

```
s = sprintf(format,a,b, ...)
```

Description

`sprintf` converts its arguments to a string. The first parameter is the format string. All the characters are copied verbatim to the output string, except for the control sequences which all begin with the character '%'. They have the form

```
%fn.dt
```

where f is zero, one or more of the following flags:

Flag	Meaning
-	left alignment (default is right alignment)
+	display of a + sign for positive numbers
0	zero padding instead of spaces
#	alternate format (see below)
space	sign replaced with space for positive numbers

n is the optional width of the field as one or more decimal digits (default is the minimum width to display the data), d is the number of digits after the decimal separator for a number displayed with a fractional part, the minimum number of displayed digits for a number displayed as an integer, or the number of characters for a string (one or more decimal digits; by default, it is 4 for a number or the length of the string for a string), and t is a single character denoting the type of conversion. In most cases, each control sequence corresponds to an additional argument. All elements of arrays are used sequentially as if they were provided separately; strings are used as a whole. The table below gives the valid values of t.

Char.	Conversion
%	single %
d	decimal number as an integer
i	same as d
x	hexadecimal number (for integers between 0 and 2ˆ32-1)
X	same as x, with uppercase digits
o	octal number (for integers between 0 and 2ˆ32-1)
f	fixed number of decimals (exp. notation if abs(x)>1e18)
F	same as f, with an uppercase E
e	scientific notation such as 1e5
E	scientific notation such as 1E5
n	engineering notation such as 100e3
N	engineering notation such as 100E3
g	decimal or scientific notation
G	same as g, with an uppercase E
k	same as g, with as few characters as possible
K	same as k, with an uppercase E
c	character
s	string

The # flag forces octal numbers to begin with 0, nonzero hexadecimal numbers to begin with 0x, and floating-point numbers to always have a decimal point even if they do not have a fractional part.

Instead of decimal digits, the width n and/or the precision d can be replaced with character *; then one or two additional arguments (or elements of an array) are consumed and used as the width or precision.

Examples

```
sprintf('%d %.2f %.2e %.2E %.2g',pi*ones(1,5))
  3 3.14 3.14e0 3.14E0 3.14
sprintf('%.1k ', 0.001, 0.11, 111, 1000)
  1e-3 0.11 111 1e3
sprintf('*%8.3f*%8.6s*%-8.6s*',pi,'abcdefgh','abcdefgh')
  *   3.142*  abcdef*abcdef  *
sprintf('%c_','a':'z')
  a_b_c_d_e_f_g_h_i_j_k_l_m_n_o_p_q_r_s_t_u_v_w_x_y_z_
sprintf('%*.*f', 15, 7, pi)
      3.1415927
sprintf('%.3d,%.3d', 12, 12345)
  012,12345
```

Caveat

Exotic formats unsupported.

See also

`fprintf`, `sscanf`, `swrite`

sread

Raw input from a string or an array of bytes.

Syntax

```
(a, count) = sread(str, size, precision)
(a, count) = sread(str, [], precision)
(a, count) = sread(bytes, ...)
```

Description

`sread(str)` reads data from string `str` or array of class `uint8` or `int8` the same way as `fread` reads data from a file.

Examples

```
(data, count) = sread('abc')
  data =
    97
    98
    99
  count =
    3
```

```
(data, count) = sread('abcdef',[2,2])
  data =
    97 98
    99 100
  count =
    4
(data, count) = sread('abcd',[inf,3])
  data =
    97 98 99
  count =
    3
```

See also

`swrite`, `bwrite`, `fread`

sscanf

Decoding of formatted numbers.

Syntax

```
r = sscanf(str, format)
(r, count) = scanf(str, format)
(r, count, nchar) = scanf(str, format)
```

Description

Numbers, characters and strings are extracted from the first argument. Exactly what is extracted is controlled by the second argument, which can contain the following elements:

Substring in format	**Meaning**
`%c`	single character
`%s`	string
`%d`	integer number in decimal
`%x`	unsigned integer number in hexadecimal
`%o`	unsigned integer number in octal
`%i`	integer number
`%f`	floating-point number
`%e`	floating-point number
`%g`	floating-point number
`%%`	%
other character	exact match

`%i` recognizes an optional sign followed by a decimal number, an hexadecimal number prefixed with `0x` or `0X`, a binary number prefixed with `0b` or `0B`, or an octal number prefixed with `0`.

The decoded elements are accumulated in the output argument, either as a column vector if the format string contains `%d`, `%o`, `%x`, `%i`, `%f`, `%e` or `%g`, or a string if the format string contains only `%c`, `%s` or literal values. If a star is inserted after the percent character, the value is decoded and discarded. A width (as one or more decimal characters) can be inserted before `s`, `d`, `x`, `o`, `i`, `f`, `e` or `g`; it limits the number of characters to be decoded. In the input string, spaces and tabulators are skipped before decoding `%s`, `%d`, `%x`, `%o`, `%i`, `%f`, `%e` or `%g`.

The format string is recycled as many times as necessary to decode the whole input string. The decoding is interrupted if a mismatch occurs.

The optional second output argument is set to the number of elements decoded successfully (may be different than the length of the first argument if decoding strings). The optional third output argument is set to the number of characters which were consumed in the input string.

Examples

```
sscanf('f(2.3)', 'f(%f)')
  2.3
sscanf('12a34x778', '%d%c')
  12
  97
  34
 120
 778
sscanf('abc def', '%s')
 abcdef
sscanf('abc def', '%c')
 abc def
sscanf('12,34','%*d,%d')
 34
sscanf('0275a0ff', '%2x')
   2
 117
 160
 255
```

See also

`sprintf`

swrite

Store data in a string.

Syntax

```
s = swrite(data)
s = swrite(data, precision)
```

Description

`swrite(fd, data)` stores the contents of the matrix `data` in a string. The third parameter is the precision, whose meaning is the same as for `fread`. Its default value is 'uint8'.

Examples

```
swrite(65:68)
  ABCD
double(swrite([1,2], 'int16'))
  1 0 2 0
double(swrite([1,2], 'int16;b'))
  0 1 0 2
```

See also

bwrite, fwrite, sprintf

3.26 Palm Database Functions

On Palm OS, databases are the most common way to store data. They replace files on computers. Databases are identified by a name, and have a four-character creator which links them to an application, and a four-character type. They contain multiple records, identified by an index; the first record has index 0.

Functions specific to databases are described in this section. Input, output, and control are done with the following generic functions:

Function	**Description**
`fclose`	close the record
`feof`	check end-of-record status
`fgetl`	read a line
`fgets`	read a line
`fprintf`	write formatted data
`fread`	read data
`fscanf`	read formatted data
`fseek`	change the current I/O position
`ftell`	get the current I/O position
`fwrite`	write data
`redirect`	redirect output

dbdeldb

Delete a database.

Syntax

```
dbdeldb(dbName)
```

Description

`dbdelrec(dbName)` deletes a database identified by its name `dbName`. All its records are discarded.

See also

dbnewdb, `dbdir`, dbdelrec

dbdelrec

Delete a database record.

Syntax

```
dbdelrec(dbName, index)
dbdelrec(dbName, index, delBackup)
```

Description

`dbdelrec(dbName,index)` deletes a record from the database identified by its name `dbName`. The record itself is identified by its index; the first record has index 0.

With a third argument `delBackup`, `dbdelrec` marks the record as deleted, so that the record will also be deleted from the backup the next time the Palm device is synchronized.

See also

`dbdeldb`, `dbdir`, dbnumrec

dbdir

List of databases.

Syntax

```
dbdir
dbdir('type')
dbdir('type/creator')
dblist = dbdir(...)
```

Description

`dbdir` displays the list of databases with their types and creators. Types and creators are strings of four characters; the type characterizes the kind of data, and the creator identifies the application which owns the database. Without argument, databases with type `'appl'`, `'libr'`, `'neti'`, `'ovly'`, or `'panl'` are not displayed.

To filter the databases which are displayed, a string argument may be provided. It contains the type, and optionally a slash character and the creator. The type or the creator can be replaced with the star character, which stands for any value.

With an output argument, `dbdir` returns a list of structures with fields name, `type`, and `creator`.

Examples

```
dbdir('DATA')
  AddressDB  DATA/addr
  DatebookDB  DATA/date
  MailDB  DATA/mail
  MemoDB  DATA/memo
  ConnectionDB  DATA/modm
  NetworkDB  DATA/netw
  ToDoDB  DATA/todo
db = dbdir('*/LyME');
dumpvar('db1', db{1});
  db1 = struct('name','LyMELibDB', ...
  'type','Lml ', ...
  'creator','LyME');
```

See also

`dbnumrec`

dbinfo

Get info about a database.

Syntax

```
s = dbinfo(dbName)
dbinfo(dbName, s)
```

Description

`dbinfo(dbName)` gets the attributes of the database identified by its name `dbName` and returns them in a structure. Atrributes are the same as options of `dbset`.

`dbinfo(dbName,s)` changes the attributes database `dbName` with the fields of structure `s`.

Example

```
dbinfo('TestDB', struct('ReadOnly', true));
```

See also

`dbset`

dbnewdb

Create a new database.

Syntax

```
dbnewdb(dbName)
dbnewdb(dbName, 'type/creator')
```

Description

`dbnewdb(dbName)` creates a new database identified by its name `dbName`. The four-character type of the database is `DATA` and its four-character creator is `LyME`. The new database has no records; `dbnewrec` can be used to populate it.

The second output argument, if present, specifies the database type and creator. It is a string of two four-characters codes separated by a slash.

Example

Creation of a new database with type TEXT and creator `test`:

```
dbnewdb('TestDB', 'TEXT/test');
```

See also

dbset, dbnewrec, dbdeldb

dbnewrec

Create a new database record.

Syntax

```
fd = dbnewrec(dbName)
(fd, index) = dbnewrec(dbName)
```

Description

dbnewrec(dbName) adds a new record to the database identified by its name dbName. It returns a file descriptor which should be saved and used with functions such as fprintf and fwrite. Once the record is written, fclose should be called to terminate the record creation.

The second output argument, if present, is set to the index of the record. The first record has index 0.

Example

Creation of a new note for the Memo Pad application. Note that the record ends with a null byte.

```
fd = dbnewrec('MemoDB');
fprintf(fd, 'Sine between 0 and 90 deg\n');
for a = 0:15:90
  fprintf(fd, 'sin(%d) = %g\n', a, sin(a));
end
fwrite(fd, 0);
fclose(fd);
```

See also

fclose, dbopenrec

dbnumrec

Number of records in a database.

Syntax

```
n = dbnumrec(dbName)
```

Description

`dbnumrec(dbName)` gives the number of records in the database identified by its name `dbName`.

See also

`dbdir`

dbopenrec

Open an existing database record.

Syntax

```
fd = dbopenrec(dbName, index)
fd = dbopenrec(dbName, index, mode)
```

Description

`dbopenrec(dbName,index)` opens a record from the database identified by its name `dbName` in read-only mode. The record itself is identified by its index; the first record has index 0. `dbopenrec` returns a file descriptor which should be saved and used with functions such as `fgets`, `fscanf` and `fread`. Once the record has been read, `fclose` should be called.

A third input argument can be used to specify the access mode:

Mode	Description
`’r’`	read
`’w’`	write after discarding the previous contents
`’a’`	append to the end of the previous contents

The functions which can be used in write or append mode include `fprintf`, `fwrite` and `dumpvar`.

Example

Reading of the first line of the first note for the Memo Pad application.

```
fd = dbopenrec(’MemoDB’, 0);
line = fgets(fd);
fclose(fd);
```

See also

`fclose`, dbnewrec

dbset

Set options for dbnewdb.

Syntax

```
options = dbset
options = dbset(name1, value1, ...)
options = dbset(options0, name1, value1, ...)
```

Description

`dbset(name1,value1,...)` creates the option argument used by dbnewdb. Options are specified with name/value pairs, where the name is a string which must match exactly the names in the table below. Case is significant. Options which are not specified have a default value. The result is a structure whose fields correspond to each option. Without any input argument, `dbset` creates a structure with all the default options. Note that dbnewdb also interprets the lack of an option argument, or the empty array `[]`, as a request to use the default values.

When its first input argument is a structure, `dbset` adds or changes fields which correspond to the name/value pairs which follow.

Here is the list of permissible options:

Name	Default	Meaning
`Backup`	`true`	should be backed up
`Bundle`	`false`	bundled with its application
`CopyPrevention`	`false`	cannot be copied
`Hidden`	`false`	hidden in the launcher
`OKToInstallNewer`	`false`	if open, the backup may install a newer db
`ReadOnly`	`false`	cannot be modified
`Recyclable`	`false`	deleted when closed or upon reset

See also

dbnewdb, `dbinfo`

3.27 Palm File Streaming Functions

Palm OS provides a set of functions to simulate files on top of databases. Function `filestreamingopen` is used to create or open these files. Input, output, and control are done with the following generic functions:

Function	**Description**
`fclose`	close the file
`feof`	check end of file status
`fflush`	flush I/O buffers
`fgetl`	read a line
`fgets`	read a line
`fprintf`	write formatted data
`fread`	read data
`fscanf`	read formatted data
`fseek`	change the current I/O position
`ftell`	get the current I/O position
`fwrite`	write data
`redirect`	redirect output

filestreamingopen

Open a file.

Syntax

```
fd = filestreamingopen(filename, mode)
fd = filestreamingopen(filename, mode, creator)
fd = filestreamingopen(card, filename, mode)
fd = filestreamingopen(card, filename, mode, creator)
```

Description

`filestreamingopen(filename,mode)` opens the file whose name is `filename` for reading and/or writing. Mode is a single-character string, whose meaning is described below.

Mode	**Meaning**
'r'	read-only
'w'	read/write (reset file contents)
'u'	update (keep file contents, seek to beginning)
'a'	add (keep file contents, seek to end)

`filestreamingopen(filename,mode,creator)` sets the creator to the four-character string `creator`. The default is `'LyME'`.

`filestreamingopen(card,...)`, where `card` is an integer number, specifies the card where the file is stored. The default is 0 (internal memory).

See also

`fclose`

3.28 Palm VFS Functions

The Virtual File System (VFS) enables the operating system to support different kinds of file systems. It is available in Palm OS 4 and later. For flash memory cards, the VFAT format is used. Multiple formats can coexist on the same handheld.

VFS files and directories are identified with two strings: the volume name and the full path. This differs from other file systems where the path contains enough information to identify the volume. LyME provides two functions for opening a file: `vfsopen`, with separate volume name and path; and `fopen`, compatible with other LME applications like Sysquake.

Functions directly related to VFS are described below. Input, output, and control are done with the following generic functions:

Function	**Description**
`fclose`	close the file
`feof`	check end of file status
`fgetl`	read a line
`fgets`	read a line
`fprintf`	write formatted data
`fread`	read data
`fscanf`	read formatted data
`fseek`	change the current I/O position
`ftell`	get the current I/O position
`fwrite`	write data
`redirect`	redirect output

fopen

Open a VFS file.

Syntax

```
fd = fopen(path)
fd = fopen(path, mode)
```

Description

`fopen(path)` opens the file specified by string `path` on the first volume, in read-only mode. The argument contains either the full path of the file on the first volume, or the volume name and the full path separated with a colon (e.g. `'card:/dir/file.txt'`).

`fopen(path,mode)` opens a file in read-only mode if `mode` is `'r'`, or in read-write mode if `mode` is `'w'`. `mode` can have a second character which is ignored, for compatibility with other versions of `fopen`.

Example

```
fd = fopen('Data:/Measures/data.txt', 'w');
for i = 1:size(data, 1)
  fprintf('%g\t', data(i,:));
  fprintf('\n');
end
fclose(fd)
```

See also

`vfsopen`, `fclose`, `vfsgetvolumes`, `vfsdir`

vfsdelete

Delete a file or an empty directory.

Syntax

```
vfsdelete(volume, path)
```

Description

`vfsdelete(volume,path)` deletes a file or an empty directory whose absolute path is `path` on volume `volume`. Both arguments are strings.

See also

`vfsdir`

vfsdir

Get the list of files and directories.

Syntax

```
vfsdir(volume)
vfsdir(volume, directorypath)
list = vfsdir(...)
```

Description

`vfsdir(volume)` displays the list of files and directories at the root level of volume `volume`. Hidden files are not displayed. Directories are followed with a slash (`'/'`); read-only files, with `'ro'`; system files, with `'s'`; and links, with `'l'`.

`vfsdir(volume,directorypath)` displays the list of files and directories in the directory `directorypath` of volume `volume`. Both arguments are strings. The directory path must be absolute (it begins with a slash).

With an output argument, `vfsdir` returns the result in a list of structures. Each element corresponds to a file or a directory in the specified location. Hidden elements are also included. Structure fields include name, the file or directory name (a string), and logical values for the element attributes: `readonly`, `hidden`, `system`, `volumelabel`, `directory`, `archive`, and `link`.

Example

```
vfsdir('Music', '/classic')
  Bach/
  Brahms/
  5th.mp3 ro
```

See also

`vfsgetvolumes`, `vfsmkdir`

vfsgetvolumes

Get the list of volumes.

Syntax

```
list = vfsgetvolumes
```

Description

`vfsgetvolumes` gets the list of all volumes available on the handheld. Volumes are identified by their name (a string). They are used with the path to identify a directory or a file in VFS.

Example

```
vfsgetvolumes
  {'Music'}
```

See also

`vfsdir`

vfsmkdir

Make a new directory.

Syntax

```
vfsmkdir(volume, path)
```

Description

`vfsmkdir(volume,path)` creates a new directory whose absolute path is `path` on volume `volume`. Both arguments are strings.

Example

```
vfsmkdir('Music', '/mp3/classic/Bach');
```

See also

`vfsdir`

vfsopen

Open a VFS file.

Syntax

```
fd = vfsopen(volume, path)
fd = vfsopen(volume, path, mode)
```

Description

`vfsopen(volume,path)` opens the file whose absolute path is `path` on volume `volume`, in read-only mode. Both arguments are strings.

`vfsopen(volume,path,mode)` opens a file in read-only mode if `mode` is `'r'`, or in read-write mode if `mode` is `'w'`.

Example

```
fd = vfsopen('Data', '/Measures/data.txt', 'w');
for i = 1:size(data, 1)
  fprintf('%g\t', data(i,:));
  fprintf('\n');
end
fclose(fd)
```

See also

`fopen`, `fclose`, `vfsgetvolumes`, `vfsdir`

vfsrename

Rename a file or a directory.

Syntax

```
vfsrename(volume, path, newname)
```

Description

`vfsrename(volume,path,newname)` changes the name of the file or directory whose absolute path is `path` on volume `volume` to `newname`. All arguments are strings.

Example

```
vfsrename('Pictures', '/DCIM/0003.jpg', 'jean.jpg');
```

See also

`vfsdir`

3.29 Time Functions

clock

Current date and time.

Syntax

```
t = clock
```

Description

`clock` returns a 1x6 row vector, containing the year (four digits), the month, the day, the hour, the minute and the second of the current date and time. All numbers are integers, except for the seconds which are fractional. The absolute precision is plus or minus one second with respect to the computer's clock; the relative precision is plus or minus 1 microsecond on a Macintosh, and plus or minus 1 millisecond on Windows.

Example

```
clock
  1999 3 11 15 37 34.9167
```

See also

`tic`, `toc`

tic

Start stopwatch.

Syntax

```
tic
```

Description

`tic` resets the stopwatch. Typically, `tic` is used once at the beginning of the block to be timed.

See also

`toc`, `clock`

toc

Elapsed time of stopwatch.

Syntax

```
elapsed_time = toc
```

Description

`toc` gets the time elapsed since the last execution of `tic`. Typically, `toc` is used at the end of the block of statements to be timed.

On multi-tasking operating systems like Windows, Mac OS X and Unix, `toc` measures only the time spent in the LME application. Other processes do not have a large impact. For instance, typing `tic` at the command-line prompt, waiting 5 seconds, and typing `toc` will show a value much smaller than 5.

Example

```
 tic; x = eig(rand(200)); toc
   0.3046
```

See also

`tic`, `clock`

3.30 Date Conversion Functions

Date functions perform date and time conversions between the calendar date and the julian date.

The *calendar date* is the date of the proleptic Gregorian calendar, i.e. the calendar used in most countries today where centennial years are not leap unless they are a multiple of 400. This calendar was introduced by Pope Gregory XIII on October 5, 1582 (Julian Calendar, the calendar used until then) which became October 15. The calendar used in this library is proleptic, which means the rule for leap years is applied back to the past, before its introduction. Negative years are permitted; the year 0 does exist.

The *julian date* is the number of days since the reference point, January 1st -4713 B.C. (Julian calendar) at noon. The fractional part corresponds to the fraction of day after noon: a fraction of 0.25, for instance, is 18:00 or 6 P.M. The julian date is used by astronomers with GMT; but using a local time zone is fine as long as an absolute time is not required.

cal2julian

Calendar to julian date conversion.

Syntax

```
jd = cal2julian(datetime)
jd = cal2julian(year, month, day)
jd = cal2julian(year, month, day, hour, minute, second)
```

Description

`cal2julian(datetime)` converts the calendar date and time to the julian date. Input arguments can be a vector of 3 components (year, month and day) or 6 components (date and hour, minute and seconds), or scalar values provided separately. The result of `clock` can be used directly.

Example

Number of days between October 4 1967 and April 18 2005:

```
cal2julian(2005, 4, 18) - cal2julian(1967, 10, 4)
  14624
```

See also

`julian2cal`, `clock`

julian2cal

Julian date to calendar conversion.

Syntax

```
datetime = julian2cal(jd)
(year, month, day, hour, minute, second) = julian2cal(jd)
```

Description

`julian2cal(jd)` converts the julian date to calendar date and time. With a single output, the result is given a a row vector of 6 values for the year, month, day, hour, minute and second; with more output arguments, values are given separately.

Example

Date 1000 days after April 18 2005:

```
julian2cal(cal2julian(2005, 4, 18) + 1000)
  2006  11  14   0   0   0
```

See also

`cal2julian`

3.31 Quaternions

Quaternion functions support scalar and arrays of quaternions. Basic arithmetic operators and functions are overloaded to support expressions with the same syntax as for numbers and matrices.

Quaternions are numbers similar to complex numbers, but with four components instead of two. The unit imaginary parts are named i, j, and k. A quaternion can be written $w + ix + jy + kz$. The following relationships hold:

$$i^2 = j^2 = k^2 = ijk = -1$$

It follows that the product of two quaternions is not commutative; for instance, $ij = k$ but $ji = -k$.

Quaternions are convenient to represent arbitrary rotations in the 3d space. They are more compact than matrices and are easier to normalize. This makes them suitable to simulation and control of mechanical systems and vehicles, such as flight simulators and robotics.

Functions below are specific to quaternions:

Function	**Purpose**
`isquaternion`	test for quaternion type
`q2mat`	conversion to rotation matrix
`q2rpy`	conversion to attitude angles
`q2str`	conversion to string
`qimag`	imaginary parts
`qinv`	element-wise inverse
`qnorm`	scalar norm
`qslerp`	spherical linear interpolation
`quaternion`	quaternion creation
`rpy2q`	conversion from attitude angles

Operators below accept quaternions as arguments:

Function	**Operator**	**Purpose**
`ctranspose`	`'`	conjugate transpose
`eq`	`==`	element-wise equality
`horzcat`	`[,]`	horizontal array concatenation
`ldivide`	`.\`	left division
`ne`	`~=`	element-wise inequality
`minus`	`-`	difference
`mldivide`	`\`	matrix left division
`mrdivide`	`/`	matrix right division
`mtimes`	`*`	matrix multiplication
`plus`	`+`	addition
`rdivide`	`./`	division
`times`	`.*`	multiplication
`transpose`	`.'`	transpose
`uminus`	`-`	unary minus
`uplus`	`+`	unary plus
`vertcat`	`[;]`	vertical array concatenation

Most of these operators work as expected, like with complex scalars and matrices. Multiplication and left/right division are not commutative. Matrix operations are not supported: operators `*`, `/`, `\`, and `^` are defined as a convenience (they are equivalent to `.*`, `./`, `.\`, and `.^` respectively) and work only element-wise with scalar arguments.

Mathematical functions below accept quaternions as arguments; with arrays of quaternions, they are applied to each element separately.

Function	**Purpose**
`abs`	absolute value
`conj`	conjugate
`cos`	cosine
`exp`	exponential
`log`	natural logarithm
`real`	real part
`sign`	quaternion sign (normalization)
`sin`	sine
`sqrt`	square root

Functions below performs computations on arrays of quaternions.

Function	Purpose
`cumsum`	cumulative sum
`diff`	differences
`double`	conversion to array of double
`mean`	arithmetic mean
`sum`	sum

Functions below are related to array size.

Function	Purpose
`beginning`	first subscript
`cat`	array concatenation
`end`	last subscript
`flipdim`	flip array
`fliplr`	flip left-right
`flipud`	flip upside-down
`ipermute`	dimension inverse permutation
`isempty`	test for empty array
`length`	length of vector
`ndims`	number of dimensions
`numel`	number of elements
`permute`	dimension permutation
`repmat`	array replication
`reshape`	array reshaping
`rot90`	array rotation
`size`	array size
`squeeze`	remove singleton dimensions

Finally, functions below are related to output and assignment.

Function	Purpose
`disp`	display
`dumpvar`	conversion to string
`subsasgn`	assignment to subarrays or to quaternion parts
`subsref`	reference to subarrays or to quaternion parts

Function `imag` is replaced with `qimag` which gives a quaternion with the real part set to zero, because there are three imaginary components instead of one with complex numbers.

Operators and functions which accept multiple arguments convert automatically double arrays to quaternions, ignoring the imaginary part of complex numbers.

Conversion to numeric arrays with `double` adds a dimension for the real part and the three imaginary parts. For example, converting a scalar quaternion gives a 4-by-1 double column vector and converting a 2-by-2 quaternion array gives a 2-by-2-by-4 double array. Real and imaginary components can be accessed with the field access notation: `q.w` is the real part of `q`, `q.x`, `q.y`, and `q.z` are its imaginary parts, and `q.v` is its imaginary parts as an array similar to the result of `double` but without the real part.

Compatibility note: native functions for quaternions replace library `quaternion` which defined quaternion scalars and matrices. It is much faster and supports arrays of more than two dimensions; on the other hand, matrix-oriented functions are not supported anymore, and the result of `dumpvar` is not directly compatible.

isquaternion

Test for a quaternion.

Syntax

```
b = isquaternion(q)
```

Description

`isquaternion(q)` is true if the input argument is a quaternion and false otherwise.

Examples

```
isquaternion(2)
  false
isquaternion(quaternion(2))
  true
```

See also

`quaternion`, `isnumeric`

q2mat

Conversion from quaternion to rotation matrix.

Syntax

```
R = q2mat(q)
```

Description

R=q2mat(q) gives the 3x3 orthogonal matrix R corresponding to the rotation given by scalar quaternion q. For a vector a=[x;y;z] and its representation as a pure quaternion aq=quaternion(x,y,z), the rotation can be performed with quaternion multiplication bq=q*aq/q or matrix multiplication b=R*a.

Input argument q does not have to be normalized; a quaternion corresponding to a given rotation is defined up to a multiplicative factor.

Example

```
q = rpy2q(0.1, 0.3, 0.2);
R = q2mat(q)
  R =
    0.9363 -0.1688  0.3080
    0.1898  0.9810  0.0954
   -0.2955  0.0954  0.9506
aq = quaternion(1, 2, 3);
q * aq / q
  1.5228i+2.0336j+2.7469k
a = [1; 2; 3];
R * a
  1.5228
  2.4380
  2.7469
```

See also

q2rpy, rpy2q, quaternion

q2rpy

Conversion from quaternion to attitude angles.

Syntax

```
(pitch, roll, yaw) = q2rpy(q)
```

Description

q2rpy(q) gives the pitch, roll, and yaw angles corresponding to the rotation given by quaternion q. It is the inverse of rpy2q. All angles are given in radians.

If the input argument is a quaternion array, the results are arrays of the same size; conversion from quaternion to angles is performed independently on corresponding elements.

See also

`rpy2q`, `q2mat`, `quaternion`

q2str

Conversion from quaternion to string.

Syntax

```
str = q2str(q)
```

Description

`q2str(q)` converts quaternion `q` to its string representation, with the same format as `disp`.

See also

`quaternion`, `format`

qimag

Quaternion imaginary parts.

Syntax

```
b = qimag(q)
```

Description

`qimag(q)` gives the imaginary parts of quaternion `q` as a quaternion, i.e. the same quaternion where the real part is set to zero. `real(q)` gives the real part of quaternion `q` as a double number.

Example

```
q = quaternion(1,2,3,4)
  q =
    1+2i+3j+4k
real(q)
  1
qimag(q)
  2i+3j+4k
```

See also

`quaternion`

qinv

Quaternion element-wise inverse.

Syntax

```
 b = qinv(q)
```

Description

`qinv(q)` gives the inverse of quaternion `q`. If its input argument is a quaternion array, the result is an quaternion array of the same size whose elements are the inverse of the corresponding elements of the input.

The inverse of a normalized quaternion is its conjugate.

Example

```
 q = quaternion(0.4,0.1,0.2,0.2)
   q =
     0.4+0.1i+0.2j+0.2k
 p = qinv(q)
   p =
     1.6-0.4i-0.8j-0.8k
 abs(q)
   0.5
 abs(p)
   2
```

See also

`quaternion`, `qnorm`, `conj`

qnorm

Quaternion scalar norm.

Syntax

```
 n = qnorm(q)
```

Description

`qnorm(q)` gives the norm of quaternion q, i.e. the sum of squares of its components, or the square of its absolute value. If q is an array of quaternions, `qnorm` gives a double array of the same size where each element is the norm of the corresponding element of q.

See also

`quaternion`, `abs`

qslerp

Quaternion spherical linear interpolation.

Syntax

```
 q = qslerp(q1, q2, t)
```

Description

`qslerp(q1,q2,t)` performs spherical linear interpolation between quaternions q1 and q2. The result is on the smallest great circle arc defined by normalized q1 and q2 for values of real number `t` between 0 and 1.

If q1 or q2 is 0, the result is NaN. If they are opposite, the great circle arc going through 1, or 1i, is picked.

If input arguments are arrays of compatible size (same size or scalar), the result is a quaternion array of the same size; conversion from angles to quaternion is performed independently on corresponding elements.

Example

```
 q = qslerp(1, rpy2q(0, 1, -1.5), [0, 0.33, 0.66, 1]);
 (roll, pitch, yaw) = q2rpy(q)
   roll =
     0.0000  0.1843  0.2272  0.0000
   pitch =
     0.0000  0.3081  0.6636  1.0000
   yaw =
     0.0000 -0.4261 -0.8605 -1.5000
```

See also

`quaternion`, `rpy2q`, `q2rpy`

quaternion

Quaternion creation.

Syntax

```
q = quaternion
q = quaternion(w)
q = quaternion(c)
q = quaternion(x, y, z)
q = quaternion(w, x, y, z)
q = quaternion(w, v)
```

Description

With a real argument, `quaternion(x)` creates a quaternion object whose real part is `w` and imaginary parts are 0. With a complex argument, `quaternion(c)` creates the quaternion object `real(c)+i*imag(c)`.

With four real arguments, `quaternion(w,x,y,z)` creates the quaternion object `w+i*x+j*y+k*z`.

With three real arguments, `quaternion(x,y,z)` creates the pure quaternion object `i*x+j*y+k*z`.

In all these cases, the arguments may be scalars or arrays of the same size.

With two arguments, `quaternion(w,v)` creates a quaternion object whose real part is `w` and imaginary parts is array `v`. `v` must have one more dimension than `w` for the three imaginary parts.

Without argument, `quaternion` returns the zero quaternion object.

The real or imaginary parts of a quaternion can be accessed with field access, such as `q.w`, `q.x`, `q.y`, `q.z`, and `q.v`.

Examples

```
q = quaternion(1, 2, 3, 4)
  q =
    1+2i+3j+4k
q + 5
  6+2i+3j+4k
q * q
  -28+4i+6j+8k
Q = [q, 2; 2*q, 5]
  2x2 quaternion array
Q.y
  3  0
  6  0
q = quaternion(1, [5; 3; 7])
```

```
   q =
     1+5i+3j+7k
 q.v
   5
   3
   7
```

See also

`real`, `qimag`, `q2str`, `rpy2q`

rpy2q

Conversion from attitude angles to quaternion.

Syntax

```
 q = rpy2q(pitch, roll, yaw)
```

Description

`rpy2q(pitch,roll,yaw)` gives the quaternion corresponding to a rotation of angle yaw around the z axis, followed by a rotation of angle `pitch` around the y axis, followed by a rotation of angle `roll` round the x axis. All angles are given in radians. The result is a normalized quaternion whose real part is $\cos(\vartheta/2)$ and imaginary part $\sin(\vartheta/2)\left(v_x i + v_y j + v_z k\right)$, for a rotation of ϑ around unit vector $\left[v_x\ v_y\ v_z\right]^T$. The rotation is applied to a point $[x\,y\,z]^T$ given as a pure quaternion $a = xi + yj + zk$, giving point a also as a pure quaternion; then `b=q*a/q` and `a=q\b*q`. The rotation can also be seen as changing coordinates from body to absolute, where the body's attitude is given by `pitch`, `roll` and yaw.

In order to have the usual meaning of pitch, roll and yaw, the x axis must be aligned with the direction of motion, the y axis with the lateral direction, and the z axis with the vertical direction, with the usual sign conventions for cross products. Two common choices are x pointing forward, y to the left, and z upward; or x forward, y to the right, and z downward.

If input arguments are arrays of compatible size (same size or scalar), the result is a quaternion array of the same size; conversion from angles to quaternion is performed independently on corresponding elements.

Example

Conversion of two vectors from aircraft coordinates (x axis forward, y axis to the left, z axis upward) to earth coordinates (x directed to the north, y to the west, z to the zenith). In aircraft coordinates, vectors are [2;0;0] (propeller position) and [0;5;0] (left wing tip). The aircraft attitude has a pitch of 10 degrees upward, i.e. -10 degrees with the choice of axis, and null roll and yaw.

```
q = rpy2q(0, -10*pi/180, 0)
  q =
    0.9962-0.0872j
q * quaternion(2, 0, 0) / q
  1.9696i+0.3473k
q * quaternion(0, 5, 0) / q
  5j
```

See also

q2rpy, q2mat, quaternion

3.32 Serial Port Functions

Serial port functions enable communication with devices connected to the computer via an RS-232 interface. Such devices include modems, printers, and many scientific instruments. The operating system can also emulate RS-232 connections with other devices, such as built-in modems or USB (Universal Serial Bus) devices.

Functions described in this section include only those required for opening and configuring the connection. They correspond to fopen for files. Input, output, and control are done with the following generic functions:

Function	Description
fclose	close the file
fflush	flush I/O buffers
fgetl	read a line
fgets	read a line
fprintf	write formatted data
fread	read data
fscanf	read formatted data
fwrite	write data
redirect	redirect output

Functions opendevice, devicename, closedevice, and flushdevice are obsolete and may be removed in the future. They are replaced with serialdevopen and serialdevset to specify configuration settings, serialdevname, fclose, and fflush.

serialdevname

Serial device name.

Syntax

```
name = serialdevname(n)
list = serialdevname
```

Description

`serialdevname(n)` returns the name of the n:th serial device which can be opened by `serialdevopen`. Argument `n` must be 1 or higher; with other values, such as those larger than the number of serial devices available on your computer, `serialdevname` returns the empty string.

Without input argument, `serialdevname` gives the list of serial device names.

Examples

On a Macintosh with internal modem:

```
serialdevname(1)
  Internal Modem
```

Under Windows:

```
serialdevname(1)
  COM1
```

See also

`serialdevopen`

serialdevopen

Open a serial port.

Syntax

```
fd = serialdevopen(portname, options)
fd = serialdevopen(portname)
```

Description

`serialdevopen(portname)` opens a connection to the serial port whose name is `portname` and returns a file descriptor `fd`. Names depend on the operating system and can be obtained with `serialdevname`.

Some platforms do not provide a complete list of all ports; `serialdevopen` may accept additional device names and pass them directly to the corresponding function of the operating system.

The second argument of `serialdevopen(portname,options)` is a structure which contains configuration settings. It is set with `serialdevset`.

Once a connection has been opened, the file descriptor `fd` can be used with functions such as `fread`, `fwrite`, `fscanf`, and `fprintf`. The connection is closed with `fclose`.

Example

```
fd = serialdevopen(serialdevname(1), ...
       serialdevset('BPS',19200,'TextMode',true,'Timeout',2));
fprintf(fd, 'L,%d,2\n', 1);
reply = fgetl(fd)
fclose(fd);
```

See also

`fclose`, `serialdevname`, `serialdevset`, `fflush`, `fread`, `fwrite`, `fscanf`, `fgetl`, `fgets`, `fprintf`

serialdevset

Configuration settings for serial port.

Syntax

```
options = serialdevset
options = serialdevset(name1, value1, ...)
options = serialdevset(options0, name1, value1, ...)
```

Description

`serialdevset(name1,value1,...)` creates the option argument used by `serialdevopen`. Options are specified with name/value pairs, where the name is a string which must match exactly the names in the table below. Case is significant. Options which are not specified have a default value. The result is a structure whose fields correspond to each option. Without any input argument, `serialdevset` creates a structure with all the default settings. Note that `serialdevopen` also interprets the lack of an option argument, or the empty array `[]`, as a request to use the default values.

When its first input argument is a structure, `serialdevset` adds or changes fields which correspond to the name/value pairs which follow.

Here is the list of permissible options:

Name	**Default**	**Meaning**
`BPS`	`19200`	bit per seconds
`Delay`	`0`	delay after character output in seconds
`Handshake`	`false`	hardware handshake
`StopBits`	`2`	number of stop bits (1, 1.5, or 2)
`TextMode`	`false`	text mode
`Timeout`	`1`	timeout in seconds

Output operations wait for the specified delay after each character; this can be useful with slow devices without handshake.

When text mode is set, input CR and CR/LF sequences are converted to LF. Output CR and LF are not converted.

Depending on the platform, operations which use the timeout value (such as input) can be interrupted with the platform-dependent abort key(s) (typically Escape or Control-C) or are limited to 10 seconds.

Example

```
serialdevset
  BPS: 19200
  Handshake: false
  StopBits: 2
  TextMode: false
  Timeout: 1
```

See also

`serialdevopen`, `serialdevname`

3.33 Long Integers

This section describes functions which support long integers (*longint*), i.e. integer numbers with an arbitrary number of digits limited only by the memory available. Some LME functions have been overloaded: new definitions have been added and are used when at least one of their arguments is of type longint. These functions are listed in the table below.

LME	Operator	Purpose
`abs`		absolute value
`char`		conversion to string
`disp`		display
`double`		conversion to floating-point
`gcd`		greatest common divisor
`lcm`		least common multiple
`minus`	`-`	subtraction
`mldivide`	`\`	left division
`mpower`	`^`	power
`mrdivide`	`/`	right division
`mtimes`	`*`	multiplication
`plus`	`+`	addition
`rem`		remainder
`uminus`	`-`	negation
`uplus`	`+`	no operation

longint

Creation of a long integer.

Syntax

```
li = longint(i)
li = longint(str)
```

Description

`longint(i)` creates a long integer from a native LME floating-point number. `longint(str)` creates a long integer from a string of decimal digits.

Examples

```
longint('1234567890')
  1234567890
longint(2)^100
  1267650600228229401496703205376
```

13th Mersenne prime:

```
longint(2)^521-1
  6864797660130609714981900799081393217269
  4353001433054093944634591855431833976560
  5212255964066145455497729631139148085803
  7121987999716643812574028291115057151
```

Number of decimal digits in the 27th Mersenne prime:

```
length(char(longint(2)^44497-1))
  13395
```

3.34 LyME Functions

axis

Set the scale of the next graphics.

Syntax

```
axis([xmin,xmax,ymin,ymax])
axis equal
limits = axis
```

Description

With an input argument, the `axis` command, which should be placed before any other graphical command, sets the scale and scale options. The parameter is either a vector of 4 elements which sets the limits of the plot for both x and y axis, or the string `'equal'` to make the scale equal in both directions so that circles are really displayed as circles and not ellipses.

With an output argument, `axis` gives the current limits of the plot in a row vector `[xmin,xmax,ymin,ymax]`.

See also

`clf`, `hold`

bar

Vertical bar plot.

Syntax

```
bar(y)
bar(x, y)
bar(x, y, w)
bar(..., kind)
bar(..., kind, color)
```

Description

`bar(x,y)` plots the columns of `y` as vertical bars centered around the corresponding value in `x`. If `x` is not specified, its default value is `1:size(y,2)`.

`bar(x,y,w)`, where `w` is scalar, specifies the relative width of each bar with respect to the horizontal distance between the bars; with values smaller than 1, bars are separated with a gap, while with values larger than 1, bars overlap. If `w` is a vector of two components `[w1,w2]`, `w1` corresponds to the relative width of each bar in a group (columns of y), and `w2` to the relative width of each group. Default values, used if `w` is missing or is the empty matrix `[]`, is 0.8 for both `w1` and `w2`.

`bar(...,kind)`, where `kind` is a string, specifies the kind of bar plot. The following values are recognized:

`'grouped'`	Columns of `y` are grouped horizontally (default)
`'stacked'`	Columns of `y` are stacked vertically
`'interval'`	Same as `grouped`, except that bars have min and max values

With `'interval'`, intervals are defined by two consecutive rows of `y`, which must have an even number of rows.

The optional argument `color` is a string made of one or several color characters:

`'k'`	black
`'w'`	white with a black frame

First color is applied to first row of `y`, second color to second row, and so on; if there are less colors than rows, colors are recycled.

Examples

```
bar([2,4,3,6;3,5,4,1]);                        % simple bar plot
bar(1:4, magic(4), [], 'stacked');             % stacked bar plot
bar(1:4, [2,4,3,1;5,6,4,6], [], 'interval');  % interval plot
```

See also

`barh`, `plot`

barh

Horizontal bar plot.

Syntax

```
barh(x)
barh(y, x)
barh(y, x, w)
barh(..., kind)
barh(..., kind, style)
```

Description

barh plots a bar plot with horizontal bars. Please see bar for a description of its behavior and arguments.

Examples

```
barh([2,4,3,6;3,5,4,1]);                          % simple bar plot
barh(1:4, magic(4), [], 'stacked');               % stacked bar plot
barh(1:4, [2,4,3,1;5,6,4,6], [], 'interval');  % interval plot
```

See also

bar, plot

beep

Play music.

Syntax

```
beep(freq)
beep([freq, duration])
beep([freq, duration, volume])
```

Description

The beep command plays one or several sounds. Argument is a m-by-n matrix, with n between 1 and 3; first column is the frequency in Hertz, second column is duration in seconds (default 0.1), and third column is volume between 0 and 1 (default 1).

Example

```
beep(440 * 2.^((0:12)'/12));
```

See also

audioplay, pause

clf

Clear the figure window.

Syntax

```
clf
```

See also

`close`, `clc`, `hold`, plot

close

Discard the graphics output and display the text output window.

Syntax

```
close
```

See also

`clf`, `clc`

contour

Level curves.

Syntax

```
contour(z)
contour(z, [xmin, xmax, ymin, ymax])
contour(z, [xmin, xmax, ymin, ymax], levels)
```

Description

`contour(z)` plots seven contour lines corresponding to the surface whose samples at equidistant points `1:size(z,2)` in the x direction and `1:size(z,1)` on the y direction are given by `z`. Contour lines are at equidistant levels. With a second non-empty argument `[xmin, xmax, ymin, ymax]`, the samples are at equidistant points between `xmin` and `xmax` in the x direction and between `ymin` and `ymax` in the y direction. The optional third argument `levels`, if non-empty, gives the number of contour lines if it is a scalar or the levels themselves if it is a vector.

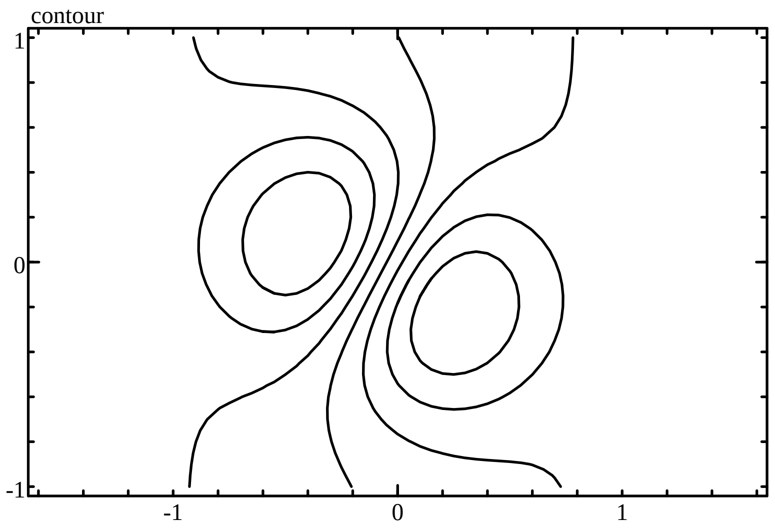


Figure 3.5 Example of `contour`

Example

A function is evaluated over a grid of two variables `x` and `y`, and is drawn with `contour` (see Fig. 3.5):

```
(x, y) = meshgrid(-2 + (0:40) / 10);
z = exp(-((x-0.2).^2+(y+0.3).^2)) ...
      - exp(-((x+0.5).^2+(y-0.1).^2)) + 0.1 * x;
axis equal;
contour(z, [-1,1,-1,1]);
```

See also

`plot`

fplot

Function plot.

Syntax

```
fplot(fun)
fplot(fun, limits)
fplot(fun, limits, style)
fplot(fun, limits, style, p1, p2, ...)
```

Description

Command `fplot(fun,limits)` plots function `fun`, specified by its name as a string, a function reference, or an inline function. The function is plotted for x between `limit(1)` and `limit(2)`; the default limits are `[-5,5]`.

The style of the plot can be specified with a third argument (see `plot` for details). Remaining input arguments of `fplot`, if any, are given as additional input arguments to function `fun`. They permit to parameterize the function. For example `fplot('fun',[0,10],'',2,5)` calls `fun` as `y=fun(x,2,5)` and displays its value for x between 0 and 10.

Examples

Plot a sine:

```
fplot(@sin);
```

Plot $(x + 0.3)^2 + a \exp -3x^2$ in red for $x \in [-2, 3]$ with $a = 7.2$ and an identifier of 1:

```
fun = inline('function y=f(x,a); y=(x+0.3)^2+a*exp(-3*x^2);');
fplot(fun, [-2,3], 'r', 7.2);
```

See also

`plot`, `hold`, clf, `inline`, operator `@`

hold

Graphic freeze.

Syntax

```
hold on
hold off
```

Description

Command `hold` controls whether the graphics window is cleared before graphical commands such as `plot` and `text` display new elements. `hold on` suspends the auto-clear feature, and `hold off` resumes it. In any case, `clf` always resumes it.

Example

```
t = 0:0.1:2*pi;
plot(t, sin(t));
hold on;
plot(t, cos(t));
hold off;
pause(3);
plot(t, sin(t).*cos(t));
```

See also

`plot`, clf

image

Image plot.

Syntax

```
image(A)
```

Description

`image(A)` displays array `A` as an image. `A` is an array of two dimensions for grayscale images or three dimensions for RGB images, with `size(A,3)==3`. `image` accepts different types of data: double arrays must contain numbers between 0 for black and 1 for maximum intensity; uint8 arrays contain numbers between 0 for black and 255 for maximum intensity; and logical arrays contain false for black and true for maximum intensity. Function `map2int` is useful for converting double values in other ranges.

The image is displayed as a low density bitmap, centered in the graphics area. The first value in the array corresponds to the top left corner.

Availability

`image` requires Palm OS 4.0 or higher.

Example

```
x = meshgrid(-2:0.1:2);    % coord for x (y is x.')
A = cos(x.^2 + x.'.^2);    % cos(r^2), element-wise
image(map2int(A, -1, 1));  % double [-1,1] to uint8
```

See also

`plot`, clf, map2int

loglog

Generic plot with a logarithmic scale along x and y axis.

Syntax

```
 loglog(y)
 loglog(x, y)
 loglog(x, y, style)
```

Description

Command `loglog` is similar to `plot`, except that the scale along both x and y axis is logarithmic.

See also

`plot`, `semilogx`, `semilogy`, `hold`, clf

pause

Put the handheld in low power mode.

Syntax

```
 pause(t)
```

Description

`pause(t)` makes the handheld wait for `t` seconds in low-power mode.

plot

Generic plot.

Syntax

```
 plot(y)
 plot(x, y)
 plot(x, y, style)
```

Description

Command plot displays graphical data. The data are given as two vectors of coordinates x and y. Depending on the style, the points are displayed as individual marks (style = 'x', 'o', or '.') or are linked with lines (style = '-'). The style may also specify the color:

Color	**Character**
black	k
blue	b
green	g
cyan	c
red	r
magenta	m
yellow	y
white	w

The default style is '-'.

If x and y are matrices, each row is considered as a separate line or set of marks; if only one of them is a matrix, the other one, a vector, is reused for each line. The style string may contain several styles which are used for each line, and recycled if necessary.

The first argument x may be omitted; its default value is 1:size(y,2).

Example

Plot a sine in black and a cosine in light blue:

```
t = 0:0.1:2*pi;
plot(t,[sin(t); cos(t)], 'kc');
```

See also

semilogx, semilogy, loglog, polar, fplot, hold, clf

polar

Polar plot.

Syntax

```
polar(phi, r)
polar(phi, r, style)
```

Description

Command polar displays graphical data in polar coordinates. The data are given as two vectors of polar coordinates phi and r; their corresponding Cartesian coordinates are x=r*cos(phi) and y=r*sin(phi). Several polar plots may be combined with hold; however, other kinds of plots should not be mixed.

If phi and r are matrices, each row is considered as a separate line or set of marks. Unlike plot, both matrices must have the same size.

See the description of plot for more information about the third argument.

Example

```
phi = 2*pi*(0:100)/100;
polar(phi, 2+cos(5*phi), 'r');
```

See also

plot, hold, clf

semilogx

Generic plot with a logarithmic scale along x axis.

Syntax

```
semilogx(y)
semilogx(x, y)
semilogx(x, y, style)
```

Description

Command semilogx is similar to plot, except that the scale along the x axis is logarithmic.

See also

plot, semilogy, loglog, hold, clf

semilogy

Generic plot with a logarithmic scale along y axis.

Syntax

```
semilogy(y)
semilogy(x, y)
semilogy(x, y, style)
```

Description

Command `semilogy` is similar to `plot`, except that the scale along the y axis is logarithmic.

See also

`plot`, `semilogx`, `loglog`, `hold`, clf

text

Display formatted text in a figure.

Syntax

```
text(x, y, string)
```

Description

`text` displays a string centered at the specified position. Function `sprintf` can be used to create a string and display numbers.

Example

The following code displays the string `(1.2,3.7)` centered around these coordinates.

```
x = 1.2;
y = 3.7;
text(x, y, sprintf('(%.1f,%.1f)', x, y));
```

See also

`disp`, `fprintf`, `sprintf`

3.35 Dialog Functions

selectday

Display a dialog for choosing a date.

Syntax

```
day = selectday(title, day0)
day = selectday(title)
```

Description

`selectday(title,day0)` displays a dialog box which lets the user choose a date. First input argument `title` is the title of the dialog box. The day which is selected by default is `day0`, given as a vector of three integer numbers `[year,month,day]`; with a single input argument, the selected day is the current date. The result is either a date as a 1-by-3 row vector, or the empty array if the user taps the Cancel button.

Example

```
birthday = selectday('Your birthday')
```

See also

selecttime

selecttime

Display a dialog for choosing a time.

Syntax

```
time = selecttime(title, time0)
time = selecttime(title)
```

Description

`selecttime(title,day0)` displays a dialog box which lets the user choose a time. First input argument `title` is the title of the dialog box. The time which is selected by default is `time0`, given as a vector of two integer numbers `[hour,minute]` (where `hour` between 0 and 23); with a single input argument, the selected time is the current time. The result is either a time as a 1-by-2 row vector, or the empty array if the user taps the Cancel button.

Example

```
t0 = selecttime('Rocket launch time', [12, 0]);
```

See also

selectday

3.36 Audio output

This section describes functions which play sounds.

audioplay

Play audio samples.

Syntax

```
audioplay(samples)
audioplay(samples, options)
```

Description

`audioplay(samples)` plays the audio samples in array `samples` at a sample rate of 44.1 kHz. Each column of `samples` is a channel (i.e. `samples` is a column vector for monophonic sound and a two-column array for stereophonic sound), and each row is a sample. Samples are stored as double or single numbers between -1 and 1, `int8` numbers between -128 and 127, or `int16` numbers between -32768 and 32767.

`audioplay(samples,options)` uses the specified options, which are typically built with `audioset`.

Examples

A monophonic bell-like sound of two seconds with a frequency of 740 Hz and a damping time constant of 0.5 second:

```
t = (0:88200)'/44100;
samples = sin(2*pi*740*t).*exp(-t/0.5);
audioplay(samples);
```

Some white noise which oscillates 5 times between left and right:

```
t = (0:44099)' / 44100;
noise = 0.1 * randn(length(t), 1);
left = cos(2 * pi * t) .* noise;
right = sin(2 * pi * t) .* noise;
opt = audioset('Repeat', 5);
audioplay([left, right], opt);
```

See also

`audioset`

audioset

Options for audio.

Syntax

```
options = audioset
options = audioset(name1, value1, ...)
options = audioset(options0, name1, value1, ...)
```

Description

`audioset(name1,value1,...)` creates the option argument used by `audioplay`. Options are specified with name/value pairs, where the name is a string which must match exactly the names in the table below. Case is significant. Options which are not specified have a default value. The result is a structure whose fields correspond to each option. Without any input argument, `audioset` creates a structure with all the default options. Note that `audioplay` also interprets the lack of an option argument, or the empty array `[]`, as a request to use the default values.

When its first input argument is a structure, `audioset` adds or changes fields which correspond to the name/value pairs which follow.

Here is the list of permissible options:

Name	**Default**	**Meaning**
`Repeat`	`1`	number of repetitions
`SampleRate`	`44100`	sample rate in Hz

Default values may be different on platforms with limited audio capabilities.

Example

Default options:

```
audioset
  Repeat: 1
  SampleRate: 44100
```

See also

`audioplay`

3.37 Machine Code Functions

This chapter describes the functions which permit LyME to call arbitrary machine code. This may be useful to access features which are not implemented directly in LyME, such as direct calls to Palm OS functions or support for hardware.

Warning 1: Calling machine code is potentially dangerous. It easily leads to crashes which may need soft or hard resets. You should backup your device first. The use of an emulator, if available, should be considered.

Warning 2: Presenting Palm device hardware and software architecture is far beyond the scope of this reference manual.

Warning 3: Functions described in this chapter are experimental and subject to change without notice.

3.38 Introduction

To support calls to machine code, a new data type is provided, `binarydata`. Variables of this type contain a vector of 16-bit words. Functions are provided to convert a string of hexadecimal digits or a vector of numbers to `binarydata`, `binarydata` to a vector of integer numbers or a string of bytes, and to execute as a machine-code subroutine the contents of `binarydata` using another `binarydata` as data.

As an example, we will develop a subroutine which fills some `binarydata` with the numbers n, n-1, ..., 2, 1. Before the subroutine is executed, the following registers are set:

Register	**Value**
A5	Beginning of the data
D0	Length of the data in words

Here is the code of the subroutine:

```
moveq.w #0, d1
loop:
 tst.w   d0
 beq     end
 move.w  d0, (a5,d1)
 subq.w  #1, d0
 addq.w  #2, d1
 bra     loop
end:
 rts
```

The data offset of the next word to set is stored in D1. As long as D0 is not 0, D0 is stored in the data at offset D1 and decremented, and D1 is incremented by 2. The subroutine ends with `rts`. Note that absolute addresses must be avoided; only relative jumps must be used.

An assembler converts this assembly code to the following machine code:

```
72004A40670A3B8010005340544160F24E75
```

To store this code in a `binarydata` variable, we enter in LyME

```
> code = binarydata('72004A40670A3B8010005340544160F24E75');
```

To execute this code with data initialized to 10 null 16-bit words, we use `feval`:

```
> dataout = feval(code, binarydata(zeros(10, 1)));
```

The result can be converted to a vector of numbers and displayed:

```
> double(dataout)
  10
   9
   8
   7
   6
   5
   4
   3
   2
   1
```

Words in binary data can also be accessed with subscripts, which must be integer values based on 0. In subscript expressions, `beginning` gives 0 (the first valid index) and end gives the number of words minus one. Logical values are not supported.

```
> dataout(end-2:end)
  3 2 1
> dataout(0:2) = 555;
> dataout(0:5)
  555 555 555 7 6 5
```

3.39 Functions

binarydata

Create binary code or data.

Syntax

```
d = binarydata(vec)
d = binarydata('hexa')
```

Description

`binarydata(vec)` creates a block of binary data from the elements of vector vec converted to words (16-bits values). If vec is a vector of class double, its elements converted directly to 16-bit words. If it is a vector of integer numbers, the conversion takes their size into account, with the most-significant word first: for instance, `binarydata(uint8([0,0,1,0])`, `binarydata(int16([0,256])`, and `binarydata(uint32(256))` all produce the same binary data containing the 16-bit words 0 and 256.

`binarydata(str)` creates a block of binary data whose value is given by the string of hexadecimal digits `str`. The length of `str` must be a multiple of 4, so that the block has an integer number of words.

See also

`double`, `uint8`, `uint16`, `uint32`, `int8`, `int16`, `int32`, `char`, `feval`

char

Convert binary data to a string of characters.

Syntax

```
str = char(d)
```

Description

`char(d)` converts binary data to a a string of characters. Each character corresponds to one byte.

See also

`binarydata`, `double`, `uint8`, `uint16`, `uint32`, `int8`, `int16`, `int32`

double

Convert binary data to a vector of double.

Syntax

```
vec = double(d)
```

Description

`double(d)` converts binary data to a column vector of double numbers.

See also

`char`, `uint8`, `uint16`, `uint32`, `int8`, `int16`, `int32`, `binarydata`

feval

Call machine language in binary data.

Syntax

```
feval(code)
dataout = feval(code, datain)
```

Description

`feval(code)` calls code in binary data `code` with the following instructions:

```
movea #0, a5
clr.w d0
jsr code
```

`feval(code,data)` calls code in binary data `code` with the following instructions:

```
lea (data), a5
move.l dataSize, d0
jsr code
```

The binary data `data` (possibly modified) is returned. In both cases, the code should be a subroutine and end with `rts`.

Warning

`feval` has the potential of crashing LyME if its arguments do not correspond to valid code and data.

See also

`binarydata`, `pcenativecall`

uint8 uint16 uint32 int8 int16 int32

Convert binary data to a vector of integer numbers.

Syntax

```
vec = int8(d)
vec = int16(d)
vec = int32(d)
vec = uint8(d)
vec = uint16(d)
vec = uint32(d)
```

Description

`int8(d)`, `int16(d)`, and `int32(d)` convert binary data `d` to a column vector of signed integer numbers of size 8, 16, or 32 respectively. `uint8(d)`, `uint16(d)`, and `uint32(d)` convert binary data `d` to a column vector of unsigned integer numbers of size 8, 16, or 32 respectively. Each 16-bit word in the binary data `d` corresponds to 2 8-bit integers, 1 16-bit integer, or half a 32-bit integer.

See also

`char`, `double`, `binarydata`

length

Number of words in a binary data object.

Syntax

```
n = length(d)
```

Description

`length(d)` gives the number of words in a binary data object.

See also

`binarydata`

pcenativecall

Call native (ARM) machine language in binary data.

Syntax

```
dataout = pcenativecall(code, data)
(dataout, result) = pcenativecall(code, datain)
```

Description

`pcenativecall(code, datain)` calls native ARM code in binary data code with an argument pointing to `datain`. It returns the same block of memory corresponding to `datain`, possibly modified by the execution of the code. This call is available only on handhelds with an ARM micro-processor. It relies on Palm OS function `PceNativeCall`.

The native function should have the following prototype, where `datain` points to the argument of `pcenativecall`:

```
unsigned long fun(const void *emulStateP,
    void *datain, Call68KFuncType *call68KFuncP);
```

Please refer to Palm OS documentation at http://www.palmos.com for more informations.

Warning

`pcenativecall` has the potential of crashing LyME if its arguments do not correspond to valid code and data.

See also

`binarydata`, `feval`, `processorname`

peek

Get a word anywhere in memory.

Syntax

```
value = peek(address)
```

Description

`peek(address)` reads a short word (two bytes) of memory at the address specified, which must be even. Several words may be read in one command if the argument is a vector or a matrix.

See also

poke

poke

Store a word anywhere in memory.

Syntax

```
poke(address, value)
```

Description

`poke(address,value)` stores a short word (two bytes) of memory at the address specified, which must be even. Several words may be stored in one command if the arguments are vectors or matrices. The size both arguments must be the same, or the second argument `value` must be a scalar.

See also

peek

processorname

Get the name of the microprocessor.

Syntax

```
shortname = processorname
(shortname, fullname) = processorname
```

Description

`processorname` gets the name of the microprocessor of the handheld. The first output argument is the short name, such as `'68328'` or `'ARM720T'`; the second output argument, if it exists, is the full name, such as `'Motorola 68328 (Dragonball)'` or `'ARM 720T'`.

Chapter 4

Libraries

Libraries are collections of functions which complement the set of built-in functions and operators of LME, the programming language of LyME and Sysquake. To use them, type (or add in the functions block of the SQ files which rely on them) a `use` command, such as

```
use stdlib
```

`bitfield` `bitfield` implements constructors and methods for bit fields (binary numbers). Standard operators are redefined to enable the use of & and | for bitwise operations, and subscripts for bit extraction and assignment.

`classes` `classes` implements constructors and methods for polynomial and rational functions. With them, you can use standard operator notations such as + or *.

`ratio` `ratio` implements constructors and methods for rational numbers based on long integers. Standard arithmetic and boolean operators can be used.

`constants` `constants` defines common physical constants.

`control` `control` implements basic time- and frequency-domain responses for dynamical systems.

`date` `date` implements functions for date and time manipulation and conversion to and from strings.

`filter` `filter` provides functions for the design of analog and digital filters.

`stat` `stat` provides more advanced statistical functions.

`stdlib` `stdlib` is the standard library of general-purpose functions for LME. Functions span from array creation and manipulation to coordinates transform and basic statistics.

4.1 stdlib

`stdlib` is a library which extends the native LME functions in the following areas:

– creation of matrices: `blkdiag`, `compan`, `hankel`, `linspace`, `logspace`, `toeplitz`

– geometry: `cart2sph`, `cart2pol`, `pol2cart`, `sph2cart`, `subspace`

– functions on integers: `primes`

– statistics: `corrcoef`, `median`, `perms`

– data processing: `circshift`, `cumtrapz`, `fftshift`, `filter2`, `hist`, `ifftshift`, `polyfit`, `polyvalm`, `trapz`

– other: `isreal`, `sortrows`

The following statement makes available functions defined in `stdlib`:

```
use stdlib
```

cart2pol

Cartesian to polar coordinates transform.

Syntax

```
use stdlib
(phi, r) = cart2pol(x, y)
(phi, r, z) = cart2pol(x, y, z)
```

Description

`(phi,r)=cart2pol(x,y)` transforms Cartesian coordinates `x` and `y` to polar coordinates `phi` and `r` such that $x = r\cos(\varphi)$ and $x = r\sin(\varphi)$.

`(phi,r,z)=cart2pol(x,y,z)` transform Cartesian coordinates to cylindrical coordinates, leaving `z` unchanged.

Example

```
use stdlib
(phi, r) = cart2pol(1, 2)
  phi =
    1.1071
  r =
    2.2361
```

See also

`cart2sph`, `pol2cart`, `sph2cart`

cart2sph

Cartesian to spherical coordinates transform.

Syntax

```
use stdlib
(phi, theta, r) = cart2sph(x, y, z)
```

Description

`(phi,theta,r)=cart2sph(x,y,z)` transforms Cartesian coordinates `x`, `y`, and `z` to polar coordinates `phi`, `theta`, and `r` such that $x = r\cos(\varphi)\cos(\vartheta)$, $y = r\sin(\varphi)\cos(\vartheta)$, and $z = r\sin(\vartheta)$.

Example

```
use stdlib
(phi, theta, r) = cart2sph(1, 2, 3)
  phi =
    1.1071
  theta =
    0.9303
  r =
    3.7417
```

See also

`cart2pol`, `pol2cart`, `sph2cart`

circshift

Shift the elements of a matrix in a circular way.

Syntax

```
use stdlib
B = circshift(A, shift_vert)
B = circshift(A, [shift_vert, shift_hor])
```

Description

`circshift(A,sv)` shifts the rows of matrix `A` downward by `sv` rows. The `sv` bottom rows of the input matrix become the `sv` top rows of the output matrix. `sv` may be negative to go the other way around.

`circshift(A,[sv,sh])` shifts the rows of matrix `A` downward by `sv` rows, and its columns to the right by `sh` columns. The `sv` bottom rows of the input matrix become the `sv` top rows of the output matrix, and the `sh` rightmost columns become the `sh` leftmost columns.

See also

`rot90`, `fliplr`, `flipud`

blkdiag

Block-diagonal matrix.

Syntax

```
use stdlib
X = blkdiag(B1, B2, ...)
```

Description

`blkdiag(B1,B2,...)` creates a block-diagonal matrix with matrix blocks `B1`, `B2`, etc. Its input arguments do not need to be square.

Example

```
use stdlib
blkdiag([1,2;3,4], 5)
  1 2 0
  3 4 0
  0 0 5
blkdiag([1,2], [3;4])
  1 2 0
  0 0 3
  0 0 4
```

See also

`diag`

compan

Companion matrix.

Syntax

```
use stdlib
X = compan(pol)
```

Description

`compan(pol)` gives the companion matrix of polynomial `pol`, a square matrix whose eigenvalues are the roots of `pol`.

Example

```
use stdlib
compan([2,3,4,5])
  -1.5  -2.0  -2.5
   1.0   0.0   0.0
   0.0   1.0   0.0
```

See also

`poly`, `eig`

corrcoef

Correlation coefficients.

Syntax

```
use stdlib
S = corrcoef(X)
S = corrcoef(X1, X2)
```

Description

`corrcoef(X)` calculates the correlation coefficients of the columns of the m-by-n matrix X. The result is a square n-by-n matrix whose diagonal is 1.

`corrcoef(X1,X2)` calculates the correlation coefficients of `X1` and `X2` and returns a 2-by-2 matrix. It is equivalent to `corrcoef([X1(:),X2(:)])`.

Example

```
use stdlib
corrcoef([1, 3; 2, 5; 4, 4; 7, 10])
  1       0.8915
  0.8915  1
corrcoef(1:5, 5:-1:1)
  1  -1
 -1   1
```

See also

`cov`

cumtrapz

Cumulative numerical integration with trapezoidal approximation.

Syntax

```
use stdlib
S = cumtrapz(Y)
S = cumtrapz(X, Y)
S = cumtrapz(X, Y, dim)
```

Description

`cumtrapz(Y)` calculates an approximation of the cumulative integral of a function given by the samples in Y with unit intervals. The trapezoidal approximation is used. If Y is neither a row nor a column vector, integration is performed along its columns. The result has the same size as Y. The first value(s) is (are) 0.

`cumtrapz(X,Y)` specifies the location of the samples. A third argument may be used to specify along which dimension the integration is performed.

Example

```
use stdlib
cumtrapz([2, 3, 5])
  0     2.5   6.5
cumtrapz([1, 2, 5], [2, 3, 5])
  0     2.5  14.5
```

See also

`cumsum`, `trapz`

fftshift

Shift DC frequency of FFT from beginning to center of spectrum.

Syntax

```
use stdlib
Y = fftshift(X)
```

Description

`fftshift(X)` shifts halves of vector (1-d) or matrix (2-d) `X` to move the DC component to the center. It should be used after `fft` or `fft2`.

See also

`fft`, `ifftshift`

filter2

Digital 2-d filtering of data.

Syntax

```
use stdlib
Y = filter2(F, X)
Y = filter2(F, X, shape)
```

Description

`filter2(F,X)` filters matrix `X` with kernel `F` with a 2-d correlation. The result has the same size as `X`.

An optional third argument is passed to `conv2` to specify another method to handle the borders.

`filter2` and `conv2` have three differences: arguments `F` and `X` are permuted, filtering is performed with a correlation instead of a convolution (i.e. the kernel is rotated by 180 degrees), and the default method for handling the borders is `'same'` instead of `'full'`.

See also

`filter`, `conv2`

hankel

Hankel matrix.

Syntax

```
use stdlib
X = hankel(c, r)
```

Description

`hankel(c,r)` creates a Hankel matrix whose first column contains the elements of vector `c` and whose last row contains the elements of vector `r`. A Hankel matrix is a matrix whose antidiagonals have the same value. In case of conflict, the first element of `r` is ignored. The default value of `r` is a zero vector the same length as `c`.

Example

```
use stdlib
hankel(1:3, 3:8)
  1  2  3  4  5  6
  2  3  4  5  6  7
  3  4  5  6  7  8
```

See also

`toeplitz`, `diag`

hist

Histogram.

Syntax

```
use stdlib
(N, X) = hist(Y)
(N, X) = hist(Y, m)
(N, X) = hist(Y, m, dim)
N = hist(Y, X)
N = hist(Y, X, dim)
```

Description

`hist(Y)` gives the number of elements of vector `Y` in 10 equally-spaced intervals. A second input argument may be used to specify the number of intervals. The center of the intervals may be obtained in a second output argument.

If Y is an array, histograms are computed along the dimension specified by a third argument or the first non-singleton dimension; the result N has the same size except along that dimension.

When the second argument is a vector, it specifies the centers of the intervals.

Example

```
use stdlib
(N, X) = hist(logspace(0,1), 5)
  N =
    45    21    14    11     9
  X =
     1.9   3.7   5.5   7.3   9.1
```

ifftshift

Shift DC frequency of FFT from center to beginning of spectrum.

Syntax

```
use stdlib
Y = ifftshift(X)
```

Description

`ifftshift(X)` shifts halves of vector (1-d) or matrix (2-d) `X` to move the DC component from the center. It should be used before `ifft` or `ifft2`. It reverses the effect of `fftshift`.

See also

`ifft`, `fftshift`

isreal

Test for a real number.

Syntax

```
use stdlib
b = isreal(x)
```

Description

`isreal(x)` is true if x is a real scalar or a matrix whose entries are all real.

Examples

```
use stdlib
isreal([2,5])
  true
isreal([2,3+2j])
  false
isreal(exp(pi*1j))
  true
```

See also

`isnumeric`, `isfloat`, `isscalar`

linspace

Sequence of linearly-spaced elements.

Syntax

```
use stdlib
v = linspace(x1, x2)
v = linspace(x1, x2, n)
```

Description

`linspace(x1,x2)` produces a row vector of 100 values spaced linearly from x1 and x2 inclusive. With a third argument, `linspace(x1,x2,n)` produces a row vector of n values.

Examples

```
use stdlib
linspace(1,10)
  1.0000 1.0909 1.1818 ... 9.9091 10.0000
linspace(1,2,6)
  1.0  1.2  1.4  1.6  1.8  2.0
```

See also

`logspace`, operator `:`

logspace

Sequence of logarithmically-spaced elements.

Syntax

```
use stdlib
v = logspace(x1, x2)
v = logspace(x1, x2, n)
```

Description

`logspace(x1,x2)` produces a row vector of 100 values spaced logarithmically from 10ˆx1 and 10ˆx2 inclusive. With a third argument, `logspace(x1,x2,n)` produces a row vector of `n` values.

Example

```
logspace(0,1)
  1.0000 1.0235 1.0476 ... 9.5455 9.7701 10.0000
```

See also

`linspace`, operator `:`

median

Median.

Syntax

```
use stdlib
x = median(v)
v = median(M)
v = median(M, dim)
```

Description

`median(v)` gives the median of vector `v`, i.e. the value `x` such that half of the elements of `v` are smaller and half of the elements are larger.

`median(M)` gives a row vector which contains the median of the columns of `M`. With a second argument, `median(M,dim)` operates along dimension `dim`.

Example

```
use stdlib
median([1, 2, 5, 6, inf])
  5
```

See also

mean, sort

perms

Array of permutations.

Syntax

```
use stdlib
M = perms(v)
```

Description

perm(v) gives an array whose rows are all the possible permutations of vector v.

Example

```
use stdlib
perms(1:3)
  3  2  1
  3  1  2
  2  3  1
  1  3  2
  2  1  3
  1  2  3
```

See also

sort

pol2cart

Polar to Cartesian coordinates transform.

Syntax

```
use stdlib
(x, y) = pol2cart(phi, r)
(x, y, z) = pol2cart(phi, r, z)
```

Description

`(x,y)=pol2cart(phi,r)` transforms polar coordinates `phi` and `r` to Cartesian coordinates `x` and `y` such that $x = r\cos(\varphi)$ and $x = r\sin(\varphi)$.

`(x,y,z)=pol2cart(phi,r,z)` transforms cylindrical coordinates to Cartesian coordinates, leaving `z` unchanged.

Example

```
use stdlib
(x, y) = pol2cart(1, 2)
  x =
    1.0806
  y =
    1.6829
```

See also

`cart2pol`, `cart2sph`, `sph2cart`

polyfit

Polynomial fit.

Syntax

```
use stdlib
pol = polyfit(x, y, n)
```

Description

`polyfit(x,y,n)` calculates the polynomial (given as a vector of descending power coefficients) of order `n` which best fits the points given by vectors `x` and `y`. The least-square algorithm is used.

Example

```
use stdlib
pol = polyfit(1:5, [2, 1, 4, 5, 2], 3)
  pol =
    -0.6667  5.5714 -12.7619  9.8000
polyval(pol, 1:5)
    1.9429  1.2286  3.6571  5.2286  1.9429
```

polyvalm

Value of a polynomial with square matrix argument.

Syntax

```
use stdlib
Y = polyvalm(pol, X)
```

Description

polyvalm(pol,X) evaluates the polynomial given by the coefficients pol (in descending power order) with a square matrix argument.

Example

```
use stdlib
polyvalm([1,2,8],[2,1;0,1])
  16  5
   0 11
```

See also

polyval

primes

List of primes.

Syntax

```
use stdlib
v = primes(n)
```

Description

primes(n) gives a row vector which contains the primes up to n.

Example

```
use stdlib
primes(20)
  2  3  5  7 11 13 17 19
```

sortrows

Sort matrix rows.

Syntax

```
use stdlib
(S, index) = sortrows(M)
(S, index) = sortrows(M, sel)
(S, index) = sortrows(M, sel, dim)
```

Description

`sortrows(M)` sort the rows of matrix `M`. The sort order is based on the first column of `M`, then on the second one for rows with the same value in the first column, and so on.

`sortrows(M,sel)` use the columns specified in `sel` for comparing the rows of `M`. A third argument `dim` can be used to specify the dimension of the sort: 1 for sorting the rows, or 2 for sorting the columns.

The second output argument of `sortrows` gives the new order of the rows or columns as a vector of indices.

Example

```
use stdlib
sortrows([3, 1, 2; 2, 2, 1; 2, 1, 2])
  2  1  2
  2  2  1
  3  1  2
```

See also

`sort`

sph2cart

Spherical to Cartesian coordinates transform.

Syntax

```
use stdlib
(x, y, z) = sph2cart(phi, theta, r)
```

Description

`(x,y,z)=sph2cart(phi,theta,r)` transforms polar coordinates `phi`, `theta`, and `r` to Cartesian coordinates `x`, `y`, and `z` such that $x = r\cos(\varphi)\cos(\vartheta)$, $y = r\sin(\varphi)\cos(\vartheta)$, and $z = r\sin(\vartheta)$.

Example

```
use stdlib
(x, y, z) = sph2cart(1, 2, 3)
  x =
    -0.6745
  y =
    -1.0505
  z =
    2.7279
```

See also

`cart2pol`, `cart2sph`, `pol2cart`

subspace

Angle between two subspaces.

Syntax

```
use stdlib
theta = subspace(A, B)
```

Description

`subspace(A,B)` gives the angle between the two subspaces spanned by the columns of A and B.

Examples

Angle between two vectors in Rˆ2:

```
use stdlib
a = [3; 2];
b = [1; 5];
subspace(a, b)
  0.7854
```

Angle between the vector `[1;1;1]` and the plane spanned by `[2;5;3]` and `[7;1;0]` in Rˆ3:

```
subspace([1;1;1], [2,7;5,1;3,0])
  0.2226
```

toeplitz

Toeplitz matrix.

Syntax

```
use stdlib
X = toeplitz(c, r)
X = toeplitz(c)
```

Description

`toeplitz(c,r)` creates a Toeplitz matrix whose first column contains the elements of vector `c` and whose first row contains the elements of vector `r`. A Toeplitz matrix is a matrix whose diagonals have the same value. In case of conflict, the first element of `r` is ignored. With one argument, `toeplitz` gives a symmetric square matrix.

Example

```
use stdlib
toeplitz(1:3, 1:5)
  1  2  3  4  5
  2  1  2  3  4
  3  2  1  2  3
```

See also

`hankel`, `diag`

trapz

Numerical integration with trapezoidal approximation.

Syntax

```
use stdlib
s = trapz(Y)
s = trapz(X, Y)
s = trapz(X, Y, dim)
```

Description

`trapz(Y)` calculates an approximation of the integral of a function given by the samples in Y with unit intervals. The trapezoidal approximation is used. If Y is an array, integration is performed along the first non-singleton dimension.

`trapz(X,Y)` specifies the location of the samples. A third argument may be used to specify along which dimension the integration is performed.

Example

```
use stdlib
trapz([2, 3, 5])
  6.5
trapz([1, 2, 5], [2, 3, 5])
  14.5
```

See also

`sum`, `cumtrapz`

4.2 stat

`stat` is a library which adds to LME advanced statistical functions.

The following statement makes available functions defined in `stat`:

```
use stat
```

bootstrp

Bootstrap estimate.

Syntax

```
use stat
(stats, samples) = bootstrp(n, fun, D1, ...)
```

Description

`bootstrp(n,fun,D)` picks random observations from the rows of matrix (or column vector) `D` to form `n` sets which have all the same size as `D`; then it applies function `fun` (a function name or reference or an inline function) to each set and returns the results in the columns of stats. Up to three different set of data can be provided.

`bootstrp` gives an idea of the robustness of the estimate with respect to the choice of the observations.

Example

```
use stat
D = rand(1000, 1);
bootstrp(5, @std, D)
    0.2938
    0.2878
    0.2793
    0.2859
    0.2844
```

geomean

Geometric mean of a set of values.

Syntax

```
use stat
m = geomean(A)
m = geomean(A, dim)
```

Description

`geomean(A)` gives the geometric mean of the columns of array `A` or of the row vector `A`. The dimension along which geomean proceeds may be specified with a second argument.

The geometric mean of vector v of length n is defined as $(\prod_i v_i)^{1/n}$.

Example

```
use stat
geomean(1:10)
  4.5287
mean(1:10)
  5.5
exp(mean(log(1:10)))
  4.5287
```

See also

harmmean, mean

harmmean

Harmonic mean of a set of values.

Syntax

```
use stat
m = harmmean(A)
m = harmmean(A, dim)
```

Description

harmmean(A) gives the harmonic mean of the columns of array A or of the row vector A. The dimension along which harmmean proceeds may be specified with a second argument.

The inverse of the harmonic mean is the arithmetic mean of the inverse of the observations.

Example

```
use stat
harmmean(1:10)
  3.4142
mean(1:10)
  5.5
```

See also

geomean, mean

iqr

Interquartile range.

Syntax

```
use stat
m = iqr(A)
m = iqr(A, dim)
```

Description

`iqr(A)` gives the interquartile range of the columns of array `A` or of the row vector `A`. The dimension along which `iqr` proceeds may be specified with a second argument.

The interquartile range is the difference between the 75th percentile and the 25th percentile.

Example

```
use stat
iqr(rand(1,1000))
  0.5158
```

See also

`trimmean`, `prctile`

mad

Mean absolute deviation.

Syntax

```
use stat
m = mad(A)
m = mad(A, dim)
```

Description

`mad(A)` gives the mean absolute deviation of the columns of array `A` or of the row vector `A`. The dimension along which `mad` proceeds may be specified with a second argument.

The mean absolute deviation is the mean of the absolute value of the deviation between each observation and the arithmetic mean.

Example

```
use stat
mad(rand(1,1000))
  0.2446
```

See also

`trimmean`, `mean`, `iqr`

nancorrcoef

Correlation coefficients after discarding NaNs.

Syntax

```
use stat
S = nancorrcoef(X)
S = nancorrcoef(X1, X2)
```

Description

nancorrcoef(X) calculates the correlation coefficients of the columns of the m-by-n matrix X. NaN values are ignored. The result is a square n-by-n matrix whose diagonal is 1.

nancorrcoef(X1,X2) calculates the correlation coefficients of X1 and X2 and returns a 2-by-2 matrix, ignoring NaN values. It is equivalent to nancorrcoef([X1(:),X2(:)]).

See also

nanmean, nanstd, nancov, corrcoef

nancov

Covariance after discarding NaNs.

Syntax

```
use stat
M = nancov(data)
M = nancov(data, 0)
M = nancov(data, 1)
```

Description

nancov(data) returns the best unbiased estimate m-by-m covariance matrix of the n-by-m matrix data for a normal distribution. NaN values are ignored. Each row of data is an observation where n quantities were measured. nancov(data,0) is the same as nancov(data).

nancov(data,1) returns the m-by-m covariance matrix of the n-by-m matrix data which contains the whole population; NaN values are ignored.

See also

nanmean, nanstd, nancorrcoef, cov

nanmean

Mean after discarding NaNs.

Syntax

```
use stat
y = nanmean(A)
y = nanmean(A, dim)
```

Description

nanmean(v) returns the arithmetic mean of the elements of vector v. nanmean(A) returns a row vector whose elements are the means of the corresponding columns of array A. nanmean(A,dim) returns the mean of array A along dimension dim; the result is a row vector if dim is 1, or a column vector if dim is 2. In all cases, NaN values are ignored.

Examples

```
use stat
nanmean([1,2,nan;nan,6,7])
  1 4 7
nanmean([1,2,nan;nan,6,7],2)
  1.5
  6.5
nanmean([nan,nan])
  nan
```

See also

nanmedian, nanstd, mean

nanmedian

Median after discarding NaNs.

Syntax

```
use stat
y = nanmedian(A)
y = nanmedian(A, dim)
```

Description

`nanmedian(v)` gives the median of vector `v`, i.e. the value `x` such that half of the elements of `v` are smaller and half of the elements are larger. NaN values are ignored.

`nanmedian(A)` gives a row vector which contains the median of the columns of `A`. With a second argument, `nanmedian(A,dim)` operates along dimension `dim`.

See also

`nanmean`, `median`

nanstd

Standard deviation after discarding NaNs.

Syntax

```
use stat
y = nanstd(A)
y = nanstd(A, p)
y = nanstd(A, p, dim)
```

Description

`nanstd(v)` returns the standard deviation of vector `v` with NaN values ignored, normalized by one less than the number of non-NaN values. With a second argument, `nanstd(v,p)` normalizes by one less than the number of non-NaN values if `p` is true, or by the number of non-NaN values if `p` is false.

`nanstd(M)` gives a row vector which contains the standard deviation of the columns of `M`. With a third argument, `nanstd(M,p,dim)` operates along dimension `dim`. In all cases, NaN values are ignored.

Example

```
use stat
nanstd([1,2,nan;nan,6,7;10,11,12])
  6.3640 4.5092 3.5355
```

See also

`nanmedian`, `nanstd`, `mean`

nansum

Sum after discarding NaNs.

Syntax

```
use stat
y = nansum(A)
y = nansum(A, dim)
```

Description

`nansum(v)` returns the sum of the elements of vector `v`. NaN values are ignored. `nansum(A)` returns a row vector whose elements are the sums of the corresponding columns of array `A`. `nansum(A,dim)` returns the sum of array `A` along dimension `dim`; the result is a row vector if `dim` is 1, or a column vector if `dim` is 2.

See also

nanmean, `sum`

pdist

Pairwise distance between observations.

Syntax

```
use stat
d = pdist(M)
d = pdist(M, metric)
d = pdist(M, metric, p)
```

Description

`pdist` calculates the distance between pairs of rows of the observation matrix `M`. The result is a column vector which contains the distances between rows `i` and `j` with `i<j`. It can be resized to a square matrix with `squareform`.

By default, the metric used to calculate the distance is the euclidean distance; but it can be specified with a second argument:

`'euclid'`	euclidean distance
`'seuclid'`	standardized euclidean distance
`'mahal'`	Mahalanobis distance
`'cityblock'`	sum of absolute values
`'minkowski'`	Minkowski metric with parameter p

The standardized euclidean distance is the euclidean distance after each column of `M` has been divided by its standard deviation. The Minkowski metric is based on the p-norm of vector differences.

Examples

```
use stat
pdist((1:3)')
  1 2 1
squareform(pdist((1:3)'))
  0 1 2
  1 0 1
  2 1 0
squareform(pdist([1,2,6; 3,1,7;6,1,2]))
  0         2.4495    6.4807
  2.4495    0         5.831
  6.4807    5.831     0
```

See also

`squareform`

prctile

Percentile.

Syntax

```
use stat
m = prctile(A, prc)
m = prctile(A, prc, dim)
```

Description

`prctile(A,prc)` gives the smallest values larger than `prc` percent of the elements of each column of array `A` or of the row vector `A`. The dimension along which `prctile` proceeds may be specified with a third argument.

Example

```
 prctile(rand(1,1000),90)
   0.8966
```

See also

`trimmean`, `iqr`

range

Mean absolute deviation.

Syntax

```
 use stat
 m = range(A)
 m = range(A, dim)
```

Description

`range(A)` gives the differences between the maximum and minimum values of the columns of array `A` or of the row vector `A`. The dimension along which range proceeds may be specified with a second argument.

Example

```
 range(rand(1,100))
   0.9602
```

See also

`iqr`

squareform

Resize the output of `pdist` to a square matrix.

Syntax

```
 use stat
 D = squareform(d)
```

Description

`squareform(d)` resize `d`, which should be the output of `pdist`, into a symmetric square matrix `D`, so that the distance between observations `i` and `j` is `D(i,j)`.

See also

`pdist`

trimmean

Trimmed mean of a set of values.

Syntax

```
 use stat
 m = trimmean(A, prc)
 m = trimmean(A, prc, dim)
```

Description

`trimmean(A,prc)` gives the arithmetic mean of the columns of array `A` or of the row vector `A` once `prc/2` percent of the values have been removed from each end. The dimension along which `trimmean` proceeds may be specified with a third argument.

`trimmean` is less sensitive to outliers than the regular arithmetic mean.

See also

`prctile`, `geomean`, `median`, `mean`

zscore

Z score (normalized deviation).

Syntax

```
 use stat
 Y = zscore(X)
 Y = zscore(X, dim)
```

Description

`zscore(X)` normalizes the columns of array `X` or the row vector `X` by subtracting their mean and dividing by their standard deviation. The dimension along which `zscore` proceeds may be specified with a second argument.

4.3 classes

Library `classes` implements the constructors and methods of two classes: `polynom` for polynomials, and `ratfun` for rational functions. Basic arithmetic operators and functions are overloaded to support expressions with the same syntax as for numbers and matrices.

The following statement makes available functions defined in `classes`:

```
use classes
```

polynom::polynom

Polynom object constructor.

Syntax

```
use classes
a = polynom
a = polynom(coef)
```

Description

`polynom(coef)` creates a polynom object initialized with the coefficients in vector `coef`, given in descending powers of the variable. Without argument, `polynom` returns a polynom object initialized to 0.

The following operators and functions may be used with polynom arguments, with results analog to the corresponding functions of LME.

`-`	`minus`	`+`	`plus`
`^`	`mpower`		`rem`
`\`	`mldivide`		`roots`
`/`	`mrdivide`	`-`	`uminus`
	`mtimes`	`+`	`uplus`

Examples

```
use classes
p = polynom([3,0,1,-4,2])
  p =
    3x^4+x^2-4x+2
q = 3 * p^2 + 8
  q =
    27x^8+18x^6-72x^5+39x^4-24x^3+60x^2-48x+20
```

See also

`polynom::disp`, `polynom::double`, `polynom::subst`, `polynom::diff`, `polynom::int`, `polynom::inline`, `polynom::feval`, `ratfun::ratfun`

polynom::disp

Display a polynom object.

Syntax

```
use classes
disp(a)
```

Description

`disp(a)` displays polynomial a. It is also executed implicitly when LME displays the polynom result of an expression which does not end with a semicolon.

Example

```
use classes
p = polynom([3,0,1,-4,2])
  p =
    3x^4+x^2-4x+2
```

See also

`polynom::polynom`, `disp`

polynom::double

Convert a polynom object to a vector of coefficients.

Syntax

```
use classes
coef = double(a)
```

Description

`double(a)` converts polynomial a to a row vector of descending-power coefficients.

Example

```
use classes
p = polynom([3,0,1,-4,2]);
double(p)
  3 0 1 -4 2
```

See also

`polynom::polynom`

polynom::subst

Substitute the variable of a polynom object with another polynomial.

Syntax

```
use classes
subst(a, b)
```

Description

`subst(a,b)` substitutes the variable of polynom a with polynom b.

Example

```
use classes
p = polynom([1,2,3])
  p =
    x^2+3x+9
q = polynom([2,0])
  q =
    2x
r = subst(p, q)
  r =
    4x^2+6x+9
```

See also

`polynom::polynom`, `polynom::feval`

polynom::diff

Polynom derivative.

Syntax

```
use classes
diff(a)
```

Description

`diff(a)` differentiates polynomial a.

Example

```
use classes
p = polynom([3,0,1,-4,2]);
q = diff(p)
  q =
    12x^3+2x-4
```

See also

`polynom::polynom`, `polynom::int`, `polyder`

polynom::int

Polynom integral.

Syntax

```
use classes
int(a)
```

Description

`int(a)` integrates polynomial a.

Example

```
use classes
p = polynom([3,0,1,-4,2]);
q = int(p)
  q =
    0.6x^5+0.3333x^3-2x^2+2x
```

See also

`polynom::polynom`, `polynom::diff`, `polyint`

polynom::inline

Conversion from polynom object to inline function.

Syntax

```
use classes
fun = inline(a)
```

Description

`inline(a)` converts polynomial a to an inline function which can then be used with functions such as `feval` and ode45.

Example

```
use classes
p = polynom([3,0,1,-4,2]);
fun = inline(p)
  fun =
    <inline function>
dumpvar('fun', fun);
  fun = inline('function y=f(x);y=polyval([3,0,1,-4,2],x);');
```

See also

`polynom::polynom`, `polynom::feval`, ode45

polynom::feval

Evaluate a polynom object.

Syntax

```
use classes
y = feval(a, x)
```

Description

`feval(a,x)` evaluates polynomial a for the value of x. If x is a vector or a matrix, the evaluation is performed separately on each element and the result has the same size as x.

Example

```
use classes
p = polynom([3,0,1,-4,2]);
y = feval(p, 1:5)
  y =
    2    46   242   770  1882
```

See also

`polynom::polynom`, `polynom::inline`, `feval`

ratfun::ratfun

Ratfun object constructor.

Syntax

```
use classes
a = ratfun
a = ratfun(coefnum)
a = ratfun(coefnum, coefden)
```

Description

`ratfun(coefnum,coefden)` creates a ratfun object initialized with the coefficients in vectors `coefnum` and `coefden`, given in descending powers of the variable. Without argument, `ratfun` returns a ratfun object initialized to 0. If omitted, `coefden` defaults to 1.

The following operators and functions may be used with ratfun arguments, with results analog to the corresponding functions of LME.

	`inv`	`*`	`mtimes`
`-`	`minus`	`+`	`plus`
`\`	`mldivide`	`-`	`uminus`
`ˆ`	`mpower`	`+`	`uplus`
`/`	`mrdivide`		

Example

```
use classes
r = ratfun([3,0,1,-4,2], [2,5,0,1])
  r =
    (3xˆ4+xˆ2-4x+2)/(2xˆ3+5xˆ2+1)
```

See also

`ratfun::disp`, `ratfun::inline`, `ratfun::feval`, `polynom::polynom`

ratfun::disp

Display a ratfun object.

Syntax

```
use classes
disp(a)
```

Description

`disp(a)` displays rational function a. It is also executed implicitly when LME displays the ratfun result of an expression which does not end with a semicolon.

See also

`ratfun::ratfun`, `disp`

ratfun::num

Get the numerator of a ratfun as a vector of coefficients.

Syntax

```
use classes
coef = num(a)
```

Description

`num(a)` gets the numerator of a as a row vector of descending-power coefficients.

See also

`ratfun::den`, `ratfun::ratfun`

ratfun::den

Get the denominator of a ratfun as a vector of coefficients.

Syntax

```
use classes
coef = den(a)
```

Description

`den(a)` gets the denominator of a as a row vector of descending-power coefficients.

See also

`ratfun::num`, `ratfun::ratfun`

ratfun::diff

Ratfun derivative.

Syntax

```
use classes
diff(a)
```

Description

`diff(a)` differentiates ratfun a.

Example

```
use classes
r = ratfun([1,3,0,1],[2,5]);
q = diff(r)
  q =
    (4x^3+21x^2+30x-2)/(4x^2+20x+25)
```

See also

`ratfun::ratfun`

ratfun::inline

Conversion from ratfun to inline function.

Syntax

```
use classes
fun = inline(a)
```

Description

`inline(a)` converts ratfun a to an inline function which can then be used with functions such as `feval` and ode45.

See also

`ratfun::ratfun`, `ratfun::feval`, ode45

ratfun::feval

Evaluate a ratfun object.

Syntax

```
use classes
y = feval(a, x)
```

Description

`feval(a,x)` evaluates ratfun a for the value of x. If x is a vector or a matrix, the evaluation is performed separately on each element and the result has the same size as x.

Example

```
use classes
r = ratfun([1,3,0,1],[2,5]);
y = feval(r, 1:5)
  y =
    0.7143    2.3333    5.0000    8.6923   13.4000
```

See also

`ratfun::ratfun`, `ratfun::inline`, `feval`

4.4 ratio

Library `ratio` implements the constructors and methods of class `ratio` for rational numbers. It is based on long integers, so that the precision is limited only by available memory. Basic arithmetic operators and functions are overloaded to support expressions with the same syntax as for numbers.

The following statement makes available functions defined in `ratio`:

```
use ratio
```

ratio::ratio

Ratio object constructor.

Syntax

```
use ratio
r = ratio
r = ratio(n)
r = ratio(num, den)
r = ratio(r)
```

Description

`ratio(num, den)` creates a rational fraction object whose value is num/den. Arguments num and den may be double integer numbers or longint. Common factors are canceled out. With one numeric input argument, `ratio(n)` creates a rational fraction whose denominator is 1. Without input argument, `ratio` creates a rational number whose value is 0.

With one input argument which is already a `ratio` object, `ratio` returns it without change.

The following operators and functions may be used with `ratio` objects, with results analog to the corresponding functions of LME.

`==`	`eq`	`\`	`mldivide`
`>=`	`ge`	`^`	`mpower`
`>`	`gt`	`/`	`mrdivide`
	`inv`	`*`	`mtimes`
`<=`	`le`	`~=`	`ne`
`<`	`lt`	`+`	`plus`
	`max`	`-`	`uminus`
	`min`	`+`	`uplus`
`-`	`minus`		

Examples

```
use ratio
r = ratio(2, 3)
  r =
    2/3
q = 5 * r - 1
  q =
    7/3
```

See also

`ratio::disp`, `ratio::double`, `ratio::char`

ratio::char

Display a ratio object.

Syntax

```
use ratio
char(r)
```

Description

`char(r)` converts ratio `r` to a character string.

See also

`ratio::ratio`, `ratio::disp`, `char`

ratio::disp

Display a ratio object.

Syntax

```
use ratio
disp(r)
```

Description

`disp(r)` displays ratio `r` with the same format as `char`. It is also executed implicitly when LME displays the ratio result of an expression which does not end with a semicolon.

See also

`ratio::ratio`, `ratio::char`, `disp`

ratio::double

Convert a ratio object to a floating-point number.

Syntax

```
use ratio
x = double(r)
```

Description

`double(r)` converts ratio `r` to a floating-point number of class double.

Example

```
use ratio
r = ratio(2, 3);
double(r)
  0.6666
```

See also

`ratio::ratio`

4.5 bitfield

Library `bitfield` implements the constructor and methods of class `bitfield` for bit fields (binary numbers). Basic arithmetic operators and functions are overloaded to support expressions with the same syntax as for numbers and matrices. Contrary to integer numbers, bitfield objects have a length (between 1 and 32) and are displayed in binary.

The following statement makes available functions defined in `bitfield`:

```
use bitfield
```

bitfield::beginning

First bit position in a bitfield.

Syntax

```
use bitfield
a(...beginning...)
```

Description

In the index expression of a bitfield, `beginning` is the position of the least-significant bit, i.e. 0.

See also

`bitfield::bitfield`, `bitfield::end`

bitfield::bitfield

Bitfield object constructor.

Syntax

```
use bitfield
a = bitfield
a = bitfield(n)
a = bitfield(n, wordlength)
```

Description

`bitfield(n,wordlength)` creates a bitfield object initialized with the `wordlength` least significant bits of the nonnegative integer number `n`. The default value of `wordlength` is 32 if `n` is a double, an int32 or a uint32 number; 16 is `n` is an int16 or uint16 number; or 8 if `n` is an int8 or uint8 number. Without argument, `bitfield` gives a bit field of 32 bits 0. Like any integer number in LME, `n` may be written in base 2, 8, 10, or 16: `0b1100`, `014`, 12, and `0xc` all represent the same number.

The following operators and functions may be used with bitfield arguments, with results analog to the corresponding functions of LME. Logical functions operate bitwise.

`&`	`and`	`~`	`not`
`==`	`eq`	`|`	`or`
`-`	`minus`	`+`	`plus`
`\`	`mldivide`	`-`	`uminus`
`/`	`mrdivide`	`+`	`uplus`
	`mtimes`		`xor`
`~=`	`ne`		

Indexes into bit fields are non-negative integers: 0 represents the least-significant bit, and wordlength-1 the most-significant bit. Unlike arrays, bits are not selected with logical arrays, but with other bit fields where ones represent the bits to be selected; for example `a(0b1011)` selects bits 0, 1 and 3. This is consistent with the way `bitfield::find` is defined.

Examples

```
use bitfield
a = bitfield(123, 16)
  a =
    0b0000000001111011
b = ~a
  b =
    0b1111111110000100
b = a * 5
  b =
    0b0000001001100111
```

See also

`bitfield::disp`, `bitfield::double`

bitfield::disp

Display a bitfield object.

Syntax

```
use bitfield
disp(a)
```

Description

`disp(a)` displays bitfield a. It is also executed implicitly when LME displays the bitfield result of an expression which does not end with a semicolon.

See also

`bitfield::bitfield`, `disp`

bitfield::double

Convert a bitfield object to a double number.

Syntax

```
use bitfield
n = double(a)
```

Description

`double(a)` converts bitfield a to double number.

Example

```
use bitfield
a = bitfield(123, 16);
double(a)
  123
```

See also

`bitfield::bitfield`

bitfield::end

Last bit position in a bitfield.

Syntax

```
use bitfield
a(...end...)
```

Description

In the index expression of a bitfield, end is the position of the most-significant bit, i.e. 1 less than the word length.

See also

`bitfield::bitfield`, `bitfield::beginning`

bitfield::find

Find the ones in a bitfield.

Syntax

```
use bitfield
ix = find(a)
```

Description

`find(a)` finds the bits equal to 1 in bitfield a. The result is a vector of bit positions in ascending order; the least-significant bit is number 0.

Example

```
use bitfield
a = bitfield(123, 16)
  a =
    0b0000000001111011
ix = find(a)
  ix =
     0 1 3 4 5 6
```

See also

`bitfield::bitfield`, `find`

bitfield::int8 bitfield::int16 bitfield::int32

Convert a bitfield object to a signed integer number, with sign extension.

Syntax

```
use bitfield
n = int8(a)
n = int16(a)
n = int32(a)
```

Description

int8(a), int16(a), and int32(a) convert bitfield a to an int8, int16, or int32 number respectively. If a has less bits than the target integer and the most significant bit of a is 1, sign extension is performed; i.e. the most significant bits of the result are set to 1, so that it is negative. If a has more bits than the target integer, most significant bits are ignored.

Example

```
use bitfield
a = bitfield(9, 4);
  a =
    0x1001
i = int8(a)
  i =
    210
b = bitfield(i)
  b =
    0b11111001
```

See also

uint8, uint16, uint32, bitfield::int8, bitfield::int16, bitfield::int32, bitfield::double, bitfield::bitfield

bitfield::length

Word length of a bitfield.

Syntax

```
use bitfield
wordlength = length(a)
```

Description

length(a) gives the number of bits of bitfield a.

Example

```
use bitfield
a = bitfield(123, 16);
length(a)
  16
```

See also

`bitfield::bitfield`, `length`

bitfield::sign

Get the sign of a bitfield.

Syntax

```
use bitfield
s = sign(a)
```

Description

`sign(a)` gets the sign of bitfield a. The result is -1 if the most-significant bit of a is 1, 0 if all bits of a are 0, or 1 otherwise.

Example

```
use bitfield
a = bitfield(5, 3)
  a =
    0b101
sign(a)
  -1
```

See also

`bitfield::bitfield`, `sign`

bitfield::uint8 bitfield::uint16 bitfield::uint32

Convert a bitfield object to an unsigned integer number.

Syntax

```
use bitfield
n = uint8(a)
n = uint16(a)
n = uint32(a)
```

Description

`uint8(a)`, `uint16(a)`, and `uint32(a)` convert bitfield a to a uint8, uint16, or uint32 number respectively. If a has more bits than the target integer, most significant bits are ignored.

Example

```
use bitfield
a = bitfield(1234, 16);
uint8(a)
  210
```

See also

`uint8`, `uint16`, `uint32`, `bitfield::int8`, `bitfield::int16`, `bitfield::int32`, `bitfield::double`, `bitfield::bitfield`

4.6 filter

`filter` is a library which adds to LME functions for designing analog (continuous-time) and digital (discrete-time) linear filters.

The following statement makes available functions defined in `filter`:

```
use filter
```

This library provides three kinds of functions:

– `besselap`, `buttap`, `cheb1ap`, `cheb2ap`, and `ellipap`, which compute the zeros, poles and gain of the prototype of analog low-pass filter with a cutoff frequency of 1 rad/s. They correspond respectively to Bessel, Butterworth, Chebyshev type 1, Chebyshev type 2, and elliptic filters.

– `besself`, `butter`, `cheby1`, `cheby2`, and `ellip`, which provide a higher-level interface to design filters of these different types. In addition to the filter parameters (degree, bandpass and bandstop ripples), one can specify the kind of filter (lowpass, highpass, bandpass or bandstop) and the cutoff frequency or frequencies. The result can be an analog or a digital filter, given as a rational transfer function or as zeros, poles and gain.

– `lp2lp`, `lp2hp`, `lp2bp`, and `lp2bs`, which convert analog lowpass filters respectively to lowpass, highpass, bandpass, and bandstop with specified cutoff frequency or frequencies.

Transfer functions are expressed as the coefficient vectors of their numerator `num` and denominator `den` in decreasing powers of `s` (Laplace transform for analog filters) or `z` (z transform for digital filters); or as the zeros `z`, poles `p`, and gain `k`.

besselap

Bessel analog filter prototype.

Syntax

```
use filter
(z, p, k) = besselap(n)
```

Description

`besselap(n)` calculates the zeros, the poles, and the gain of a Bessel analog filter of degree `n` with a cutoff angular frequency of 1 rad/s.

See also

`besself`, `buttap`, `cheb1ap`, `cheb2ap`, `ellipap`

besself

Bessel filter.

Syntax

```
use filter
(z, p, k) = besself(n, w0)
(num, den) = besself(n, w0)
(...) = besself(n, [wl, wh])
(...) = besself(n, w0, 'high')
(...) = besself(n, [wl, wh], 'stop')
(...) = besself(..., 's')
```

Description

besself calculates a Bessel filter. The result is given as zeros, poles and gain if there are three output arguments, or as numerator and denominator coefficient vectors if there are two output arguments.

besself(n,w0), where w0 is a scalar, gives a nth-order digital lowpass filter with a cutoff frequency of w0 relatively to half the sampling frequency.

besself(n,[wl,wh]), where the second input argument is a vector of two numbers, gives a 2nth-order digital bandpass filter with passband between wl and wh relatively to half the sampling frequency.

besself(n,w0,'high') gives a nth-order digital highpass filter with a cutoff frequency of w0 relatively to half the sampling frequency.

besself(n,[wl,wh],'stop'), where the second input argument is a vector of two numbers, gives a 2nth-order digital bandstop filter with stopband between wl and wh relatively to half the sampling frequency.

With an additional input argument which is the string 's', besself gives an analog Bessel filter. Frequencies are given in rad/s.

See also

besselap, butter, cheby1, cheby2, ellip

bilinear

Analog-to-digital conversion with bilinear transformation.

Syntax

```
use filter
(zd, pd, kd) = bilinear(zc, pc, kc, fs)
(numd, dend) = bilinear(numc, denc, fs)
```

Description

bilinear(zc,pc,kc,fs) converts the analog (continuous-time) transfer function given by its zeros zc, poles pc, and gain kc to a digital (discrete-time) transfer function given by its zeros, poles, and gain in the domain of the forward-shift operator q. The sampling frequency is fs. Conversion is performed with the bilinear transormation $z_d = (1 + z_c/2f_s)/(1 - z_c/2f_s)$. If the analog transfer function has less zeros than poles, additional digital zeros are added at -1 to avoid a delay.

With three input arguments, bilinear(numc,denc,fs) uses the coefficients of the numerators and denominators instead of their zeros, poles and gain.

buttap

Butterworth analog filter prototype.

Syntax

```
use filter
(z, p, k) = buttap(n)
```

Description

`buttap(n)` calculates the zeros, the poles, and the gain of a Butterworth analog filter of degree `n` with a cutoff angular frequency of 1 rad/s.

See also

`butter`, `besselap`, `cheb1ap`, `cheb2ap`, `ellipap`

butter

Butterworth filter.

Syntax

```
use filter
(z, p, k) = butter(n, w0)
(num, den) = butter(n, w0)
(...) = butter(n, [wl, wh])
(...) = butter(n, w0, 'high')
(...) = butter(n, [wl, wh], 'stop')
(...) = butter(..., 's')
```

Description

`butter` calculates a Butterworth filter. The result is given as zeros, poles and gain if there are three output arguments, or as numerator and denominator coefficient vectors if there are two output arguments.

`butter(n,w0)`, where `w0` is a scalar, gives a nth-order digital lowpass filter with a cutoff frequency of `w0` relatively to half the sampling frequency.

`butter(n,[wl,wh])`, where the second input argument is a vector of two numbers, gives a 2nth-order digital bandpass filter with passband between `wl` and `wh` relatively to half the sampling frequency.

butter(n,w0,'high') gives a nth-order digital highpass filter with a cutoff frequency of w0 relatively to half the sampling frequency.

butter(n,[wl,wh],'stop'), where the second input argument is a vector of two numbers, gives a 2nth-order digital bandstop filter with stopband between wl and wh relatively to half the sampling frequency.

With an additional input argument which is the string 's', butter gives an analog Butterworth filter. Frequencies are given in rad/s.

See also

buttap, besself, cheby1, cheby2, ellip

cheb1ap

Chebyshev type 1 analog filter prototype.

Syntax

```
use filter
(z, p, k) = cheb1ap(n, rp)
```

Description

cheb1ap(n,rp) calculates the zeros, the poles, and the gain of a Chebyshev type 1 analog filter of degree n with a cutoff angular frequency of 1 rad/s. Ripples in the passband have a peak-to-peak magnitude of rp dB.

See also

cheby1, cheb2ap, ellipap, besselap, buttap

cheb2ap

Chebyshev type 2 analog filter prototype.

Syntax

```
use filter
(z, p, k) = cheb2ap(n, rs)
```

Description

cheb2ap(n,rs) calculates the zeros, the poles, and the gain of a Chebyshev type 2 analog filter of degree n with a cutoff angular frequency of 1 rad/s. Ripples in the stopband have a peak-to-peak magnitude of rs dB.

See also

cheby1, cheb1ap, ellipap, besselap, buttap

cheby1

Chebyshev type 1 filter.

Syntax

```
use filter
(z, p, k) = cheby1(n, w0)
(num, den) = cheby1(n, w0)
(...) = cheby1(n, [wl, wh])
(...) = cheby1(n, w0, 'high')
(...) = cheby1(n, [wl, wh], 'stop')
(...) = cheby1(..., 's')
```

Description

cheby1 calculates a Chebyshev type 1 filter. The result is given as zeros, poles and gain if there are three output arguments, or as numerator and denominator coefficient vectors if there are two output arguments.

cheby1(n,w0), where w0 is a scalar, gives a nth-order digital lowpass filter with a cutoff frequency of w0 relatively to half the sampling frequency.

cheby1(n,[wl,wh]), where the second input argument is a vector of two numbers, gives a 2nth-order digital bandpass filter with passband between wl and wh relatively to half the sampling frequency.

cheby1(n,w0,'high') gives a nth-order digital highpass filter with a cutoff frequency of w0 relatively to half the sampling frequency.

cheby1(n,[wl,wh],'stop'), where the second input argument is a vector of two numbers, gives a 2nth-order digital bandstop filter with stopband between wl and wh relatively to half the sampling frequency.

With an additional input argument which is the string 's', cheby1 gives an analog Chebyshev type 1 filter. Frequencies are given in rad/s.

See also

`cheb1ap`, `besself`, `butter`, `cheby2`, `ellip`

cheby2

Chebyshev type 2 filter.

Syntax

```
use filter
(z, p, k) = cheby2(n, w0)
(num, den) = cheby2(n, w0)
(...) = cheby2(n, [wl, wh])
(...) = cheby2(n, w0, 'high')
(...) = cheby2(n, [wl, wh], 'stop')
(...) = cheby2(..., 's')
```

Description

cheby2 calculates a Chebyshev type 2 filter. The result is given as zeros, poles and gain if there are three output arguments, or as numerator and denominator coefficient vectors if there are two output arguments.

`cheby2(n,w0)`, where `w0` is a scalar, gives a nth-order digital lowpass filter with a cutoff frequency of `w0` relatively to half the sampling frequency.

`cheby2(n,[wl,wh])`, where the second input argument is a vector of two numbers, gives a 2nth-order digital bandpass filter with passband between `wl` and `wh` relatively to half the sampling frequency.

`cheby2(n,w0,'high')` gives a nth-order digital highpass filter with a cutoff frequency of `w0` relatively to half the sampling frequency.

`cheby2(n,[wl,wh],'stop')`, where the second input argument is a vector of two numbers, gives a 2nth-order digital bandstop filter with stopband between `wl` and `wh` relatively to half the sampling frequency.

With an additional input argument which is the string `'s'`, cheby2 gives an analog Chebyshev type 2 filter. Frequencies are given in rad/s.

See also

`cheb2ap`, `besself`, `butter`, `cheby1`, `ellip`

ellip

Elliptic filter.

Syntax

```
use filter
(z, p, k) = ellip(n, w0)
(num, den) = ellip(n, w0)
(...) = ellip(n, [wl, wh])
(...) = ellip(n, w0, 'high')
(...) = ellip(n, [wl, wh], 'stop')
(...) = ellip(..., 's')
```

Description

`ellip` calculates a elliptic filter, or Cauer filter. The result is given as zeros, poles and gain if there are three output arguments, or as numerator and denominator coefficient vectors if there are two output arguments.

`ellip(n,w0)`, where `w0` is a scalar, gives a nth-order digital lowpass filter with a cutoff frequency of `w0` relatively to half the sampling frequency.

`ellip(n,[wl,wh])`, where the second input argument is a vector of two numbers, gives a 2nth-order digital bandpass filter with passband between `wl` and `wh` relatively to half the sampling frequency.

`ellip(n,w0,'high')` gives a nth-order digital highpass filter with a cutoff frequency of `w0` relatively to half the sampling frequency.

`ellip(n,[wl,wh],'stop')`, where the second input argument is a vector of two numbers, gives a 2nth-order digital bandstop filter with stopband between `wl` and `wh` relatively to half the sampling frequency.

With an additional input argument which is the string `'s'`, `ellip` gives an analog elliptic filter. Frequencies are given in rad/s.

See also

`ellipap`, `besself`, `butter`, `cheby1`, `cheby2`

ellipap

Elliptic analog filter prototype.

Syntax

```
use filter
(z, p, k) = ellipap(n, rp, rs)
```

Description

`ellipap(n,rp,rs)` calculates the zeros, the poles, and the gain of an elliptic analog filter of degree `n` with a cutoff angular frequency of 1 rad/s. Ripples have a peak-to-peak magnitude of `rp` dB in the passband and of `rs` dB in the stopband.

See also

`ellip`, `cheb1ap`, `cheb1ap`, `besselap`, `buttap`

lp2bp

Lowpass prototype to bandpass filter conversion.

Syntax

```
use filter
(z, p, k) = lp2bp(z0, p0, k0, wc, ww)
(num, den) = lp2bp(num0, den0, wc, ww)
```

Description

`lp2bp` convert a lowpass analog filter prototype (with unit angular frequency) to a bandpass analog filter with the specified center angular frequency `w0` and bandwidth `ww`. `lp2bp(z0,p0,k0,wc,ww)` converts a filter given by its zeros, poles, and gain; `lp2bp(num0,den0,wc,ww)` converts a filter given by its numerator and denominator coefficients in decreasing powers of s.

The new filter $F(s)$ is

$$F(s) = F_0\left(\frac{s^2+\omega_c^2-\omega_w^2/4}{\omega_w s}\right)$$

where $F_0(s)$ is the filter prototype. The filter order is doubled.

See also

`lp2lp`, `lp2hp`, `lp2bs`

lp2bs

Lowpass prototype to bandstop filter conversion.

Syntax

```
use filter
(z, p, k) = lp2bs(z0, p0, k0, wc, ww)
(num, den) = lp2bs(num0, den0, wc, ww)
```

Description

`lp2bs` convert a lowpass analog filter prototype (with unit angular frequency) to a bandstop analog filter with the specified center angular frequency `w0` and bandwidth `ww`. `lp2bs(z0,p0,k0,wc,ww)` converts a filter given by its zeros, poles, and gain; `lp2bs(num0,den0,wc,ww)` converts a filter given by its numerator and denominator coefficients in decreasing powers of s.

The new filter $F(s)$ is

$$F(s) = F_0\left(\frac{\omega_w s}{s^2 + \omega_c^2 - \omega_w^2/4}\right)$$

where $F_0(s)$ is the filter prototype. The filter order is doubled.

See also

`lp2lp`, `lp2hp`, `lp2bp`

lp2hp

Lowpass prototype to highpass filter conversion.

Syntax

```
use filter
(z, p, k) = lp2hp(z0, p0, k0, w0)
(num, den) = lp2hp(num0, den0, w0)
```

Description

`lp2hp` convert a lowpass analog filter prototype (with unit angular frequency) to a highpass analog filter with the specified cutoff angular frequency `w0`. `lp2hp(z0,p0,k0,w0)` converts a filter given by its zeros, poles, and gain; `lp2hp(num0,den0,w0)` converts a filter given by its numerator and denominator coefficients in decreasing powers of s.

The new filter $F(s)$ is

$$F(s) = F_0(\frac{1}{\omega_0 s})$$

where $F_0(s)$ is the filter prototype.

See also

`lp2lp`, `lp2bp`, `lp2bs`

lp2lp

Lowpass prototype to lowpass filter conversion.

Syntax

```
use filter
(z, p, k) = lp2lp(z0, p0, k0, w0)
(num, den) = lp2lp(num0, den0, w0)
```

Description

`lp2lp` convert a lowpass analog filter prototype (with unit angular frequency) to a lowpass analog filter with the specified cutoff angular frequency `w0`. `lp2lp(z0,p0,k0,w0)` converts a filter given by its zeros, poles, and gain; `lp2lp(num0,den0,w0)` converts a filter given by its numerator and denominator coefficients in decreasing powers of s.

The new filter $F(s)$ is

$$F(s) = F_0\left(\frac{s}{\omega_0}\right)$$

where $F_0(s)$ is the filter prototype.

See also

`lp2hp`, `lp2bp`, `lp2bs`

4.7 lti

Library `lti` defines methods related to objects which represent linear time-invariant dynamical systems. LTI systems may be used to model many different systems: electro-mechanical devices, robots, chemical processes, filters, etc. LTI systems map one or more inputs `u` to one or more outputs `y`. The mapping is defined as a state-space model or as a matrix of transfer functions, either in continuous time or in discrete time. Methods are provided to create, combine, and analyze LTI objects.

Graphical methods are based on the corresponding graphical functions; the numerator and denominator coefficient vectors or the state-space matrices are replaced with an LTI object. They accept the same optional arguments, such as a character string for the style.

The following statement makes available functions defined in `lti`:

```
use lti
```

ss::ss

LTI state-space constructor.

Syntax

```
use lti
a = ss
a = ss(A, B, C, D)
a = ss(A, B, C, D, Ts)
a = ss(A, B, C, D, Ts, var)
a = ss(A, B, C, D, b)
a = ss(b)
```

Description

`ss(A,B,C,D)` creates an LTI object which represents the continuous-time state-space model

```
x'(t) = A x(t) + B u(t)
y(t)  = C x(t) + D u(t)
```

`ss(A,B,C,D,Ts)` creates an LTI object which represents the discrete-time state-space model with sampling period Ts

```
x(k+1) = A x(k) + B u(k)
y(k)   = C x(k) + D u(k)
```

In both cases, if `D` is `0`, it is resized to match the size of `B` and `C` if necessary. An additional argument `var` may be used to specify the variable of the Laplace (`'s'` (default) or `'p'`) or z transform (`'z'` (default) or `'q'`).

`ss(A,B,C,D,b)`, where `b` is an LTI object, creates a state-space model of the same kind (continuous/discrete time, sampling time and variable) as `b`.

`ss(b)` converts the LTI object `b` to a state-space model.

Examples

```
use lti
sc = ss(-1, [1,2], [2;5], 0)
  sc =
    continuous-time LTI state-space system
    A =
        -1
    B =
         1     2
    C =
         2
         5
    D =
         0     0
         0     0
sd = ss(tf(1,[1,2,3,4],0.1))
  sd =
    discrete-time LTI state-space system, Ts=0.1
    A =
      -2    -3    -4
       1     0     0
       0     1     0
    B =
       1
       0
       0
    C =
       0     0     1
    D =
       0
```

See also

tf::tf

tf::tf

LTI transfer function constructor.

Syntax

```
use lti
a = tf
a = tf(num, den)
a = tf(numlist, denlist)
a = tf(..., Ts)
a = tf(..., Ts, var)
a = tf(..., b)
a = tf(gain)
a = tf(b)
```

Description

tf(num,den) creates an LTI object which represents the continuous-time transfer function specified by descending-power coefficient vectors num and den. tf(num,den,Ts) creates an LTI object which represents a discrete-time transfer function with sampling period Ts.

In both cases, num and den may be replaced with cell arrays of coefficients whose elements are the descending-power coefficient vectors. The number of rows is the number of system outputs, and the number of columns is the number of system inputs.

An additional argument var may be used to specify the variable of the Laplace ('s' (default) or 'p') or z transform ('z' (default) or 'q').

tf(...,b), where b is an LTI object, creates a transfer function of the same kind (continuous/discrete time, sampling time and variable) as b.

tf(b) converts the LTI object b to a transfer function.

tf(gain), where gain is a matrix, creates a matrix of gains.

Examples

Simple continuous-time system with variable p (p is used only for display):

```
use lti
sc = tf(1,[1,2,3,4],'p')
  sc =
    continuous-time transfer function
    1/(p^3+2p^2+3p+4)
```

Matrix of discrete-time transfer functions for one input and two outputs, with a sampling period of 1ms:

```
sd = tf({0.1; 0.15}, {[1, -0.8]; [1; -0.78]}, 1e-3)
  sd =
    discrete-time transfer function, Ts=1e-3
    y1/u1: 0.1/(s-0.8)
    y2/u1: 0.15/(s-0.78)
```

See also

ss::ss

lti::append

Append the inputs and outputs of systems.

Syntax

```
use lti
b = append(a1, a2, ...)
```

Description

`append(a1,a2)` builds a system with inputs `[u1;u2]` and outputs `[y1;y2]`, where `u1` and `u2` are the inputs of `a1` and `y1` and `y2` their outputs, respectively. append accepts any number of input arguments.

See also

`lti::connect`, `ss::augstate`

ss::augstate

Extend the output of a system with its states.

Syntax

```
use lti
b = augstate(a)
```

Description

`augstate(a)` extends the `ss` object a by adding its states to its outputs. The new output is `[y;x]`, where `y` is the output of a and `x` is its states.

See also

`lti::append`

lti::beginning

First index.

Syntax

```
use lti
var(...beginning...)
```

Description

In an expression used as an index between parenthesis, `beginning(a)` gives the first valid value for an index. It is always 1.

See also

`lti::end`, `lti::subsasgn`, `lti::subsref`

lti::c2d

Conversion from continuous time to discrete time.

Syntax

```
use lti
b = c2d(a, Ts)
b = c2d(a, Ts, method)
```

Description

`c2d(a,Ts)` converts the continuous-time system a to a discrete-time system with sampling period `Ts`.

`c2d(a,Ts,method)` uses the specified conversion method. `method` is one of the methods supported by `c2dm`.

See also

`lti::d2c`, `c2dm`

lti::connect

Arbitrary feedback connections.

Syntax

```
use lti
b = connect(a, links, in, out)
```

Description

`connect(a,links,in,out)` modifies `lti` object a by connecting some of the outputs to some of the inputs and by keeping some of the inputs and some of the outputs. Connections are specified by the rows of matrix `link`. In each row, the first element is the index of the system input where the connection ends; other elements are indices to system outputs which are summed. The sign of the indices to outputs gives the sign of the unit weight in the sum. Zeros are ignored. Arguments `in` and `out` specify which input and output to keep.

See also

`lti::feedback`

lti::d2c

Conversion from discrete time to continuous time.

Syntax

```
use lti
b = d2c(a)
b = d2c(a, method)
```

Description

`d2c(a)` converts the discrete-time system a to a continuous-time system.

`d2c(a,method)` uses the specified conversion method. `method` is one of the methods supported by `d2cm`.

See also

`lti::c2d`, `d2cm`

lti::end

Last index.

Syntax

```
use lti
var(...end...)
```

Description

In an expression used as an index between parenthesis, end gives the last valid value for that index. It is `size(var,1)` or `size(var,2)`.

Example

Time response when the last input is a step:

```
use lti
P = ss([1,2;-3,-4],[1,0;0,1],[3,5]);
P1 = P(:, end)
  continuous-time LTI state-space system
  A =
     1   2
    -3  -4
  B =
     0
     1
  C =
     3   5
  D =
     0
step(P1);
```

See also

`lti::beginning`, `lti::subsasgn`, `lti::subsref`

lti::evalfr

Frequency value.

Syntax

```
use lti
y = evalfr(a, x)
```

Description

`evalfr(a,x)` evaluates system a at complex value or values x. If x is a vector of values, results are stacked along the third dimension.

Example

```
use lti
sys = [tf(1, [1,2,3]), tf(2, [1,2,3,4])];
evalfr(sys, 0:1j:3j)
  ans =
    1x2x4 array
    (:,:,1) =
      0.3333                 0.5
    (:,:,2) =
      0.25     -0.25j        0.5      -0.5j
    (:,:,3) =
     -5.8824e-2-0.2353j     -0.4      +0.2j
    (:,:,4) =
     -8.3333e-2-8.3333e-2j   -5.3846e-2+6.9231e-2j
```

See also

`polyval`

ss::ctrb

Controllability matrix.

Syntax

```
use lti
C = crtb(a)
```

Description

`ctrb(a)` gives the controllability matrix of system a, which is full-rank if and only if a is controllable.

See also

`ss::obsv`

lti::dcgain

Steady-state gain.

Syntax

```
use lti
g = dcgain(a)
```

Description

`dcgain(a)` gives the steady-state gain of system a.

See also

`lti::norm`

lti::feedback

Feedback connection.

Syntax

```
use lti
c = feedback(a, b)
c = feedback(a, b, sign)
c = feedback(a, b, ina, outa)
c = feedback(a, b, ina, outa, sign)
```

Description

`feedback(a,b)` connects all the outputs of `lti` object a to all its inputs via the negative feedback `lti` object `b`.

`feedback(a,b,sign)` applies positive feedback with weight `sign`; the default value of `sign` is `-1`.

`feedback(a,b,ina,outa)` specifies which inputs and outputs of a to use for feedback. The inputs and outputs of the result always correspond to the ones of a.

See also

`lti::connect`

lti::inv

System inverse.

Syntax

```
use lti
b = inv(a)
```

Description

`inv(a)` gives the inverse of system a.

See also

`lti::mldivide`, `lti::mrdivide`

isct

Test for a continous-time LTI.

Syntax

```
use lti
b = isct(a)
```

Description

`isct(a)` is true if system a is continuous-time or static, and false otherwise.

See also

`isdt`

isdt

Test for a discrete-time LTI.

Syntax

```
use lti
b = isdt(a)
```

Description

`isdt(a)` is true if system a is discrete-time or static, and false otherwise.

See also

`isct`

lti::isempty

Test for an LTI without input/output.

Syntax

```
use lti
b = isempty(a)
```

Description

`isempty(a)` is true if system a has no input and/or no output, and false otherwise.

See also

`lti::size`, `lti::issiso`

lti::isproper

Test for a proper (causal) LTI.

Syntax

```
use lti
b = isproper(a)
```

Description

`isproper(a)` is `true` if `lti` object a is causal, or `false` otherwise. An `ss` object is always causal. A `tf` object is causal if all the transfer functions are proper, i.e. if the degrees of the denominators are at least as large as the degrees of the numerators.

lti::issiso

Test for a single-input single-output LTI.

Syntax

```
use lti
b = issiso(a)
```

Description

`issiso(a)` is `true` if `lti` object a has one input and one output (single-input single-output system, or SISO), or `false` otherwise.
`lti::size`, `lti::isempty`

lti::minreal

Minimum realization.

Syntax

```
use lti
b = minreal(a)
b = minreal(a, tol)
```

Description

`minreal(a)` modifies `lti` object a in order to remove states which are not controllable and/or not observable. For `tf` objects, identical zeros and poles are canceled out.

`minreal(a,tol)` uses tolerance `tol` to decide whether to discard a state or a pair of pole/zero.

lti::minus

System difference.

Syntax

```
use lti
c = a - b
c = minus(a, b)
```

Description

`a-b` computes the system whose inputs are fed to both a and `b` and whose outputs are the difference between outputs of a and `b`. If a and `b` are transfer functions or matrices of transfer functions, this is equivalent to a difference of matrices.

See also

`lti::parallel`, `lti::plus`, `lti::uminus`

lti::mldivide

System left division.

Syntax

```
use lti
c = a \ b
c = mldivide(a, b)
```

Description

`a/b` is equivalent to `inv(a)*b`.

See also

`lti::mrdivide`, `lti::times`, `lti::inv`

lti::mrdivide

System right division.

Syntax

```
use lti
c = a / b
c = mrdivide(a, b)
```

Description

`a/b` is equivalent to `a*inv(b)`.

See also

`lti::mldivide`, `lti::times`, `lti::inv`

lti::mtimes

System product.

Syntax

```
use lti
c = a * b
c = mtimes(a, b)
```

Description

a*b connects the outputs of lti object b to the inputs of lti object a. If a and b are transfer functions or matrices of transfer functions, this is equivalent to a product of matrices.

See also

lti::series

lti::norm

H2 norm.

Syntax

```
use lti
h2 = norm(a)
```

Description

norm(a) gives the H2 norm of the system a.

See also

lti::dcgain

ss::obsv

Observability matrix.

Syntax

```
use lti
O = obsv(a)
```

Description

obsv(a) gives the observability matrix of system a, which is full-rank if and only if a is observable.

See also

ss::ctrb

lti::parallel

Parallel connection.

Syntax

```
use lti
c = parallel(a, b)
c = parallel(a, b, ina, inb, outa, outb)
```

Description

`parallel(a,b)` connects `lti` objects a and b in such a way that the inputs of the result is applied to both a and b, and the outputs of the result is their sum.

`parallel(a,b,ina,inb,outa,outb)` specifies which inputs are shared between a and b, and which outputs are summed. The inputs of the result are partitioned as `[ua,uab,ub]` and the outputs as `[ya,yab,yb]`. Inputs uab are fed to inputs `ina` of a and `inb` of b; inputs ua are fed to the remaining inputs of a, and ub to the remaining inputs of b. Similarly, outputs yab are the sum of outputs `outa` of a and outputs `outb` of b, and ya and yb are the remaining outputs of a and b, respectively.

See also

`lti::series`

lti::plus

System sum.

Syntax

```
use lti
c = a + b
c = plus(a, b)
```

Description

a+b computes the system whose inputs are fed to both a and b and whose outputs are the sum of the outputs of a and b. If a and b are transfer functions or matrices of transfer functions, this is equivalent to a sum of matrices.

See also

`lti::parallel`, `lti::minus`

lti::series

Series connection.

Syntax

```
use lti
c = series(a, b)
c = series(a, b, outa, inb)
```

Description

`series(a,b)` connects the outputs of `lti` object a to the inputs of `lti` object b.

`series(a,b,outa,inb)` connects outputs `outa` of a to inputs `inb` of b. Unconnected outputs of a and inputs of b are discarded.

See also

`lti::mtimes`, `lti::parallel`

lti::repmat

Replicate a system.

Syntax

```
use lti
b = repmat(a, n)
b = repmat(a, [m,n])
b = repmat(a, m, n)
```

Description

`repmat(a,n)`, when a is a transfer function or a matrix of transfer functions, creates a new system described by a matrix of transfer functions where a is repeated n times horizontally and vertically. If a is a state-space system, matrices B, C, and D are replicated to obtain the same effect.

`repmat(a,[m,n])` or `repmat(a,m,n)` repeats matrix a `m` times vertically and `n` times horizontally.

See also

`lti::append`

lti::size

Number of outputs and inputs.

Syntax

```
use lti
s = size(a)
(nout, nin) = size(a)
n = size(a, dim)
```

Description

With one output argument, `size(a)` gives the row vector `[nout,nin]`, where `nout` is the number of outputs of system `a` and `nin` its number of inputs. With two output arguments, `size(a)` returns these results separately as scalars.

`size(a,1)` gives only the number of outputs, and `size(a,2)` only the number of inputs.

See also

`lti::isempty`, `lti::issiso`

lti::ssdata

Get state-space matrices.

Syntax

```
use lti
(A, B, C, D) = ssdata(a)
(A, B, C, D, Ts) = ssdata(a)
```

Description

`ssdata(a)`, where `a` is any kind of LTI object, gives the four matrices of the state-space model, and optionally the sampling period or the empty array `[]` for continuous-time systems.

See also

`lti::tfdata`

lti::subsasgn

Assignment to a part of an LTI system.

Syntax

```
use lti
var(i,j) = a
var(ix) = a
var(select) = a
var.field = value
a = subsasgn(a, s, b)
```

Description

The method `subsasgn(a)` permits the use of all kinds of assignments to a part of an LTI system. If the variable is a matrix of transfer functions, `subsasgn` produces the expected result, converting the right-hand side of the assignment to a matrix of transfer function if required. If the variable is a state-space model, the result is equivalent; the result remains a state-space model. For state-space models, changing all the inputs or all the outputs with the syntax `var(expr,:)=sys` or `var(:,expr)=sys` is much more efficient than specifying both subscripts or a single index.

The syntax for field assignment, `var.field=value`, is defined for the following fields: for state-space models, `A`, `B`, `C`, and `D` (matrices of the state-space model); for transfer functions, `num` and `den` (cell arrays of coefficients); for both, `var` (string) and `Ts` (scalar, or empty array for continuous-time systems). Field assignment must preserve the size of matrices and arrays.

The syntax with braces (`var{i}=value`) is not supported.

See also

`lti::subsref`, operator `()`, `subsasgn`

lti::subsref

Extraction of a part of an LTI system.

Syntax

```
use lti
var(i,j)
var(ix)
var(select)
var.field
b = subsref(a, s)
```

Description

The method `subsref(a)` permits the use of all kinds of extraction of a part of an LTI system. If the variable is a matrix of transfer functions, `subsref` produces the expected result. If the variable is a state-space model, the result is equivalent; the result remains a state-space model. For state-space models, extracting all the inputs or all the outputs with the syntax `var(expr,:)` or `var(:,expr)` is much more efficient than specifying both subscripts or a single index.

The syntax for field access, `var.field`, is defined for the following fields: for state-space models, `A`, `B`, `C`, and `D` (matrices of the state-space model); for transfer functions, `num` and `den` (cell arrays of coefficients); for both, `var` (string) and `Ts` (scalar, or empty array for continuous-time systems).

The syntax with braces (`var{i}`) is not supported.

See also

`lti::subsasgn`, operator `()`, `subsasgn`

lti::tfdata

Get transfer functions.

Syntax

```
use lti
(num, den) = tfdata(a)
(num, den, Ts) = ssdata(a)
```

Description

`tfdata(a)`, where a is any kind of LTI object, gives the numerator and denominator of the transfer function model, and optionally the sampling period or the empty array `[]` for continuous-time systems.

The numerators and denominators are given as a cell array of power-descending coefficient vectors; the rows of the cell arrays correcpond to the outputs, and their columns to the inputs.

See also

`lti::ssdata`

lti::uminus

Negative.

Syntax

```
 use lti
 b = -a
 b = uminus(a)
```

Description

`-a` multiplies all the outputs (or all the inputs) of system a by -1. If a is a transfer functions or a matrix of transfer functions, this is equivalent to the unary minus.

See also

`lti::minus`, `lti::uplus`

lti::uplus

Negative.

Syntax

```
 use lti
 b = +a
 b = uplus(a)
```

Description

+a gives a.

See also

`lti::uminus`, `lti::plus`

zpk

LTI transfer function constructor using zeros and poles.

Syntax

```
use lti
a = zpk(z, p, k)
a = zpk(zeroslist, poleslist, gainlist)
a = zpk(..., Ts)
a = zpk(..., Ts, var)
a = zpk(..., b)
a = zpk(b)
```

Description

zpk creates transfer-function LTI systems like `tf::tf`. Instead of using transfer function coefficients as input, it accepts a vector of zeros, a vector of poles, and a gain for a simple-input simple-output (SISO) system; or lists of sublists of zeros, poles and gains for multiple-input multiple-output (MIMO) systems.

Examples

```
use lti
sd = zpk(0.3, [0.8+0.5j; 0.8-0.5j], 10, 0.1)
  sd =
    discrete-time transfer function, Ts=0.1
    (10z-3)/(z^2-1.6z+0.89)
```

See also

`tf::tf`

lti::bodemag

Magnitude of the Bode plot.

Syntax

```
use lti
bodemag(a, ...)
... = bodemag(a, ...)
```

Description

`bodemag(a)` plots the magnitude of the Bode diagram of system a.

See also

`lti::bodephase`, `lti::nichols`, `lti::nyquist`

lti::bodephase

Phase of the Bode plot.

Syntax

```
use lti
bodephase(a, ...)
... = bodephase(a, ...)
```

Description

`bodephase(a)` plots the magnitude of the Bode diagram of system a.

See also

`lti::bodemag`, `lti::nichols`, `lti::nyquist`

lti::impulse

Impulse response.

Syntax

```
use lti
impulse(a, ...)
... = impulse(a, ...)
```

Description

`impulse(a)` plots the impulse response of system a.

See also

`lti::step`, `lti::lsim`, `lti::initial`

lti::initial

Time response with initial conditions.

Syntax

```
use lti
initial(a, x0, ...)
... = initial(a, x0, ...)
```

Description

`initial(a,x0)` plots the time response of state-space system a with initial state `x0` and null input.

See also

`lti::impulse`, `lti::step`, `lti::lsim`

lti::lsim

Time response.

Syntax

```
use lti
lsim(a, u, t, ...)
... = lsim(a, u, t)
```

Description

`lsim(a,u,t)` plots the time response of system a. For continuous-time systems, The input is piece-wise linear; it is defined by points in real vectors `t` and u, which must have the same length. Input before `t(1)` and after `t(end)` is 0. For discrete-time systems, u is sampled at the rate given by the system, and `t` is ignored or can be omitted.

See also

`lti::impulse`, `lti::step`, `lti::initial`

lti::nichols

Nichols plot.

Syntax

```
use lti
nichols(a, ...)
... = nichols(a, ...)
```

Description

`nichols(a)` plots the Nichols diagram of system a.

See also

`lti::nyquist`, `lti::bodemag`, `lti::bodephase`

lti::nyquist

Nyquist plot.

Syntax

```
use lti
nyquist(a, ...)
... = nyquist(a, ...)
```

Description

`nyquist(a)` plots the Nyquist diagram of system a.

See also

`lti::nichols`, `lti::bodemag`, `lti::bodephase`

lti::step

Step response.

Syntax

```
use lti
step(a, ...)
... = step(a, ...)
```

Description

`step(a)` plots the step response of system a.

See also

`lti::impulse`, `lti::lsim`, `lti::initial`

4.8 sigenc

sigenc is a library which adds to LME functions for encoding and decoding scalar signals. It implements quantization, DPCM (differential pulse code modulation), and companders used in telephony.

The following statement makes available functions defined in sigenc:

```
use sigenc
```

alawcompress

A-law compressor.

Syntax

```
use sigenc
output = alawcompress(input)
output = alawcompress(input, a)
```

Description

alawcompress(input,a) compresses signal input with A-law method using parameter a. The signal is assumed to be in [-1,1]; values outside this range are clipped. input can be a real array of any size and dimension. The default value of a is 87.6.

The compressor and its inverse, the expander, are static, nonlinear filters used to improve the signal-noise ratio of quantized signals. The compressor should be used before quantization (or on a signal represented with a higher precision).

See also

alawexpand, ulawcompress

alawexpand

A-law expander.

Syntax

```
use sigenc
output = alawexpand(input)
output = alawexpand(input, a)
```

Description

alawexpand(input,a) expands signal input with A-law method using parameter a. input can be a real array of any size and dimension. The default value of a is 87.6.

See also

alawcompress, ulawexpand

dpcmdeco

Differential pulse code modulation decoding.

Syntax

```
use sigenc
output = dpcmdeco(i, codebook, predictor)
```

Description

dpcmdeco(i,codebook,predictor) reconstructs a signal encoded with differential pulse code modulation. It performs the opposite of dpcmenco.

See also

dpcmenco, dpcmopt

dpcmenco

Differential pulse code modulation encoding.

Syntax

```
use sigenc
i = dpcmenco(input, codebook, partition, predictor)
```

Description

dpcmenco(input,codebook,partition,predictor) quantizes the signal in vector input with differential pulse code modulation. It predicts the future response with the finite-impulse response filter given by polynomial predictor, and it quantizes the residual error with codebook and partition like quantiz. The output i is an array of codes with the same size and dimension as input.

The prediction $y^*(k)$ for sample k s

$$y^*(k) = \sum_{i=1}^{\text{degpredictor}} \text{predictor}_i \cdot y_q(k-i)$$

where $y_q(k)$ is the quantized (reconstructed) signal. The predictor must be strictly causal: predictor(0) must be zero. To encode the difference between in(k) and yq(k-1), predictor=[0,1]. Note that there is no drift between the reconstructed signal and the input [1], contrary to the case where the input is differentiated, quantized, and integrated.

Example

```
use sigenc
t = 0:0.1:10;
x = sin(t);
codebook = -.1:.01:.1;
partition = -.0:.01:.09;
predictor = [0, 1];
i = dpcmenco(x, codebook, partition, predictor);
y = dpcmdeco(i, codebook, predictor);
```

See also

quantiz, dpcmdeco, dpcmopt

dpcmopt

Differential pulse code modulation decoding.

Syntax

```
use sigenc
(predictor, codebook, partition) = dpcmopt(in, order, n)
(predictor, codebook, partition) = dpcmopt(in, order, codebook0)
(predictor, codebook, partition) = dpcmopt(in, predictor, ...)
(predictor, codebook, partition) = dpcmopt(..., tol)
predictor = dpcmopt(in, order)
```

[1] Actually, there may be a drift if the arithmetic units used for encoding and decoding do not produce exactly the same results.

Description

dpcmopt(in,order,n) gives the optimal predictor of order order, codebook of size n and partition to encode the signal in vector in with differential pulse code modulation. The result can be used with dpcmenco to encode signals with similar properties. If the second input argument is a vector, it is used as the predictor and not optimized further; its first element must be zero. If the third input argument is a vector, it is used as an initial guess for the codebook, which has the same length. An optional fourth input argument provides the tolerance (the default is 1e-7).

If only the predictor is required, only the input and the predictor order must be supplied as input arguments.

See also

dpcmenco, dpcmdeco, lloyds

lloyds

Optimal quantization.

Syntax

```
use sigenc
(partition, codebook) = lloyds(input, n)
(partition, codebook) = lloyds(input, codebook0)
(partition, codebook) = lloyds(..., tol)
```

Description

lloyds(input,n) computes the optimal partition and codebook for quantizing signal input with n codes, using the Lloyds algorithm.

If the second input argument is a vector, lloyds(input,codebook0) uses codebook0 as an initial guess for the codebook. The result has the same length.

A third argument can be used to specify the tolerance used as the stopping criterion of the optimization loop. The default is 1e-7.

Example

We start from a suboptimal partition and compute the distortion:

```
use sigenc
partition = [-1, 0, 1];
codebook = [-2, -0.5, 0.5, 2];
```

```
in = -5:0.6:3;
(i, out, dist) = quantiz(in, partition, codebook);
dist
  2.1421
```

The partition is optimized with `lloyds`, and the same signal is quantized again. The distortion is reduced.

```
(partition_opt, codebook_opt) = lloyds(in, codebook)
  partition_opt =
       -2.9  -0.5   1.3
  codebook_opt =
    -4.1  -1.7   0.4   2.2
(i, out, dist) = quantiz(in, partition_opt, codebook_opt);
dist
  1.0543
```

See also

`quantiz`, `dpcmopt`

quantiz

Table-based signal quantization.

Syntax

```
use sigenc
i = quantiz(input, partition)
(i, output, distortion) = quantiz(input, partition, codebook)
```

Description

`quantiz(input,partition)` quantizes signal `input` using `partition` as boundaries between different ranges. Range from $-\infty$ to `partition(1)` corresponds to code 0, range from `partition(1)` to `partition(2)` corresponds to code 1, and so on. `input` may be a real array of any size and dimension; `partition` must be a sorted vector. The output `i` is an array of codes with the same size and dimension as `input`.

`quantiz(input,partition,codebook)` uses `codebook` as a look-up table to convert back from codes to signal. It should be a vector with one more element than `partition`. With a second output argument, `quantiz` gives `codebook(i)`.

With a third output argument, `quantiz` computes the distortion between `input` and `codebook(i)`, i.e. the mean of the squared error.

Example

```
use sigenc
partition = [-1, 0, 1];
codebook = [-2, -0.5, 0.5, 2];
in = randn(1, 5)
  in =
    0.1799 -9.7676e-2   -1.1431   -0.4986    1.0445
(i, out, dist) = quantiz(in, partition, codebook)
  i =
    2    1    0    1    2
  out =
    0.5 -0.5 -2   -0.5  0.5
  dist =
    0.259
```

See also

`lloyds`, `dpcmenco`

ulawcompress

mu-law compressor.

Syntax

```
use sigenc
output = ulawcompress(input)
output = ulawcompress(input, mu)
```

Description

`ulawcompress(input,a)` compresses signal `input` with mu-law method using parameter `mu`. `input` can be a real array of any size and dimension. The default value of `mu` is 255.

The compressor and its inverse, the expander, are static, nonlinear filters used to improve the signal-noise ratio of quantized signals. The compressor should be used before quantization (or on a signal represented with a higher precision).

See also

`ulawexpand`, `alawcompress`

ulawexpand

mu-law expander.

Syntax

```
use sigenc
output = ulawexpand(input)
output = ulawexpand(input, mu)
```

Description

`ulawexpand(input,a)` expands signal `input` with mu-law method using parameter a. `input` can be a real array of any size and dimension. The default value of `mu` is 255.

See also

`ulawcompress`, `alawexpand`

4.9 wav

wav is a library which adds to LME functions for encoding and decoding WAV files. WAV files contain digital sound. The wav library supports uncompressed, 8-bit and 16-bit, monophonic and polyphonic WAV files. It can also encode and decode WAV data in memory without files.

The following statement makes available functions defined in wav:

```
use wav
```

wavread

WAV decoding.

Syntax

```
use wav
(samples, samplerate, nbits) = wavread(filename)
(samples, samplerate, nbits) = wavread(filename, n)
(samples, samplerate, nbits) = wavread(filename, [n1,n2])
(samples, samplerate, nbits) = wavread(data, ...)
```

Description

`wavread(filename)` reads the WAV file `filename`. The result is a 2-d array, where each row corresponds to a sample and each column to a channel. Its class is the same as the native type of the WAV file, i.e. `int8` or `int16`.

`wavread(filename,n)`, where `n` is a scalar integer, reads the first `n` samples of the file. `wavread(filename,[n1,n2])`, where the second input argument is a vector of two integers, reads samples from `n1` to `n2` (the first sample corresponds to 1).

Instead of a file name string, the first input argument can be a vector of bytes, of class `int8` or `uint8`, which represents directly the contents of the WAV file.

In addition to the samples, `wavread` can return the sample rate in Hz (such as 8000 for phone-quality speech or 44100 for CD-quality music), and the number of bits per sample and channel.

See also

`wavwrite`

wavwrite

WAV encoding.

Syntax

```
use wav
wavwrite(samples, samplerate, nbits, filename)
data = wavwrite(samples, samplerate, nbits)
data = wavwrite(samples, samplerate)
```

Description

`wavwrite(samples,samplerate,nbits,filename)` writes a WAV file `filename` with samples in array `samples`, sample rate `samplerate` (in Hz), and `nbits` bits per sample and channel. Rows of `samples` corresponds to samples and columns to channels. `nbits` can be 8 or 16.

With 2 or 3 input arguments, `wavwrite` returns the contents of the WAV file as a vector of class `uint8`. The default word size is 16 bits per sample and channel.

Example

```
use wav
sr = 44100;
t = (0:sr)' / sr;
s = sin(2 * pi * 740 * t);
wavwrite(map2int(s, -1, 1, 'int16'), sr, 16, 'beep.wav');
```

See also

wavread

4.10 date

date is a library which adds to LME functions to convert date and time between numbers and strings.

The following statement makes available functions defined in date:

```
use date
```

datestr

Date to string conversion.

Syntax

```
use date
str = datestr(datetime)
str = datestr(date, format)
```

Description

datestr(datetime) converts the date and time to a string. The input argument can be a vector of 3 to 6 elements for the year, month, day, hour, minute, and second; a julian date as a scalar number; or a string, which is converted by datevec. The result has the following format:

```
jj-mmm-yyyy HH:MM:SS
```

where jj is the two-digit day, mmm the beginning of the month name, yyyy the four-digit year, HH the two-digit hour, MM the two-digit minute, and SS the two-digit second.

The format can be specified with a second input argument. When datestr scans the format string, it replaces the following sequences of characters and keeps the other ones unchanged:

Sequence	Replaced with
dd	day (2 digits)
ddd	day of week (3 char)
HH	hour (2 digits, 01-12 or 00-23)
MM	minute (2 digits)
mm	month (2 digits)
mmm	month (3 char)
PM	AM or PM
QQ	quarter (Q1 to Q4)
SS	second (2 digits)
yy	year (2 digits)
yyyy	year (4 digits)

If the sequence PM is found, the hour is between 1 and 12; otherwise, between 0 and 23.

Examples

```
use date
datestr(clock)
  18-Apr-2005 16:21:55
datestr(clock, 'ddd mm/dd/yyyy HH:MM PM')
  Mon 04/18/2005 04:23 PM
```

See also

`datevec`, `julian2cal`, `clock`

datevec

String to date and time conversion.

Syntax

```
use date
datetime = datevec(str)
```

Description

`datevec(str)` converts the string `str` representing the date and/or the time to a row vector of 6 elements for the year, month, day, hour, minute, and second. The following formats are recognized:

Example	**Value**
`20050418T162603`	ISO 8601 date and time
`2005-04-18`	year, month and day
`2005-Apr-18`	year, month and day
`18-Apr-2005`	day, month and year
`04/18/2005`	month, day and year
`04/18/00`	month, day and year
`18.04.2005`	day, month and year
`18.04.05`	day, month and year
`16:26:03`	hour, minute and second
`16:26`	hour and minute
`PM`	afternoon

Unrecognized characters are ignored. If the year is given as two digits, it is assumed to be between 1951 and 2050.

Examples

```
use date
datevec('Date and time: 20050418T162603')
  2005   4  18  16  26   3
datevec('03:57 PM')
     0   0   0  15  57   0
datevec('01-Aug-1291')
  1291   8   1   0   0   0
datevec('At 16:30 on 11/04/07')
  2007  11   4  16  30   0
```

See also

`datestr`

weekday

Week day of a given date.

Syntax

```
use date
(num, str) = weekday(year, month, day)
(num, str) = weekday(datetime)
(num, str) = weekday(jd)
```

Description

weekday finds the week day of the date given as input. The date can be given with three input arguments for the year, the month and the day, or with one input argument for the date or date and time vector, or julian date.

The first output argument is the number of the day, from 1 for Sunday to 7 for Saturday; and the second output argument is its name as a string of 3 characters, such as `'Mon'` for Monday.

Example

Day of week of today:

```
use date
(num, str) = weekday(clock)
  num =
    2
  str =
    Mon
```

See also

`cal2julian`

4.11 constants

`constants` is a library which defines physical constants in SI units (meter, kilogram, second, ampere).

The following statement makes available constants defined in `constants`:

```
use constants;
```

The following constants are defined:

Name	**Value**	**Unit**
avogadro_number	6.0221367e23	1/mole
boltzmann_constant	1.380658e-23	J/K
earth_mass	5.97370e24	kg
earth_radius	6.378140e6	m
electron_charge	1.60217733e-19	C
electron_mass	9.1093897e-31	kg
faraday_constant	9.6485309e4	C/mole
gravitational_constant	6.672659e-11	N mˆ2/kgˆ2
gravity_acceleration	9.80655	m/sˆ2
hubble_constant	3.2e-18	1/s
ice_point	273.15	K
induction_constant	1.256e-6	V s/A m
molar_gaz_constant	8.314510	J/K mole
molar_volume	22.41410e-3	mˆ3/mole
muon_mass	1.8835327e-28	kg
neutron_mass	1.6749286e-27	kg
plank_constant	6.6260755e-34	J s
plank_constant_reduced	1.0545727e-34	J s
plank_mass	2.17671e-8	kg
proton_mass	1.6726231e-27	kg
solar_radius	6.9599e8	m
speed_of_light	299792458	m/s
speed_of_sound	340.29205	m/s
stefan_boltzmann_constant	5.67051e-8	W/mˆ2 Kˆ-4
vacuum_permittivity	8.854187817e-12	A s/V m

Index