MATLAB®

The Language of Technical Computing

Computation

Visualization

Programming

The MATH WORKS Inc.

MATLAB Function Reference (Volume 1: Language)

Version 5

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MATLAB Function Reference

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Command Summary

This chapter lists MATLAB commands by functional area.

General Purpose Commands

Managing Commands and Functions

`addpath`	Add directories to MATLAB's search path
`doc`	Display HTML documentation in Web browser
`docopt`	Display location of help file directory for UNIX platforms
`help`	Online help for MATLAB functions and M-files
`helpdesk`	Display Help Desk page in Web browser, giving access to extensive help
`helpwin`	Display Help Window, providing access to help for all commands
`lasterr`	Last error message
`lastwarn`	Last warning message
`lookfor`	Keyword search through all help entries
`partialpath`	Partial pathname
`path`	Control MATLAB's directory search path
`pathtool`	Start Path Browser, a GUI for viewing and modifying MATLAB's path
`profile`	Start the M-file profiler, a utility for debugging and optimizing code
`profreport`	Generate a profile report
`rmpath`	Remove directories from MATLAB's search path
`type`	List file
`ver`	Display version information for MATLAB, Simulink, and toolboxes
`version`	MATLAB version number
`web`	Point Web browser at file or Web site
`what`	Directory listing of M-files, MAT-files, and MEX-files
`whatsnew`	Display README files for MATLAB and toolboxes
`which`	Locate functions and files

Managing Variables and the Workspace

`clear`	Remove items from memory
`disp`	Display text or array
`length`	Length of vector
`load`	Retrieve variables from disk
`mlock`	Prevent M-file clearing
`munlock`	Allow M-file clearing
`openvar`	Open workspace variable in Array Editor, for graphical editing
`pack`	Consolidate workspace memory
`save`	Save workspace variables on disk
`saveas`	Save figure or model using specified format
`size`	Array dimensions
`who, whos`	List directory of variables in memory
`workspace`	Display the Workspace Browser, a GUI for managing the workspace

Controlling the Command Window

`clc`	Clear command window
`echo`	Echo M-files during execution
`format`	Control the output display format
`home`	Send the cursor home
`more`	Control paged output for the command window

Working with Files and the Operating Environment

`cd`	Change working directory
`copyfile`	Copy file
`delete`	Delete files and graphics objects
`diary`	Save session in a disk file
`dir`	Directory listing
`edit`	Edit an M-file
`fileparts`	Filename parts
`fullfile`	Build full filename from parts
`inmem`	Functions in memory
`ls`	List directory on UNIX
`matlabroot`	Root directory of MATLAB installation
`mkdir`	Make directory
`open`	Open files based on extension
`pwd`	Display current directory
`tempdir`	Return the name of the system's temporary directory
`tempname`	Unique name for temporary file
`!`	Execute operating system command

Starting and Quitting MATLAB

`matlabrc`	MATLAB startup M-file
`quit`	Terminate MATLAB
`startup`	MATLAB startup M-file

Operators and Special Characters

`+`	Plus
`-`	Minus
`*`	Matrix multiplication
`.*`	Array multiplication
`^`	Matrix power
`.^`	Array power
`kron`	Kronecker tensor product

`\`	Backslash or left division
`/`	Slash or right division
`./` and `.\`	Array division, right and left
`:`	Colon
`( )`	Parentheses
`[ ]`	Brackets
`{}`	Curly braces
`.`	Decimal point
`...`	Continuation
`,`	Comma
`;`	Semicolon
`%`	Comment
`!`	Exclamation point
`'`	Transpose and quote
`.'`	Nonconjugated transpose
`=`	Assignment
`==`	Equality
`< >`	Relational operators
`&`	Logical AND
`|`	Logical OR
`~`	Logical NOT
`xor`	Logical EXCLUSIVE OR

Logical Functions

`all`	Test to determine if all elements are nonzero
`any`	Test for any nonzeros
`exist`	Check if a variable or file exists
`find`	Find indices and values of nonzero elements
`is*`	Detect state
`isa`	Detect an object of a given class
`logical`	Convert numeric values to logical
`mislocked`	True if M-file cannot be cleared

Language Constructs and Debugging

MATLAB as a Programming Language

`builtin`	Execute builtin function from overloaded method
`eval`	Interpret strings containing MATLAB expressions
`evalc`	Evaluate MATLAB expression with capture

`evalin`	Evaluate expression in workspace
`feval`	Function evaluation
`function`	Function M-files
`global`	Define global variables
`nargchk`	Check number of input arguments
`persistent`	Define persistent variable
`script`	Script M-files

Control Flow

`break`	Terminate execution of `for` loop or `while` loop
`case`	Case switch
`catch`	Begin catch block
`else`	Conditionally execute statements
`elseif`	Conditionally execute statements
`end`	Terminate `for`, `while`, `switch`, `try`, and `if` statements or indicate last index
`error`	Display error messages
`for`	Repeat statements a specific number of times
`if`	Conditionally execute statements
`otherwise`	Default part of `switch` statement
`return`	Return to the invoking function
`switch`	Switch among several cases based on expression
`try`	Begin `try` block
`warning`	Display warning message
`while`	Repeat statements an indefinite number of times

Interactive Input

`input`	Request user input
`keyboard`	Invoke the keyboard in an M-file
`menu`	Generate a menu of choices for user input
`pause`	Halt execution temporarily

Object-Oriented Programming

`class`	Create object or return class of object
`double`	Convert to double precision
`inferiorto`	Inferior class relationship
`inline`	Construct an inline object
`int8`, `int16`, `int32`	Convert to signed integer
`isa`	Detect an object of a given class

`loadobj`	Extends the `load` function for user objects
`saveobj`	Save filter for objects
`single`	Convert to single precision
`superiorto`	Superior class relationship
`uint8`, `uint16`, `uint32`	Convert to unsigned integer

Debugging

`dbclear`	Clear breakpoints
`dbcont`	Resume execution
`dbdown`	Change local workspace context
`dbmex`	Enable MEX-file debugging
`dbquit`	Quit debug mode
`dbstack`	Display function call stack
`dbstatus`	List all breakpoints
`dbstep`	Execute one or more lines from a breakpoint
`dbstop`	Set breakpoints in an M-file function
`dbtype`	List M-file with line numbers
`dbup`	Change local workspace context

Elementary Matrices and Matrix Manipulation

Elementary Matrices and Arrays

`blkdiag`	Construct a block diagonal matrix from input arguments
`eye`	Identity matrix
`linspace`	Generate linearly spaced vectors
`logspace`	Generate logarithmically spaced vectors
`ones`	Create an array of all ones
`rand`	Uniformly distributed random numbers and arrays
`randn`	Normally distributed random numbers and arrays
`zeros`	Create an array of all zeros
`:` (colon)	Regularly spaced vector

Special Variables and Constants

`ans`	The most recent answer
`computer`	Identify the computer on which MATLAB is running
`eps`	Floating-point relative accuracy
`flops`	Count floating-point operations
`i`	Imaginary unit

`Inf`	Infinity
`inputname`	Input argument name
`j`	Imaginary unit
`NaN`	Not-a-Number
`nargin`, `nargout`	Number of function arguments
`pi`	Ratio of a circle's circumference to its diameter, π
`realmax`	Largest positive floating-point number
`realmin`	Smallest positive floating-point number
`varargin`, `varargout`	Pass or return variable numbers of arguments

Time and Dates

`calendar`	Calendar
`clock`	Current time as a date vector
`cputime`	Elapsed CPU time
`date`	Current date string
`datenum`	Serial date number
`datestr`	Date string format
`datevec`	Date components
`eomday`	End of month
`etime`	Elapsed time
`now`	Current date and time
`tic, toc`	Stopwatch timer
`weekday`	Day of the week

Matrix Manipulation

`cat`	Concatenate arrays
`diag`	Diagonal matrices and diagonals of a matrix
`fliplr`	Flip matrices left-right
`flipud`	Flip matrices up-down
`repmat`	Replicate and tile an array
`reshape`	Reshape array
`rot90`	Rotate matrix 90 degrees
`tril`	Lower triangular part of a matrix
`triu`	Upper triangular part of a matrix
`:` (colon)	Index into array, rearrange array

Specialized Matrices

`compan`	Companion matrix
`gallery`	Test matrices
`hadamard`	Hadamard matrix
`hankel`	Hankel matrix
`hilb`	Hilbert matrix
`invhilb`	Inverse of the Hilbert matrix
`magic`	Magic square
`pascal`	Pascal matrix
`toeplitz`	Toeplitz matrix
`wilkinson`	Wilkinson's eigenvalue test matrix

Elementary Math Functions

`abs`	Absolute value and complex magnitude
`acos, acosh`	Inverse cosine and inverse hyperbolic cosine
`acot, acoth`	Inverse cotangent and inverse hyperbolic cotangent
`acsc, acsch`	Inverse cosecant and inverse hyperbolic cosecant
`angle`	Phase angle
`asec, asech`	Inverse secant and inverse hyperbolic secant
`asin, asinh`	Inverse sine and inverse hyperbolic sine
`atan, atanh`	Inverse tangent and inverse hyperbolic tangent
`atan2`	Four-quadrant inverse tangent
`ceil`	Round toward infinity
`complex`	Construct complex data from real and imaginary components
`conj`	Complex conjugate
`cos, cosh`	Cosine and hyperbolic cosine
`cot, coth`	Cotangent and hyperbolic cotangent
`csc, csch`	Cosecant and hyperbolic cosecant
`exp`	Exponential
`fix`	Round towards zero
`floor`	Round towards minus infinity
`gcd`	Greatest common divisor
`imag`	Imaginary part of a complex number
`lcm`	Least common multiple
`log`	Natural logarithm
`log2`	Base 2 logarithm and dissect floating-point numbers into exponent and mantissa
`log10`	Common (base 10) logarithm
`mod`	Modulus (signed remainder after division)
`nchoosek`	Binomial coefficient or all combinations

`real`	Real part of complex number
`rem`	Remainder after division
`round`	Round to nearest integer
`sec, sech`	Secant and hyperbolic secant
`sign`	Signum function
`sin, sinh`	Sine and hyperbolic sine
`sqrt`	Square root
`tan, tanh`	Tangent and hyperbolic tangent

Specialized Math Functions

`airy`	Airy functions
`besselh`	Bessel functions of the third kind (Hankel functions)
`besseli`, `besselk`	Modified Bessel functions
`besselj`, `bessely`	Bessel functions
`beta`, `betainc`, `betaln`	Beta functions
`ellipj`	Jacobi elliptic functions
`ellipke`	Complete elliptic integrals of the first and second kind
`erf`, `erfc`, `erfcx`, `erfinv`	Error functions
`expint`	Exponential integral
`factorial`	Factorial function
`gamma`, `gammainc`, `gammaln`	Gamma functions
`legendre`	Associated Legendre functions
`pow2`	Base 2 power and scale floating-point numbers
`rat, rats`	Rational fraction approximation

Coordinate System Conversion

`cart2pol`	Transform Cartesian coordinates to polar or cylindrical
`cart2sph`	Transform Cartesian coordinates to spherical
`pol2cart`	Transform polar or cylindrical coordinates to Cartesian
`sph2cart`	Transform spherical coordinates to Cartesian

Matrix Functions - Numerical Linear Algebra

Matrix Analysis

`cond`	Condition number with respect to inversion
`condeig`	Condition number with respect to eigenvalues
`det`	Matrix determinant
`norm`	Vector and matrix norms
`null`	Null space of a matrix
`orth`	Range space of a matrix
`rank`	Rank of a matrix7
`rcond`	Matrix reciprocal condition number estimate
`rref`, `rrefmovie`	Reduced row echelon form
`subspace`	Angle between two subspaces
`trace`	Sum of diagonal elements

Linear Equations

`chol`	Cholesky factorization
`inv`	Matrix inverse
`lscov`	Least squares solution in the presence of known covariance
`lu`	LU matrix factorization
`lsqnonneg`	Nonnegative least squares
`pinv`	Moore-Penrose pseudoinverse of a matrix
`qr`	Orthogonal-triangular decomposition

Eigenvalues and Singular Values

`balance`	Improve accuracy of computed eigenvalues
`cdf2rdf`	Convert complex diagonal form to real block diagonal form
`eig`	Eigenvalues and eigenvectors
`gsvd`	Generalized singular value decomposition
`hess`	Hessenberg form of a matrix
`poly`	Polynomial with specified roots
`qz`	QZ factorization for generalized eigenvalues
`rsf2csf`	Convert real Schur form to complex Schur form
`schur`	Schur decomposition
`svd`	Singular value decomposition

Matrix Functions

`expm`	Matrix exponential

`funm`	Evaluate functions of a matrix
`logm`	Matrix logarithm7
`sqrtm`	Matrix square root

Low Level Functions

`qrdelete`	Delete column from QR factorization
`qrinsert`	Insert column in QR factorization

Data Analysis and Fourier Transform Functions

Basic Operations

`convhull`	Convex hull
`cumprod`	Cumulative product
`cumsum`	Cumulative sum
`cumtrapz`	Cumulative trapezoidal numerical integration
`delaunay`	Delaunay triangulation
`dsearch`	Search for nearest point
`factor`	Prime factors
`inpolygon`	Detect points inside a polygonal region
`max`	Maximum elements of an array
`mean`	Average or mean value of arrays
`median`	Median value of arrays
`min`	Minimum elements of an array
`perms`	All possible permutations
`polyarea`	Area of polygon
`primes`	Generate list of prime numbers
`prod`	Product of array elements
`sort`	Sort elements in ascending order
`sortrows`	Sort rows in ascending order
`std`	Standard deviation
`sum`	Sum of array elements
`trapz`	Trapezoidal numerical integration
`tsearch`	Search for enclosing Delaunay triangle
`var`	Variance
`voronoi`	Voronoi diagram

Finite Differences

`del2`	Discrete Laplacian
`diff`	Differences and approximate derivatives

`gradient`	Numerical gradient

Correlation

`corrcoef`	Correlation coefficients
`cov`	Covariance matrix

Filtering and Convolution

`conv`	Convolution and polynomial multiplication
`conv2`	Two-dimensional convolution
`deconv`	Deconvolution and polynomial division
`filter`	Filter data with an infinite impulse response (IIR) or finite impulse response (FIR) filter
`filter2`	Two-dimensional digital filtering

Fourier Transforms

`abs`	Absolute value and complex magnitude
`angle`	Phase angle
`cplxpair`	Sort complex numbers into complex conjugate pairs
`fft`	One-dimensional fast Fourier transform
`fft2`	Two-dimensional fast Fourier transform
`fftshift`	Shift DC component of fast Fourier transform to center of spectrum
`ifft`	Inverse one-dimensional fast Fourier transform
`ifft2`	Inverse two-dimensional fast Fourier transform
`ifftn`	Inverse multidimensional fast Fourier transform
`ifftshift`	Inverse FFT shift
`nextpow2`	Next power of two
`unwrap`	Correct phase angles

Vector Functions

`cross`	Vector cross product
`intersect`	Set intersection of two vectors
`ismember`	Detect members of a set
`setdiff`	Return the set difference of two vector
`setxor`	Set exclusive or of two vectors
`union`	Set union of two vectors
`unique`	Unique elements of a vector

Polynomial and Interpolation Functions

Polynomials

`conv`	Convolution and polynomial multiplication
`deconv`	Deconvolution and polynomial division
`poly`	Polynomial with specified roots
`polyder`	Polynomial derivative
`polyeig`	Polynomial eigenvalue problem
`polyfit`	Polynomial curve fitting
`polyval`	Polynomial evaluation
`polyvalm`	Matrix polynomial evaluation
`residue`	Convert between partial fraction expansion and polynomial coefficients
`roots`	Polynomial roots

Data Interpolation

`griddata`	Data gridding
`interp1`	One-dimensional data interpolation (table lookup)
`interp2`	Two-dimensional data interpolation (table lookup)
`interp3`	Three-dimensional data interpolation (table lookup)
`interpft`	One-dimensional interpolation using the FFT method
`interpn`	Multidimensional data interpolation (table lookup)
`meshgrid`	Generate X and Y matrices for three-dimensional plots
`ndgrid`	Generate arrays for multidimensional functions and interpolation
`spline`	Cubic spline interpolation

Function Functions – Nonlinear Numerical Methods

`dblquad`	Numerical double integration
`fminbnd`	Minimize a function of one variable
`fminsearch`	Minimize a function of several variables
`fzero`	Zero of a function of one variable
`ode45`, `ode23`, `ode113`, `ode15s`, `ode23s`, `ode23t`, `ode23tb`	Solve differential equations
`odefile`	Define a differential equation problem for ODE solvers
`odeget`	Extract properties from options structure created with `odeset`
`odeset`	Create or alter options structure for input to ODE solvers
`quad`, `quad8`	Numerical evaluation of integrals
`vectorize`	Vectorize expression

Sparse Matrix Functions

Elementary Sparse Matrices

`spdiags`	Extract and create sparse band and diagonal matrices
`speye`	Sparse identity matrix
`sprand`	Sparse uniformly distributed random matrix
`sprandn`	Sparse normally distributed random matrix
`sprandsym`	Sparse symmetric random matrix

Full to Sparse Conversion

`find`	Find indices and values of nonzero elements
`full`	Convert sparse matrix to full matrix
`sparse`	Create sparse matrix
`spconvert`	Import matrix from sparse matrix external format

Working with Nonzero Entries of Sparse Matrices

`nnz`	Number of nonzero matrix elements
`nonzeros`	Nonzero matrix elements
`nzmax`	Amount of storage allocated for nonzero matrix elements
`spalloc`	Allocate space for sparse matrix
`spfun`	Apply function to nonzero sparse matrix elements
`spones`	Replace nonzero sparse matrix elements with ones

Visualizing Sparse Matrices

`spy`	Visualize sparsity pattern

Reordering Algorithms

`colmmd`	Sparse column minimum degree permutation
`colperm`	Sparse column permutation based on nonzero count
`dmperm`	Dulmage-Mendelsohn decomposition
`randperm`	Random permutation
`symmmd`	Sparse symmetric minimum degree ordering
`symrcm`	Sparse reverse Cuthill-McKee ordering

Norm, Condition Number, and Rank

`condest`	1-norm matrix condition number estimate
`normest`	2-norm estimate

Sparse Systems of Linear Equations

`bicg`	BiConjugate Gradients method
`bicgstab`	BiConjugate Gradients Stabilized method
`cgs`	Conjugate Gradients Squared method
`cholinc`	Sparse Incomplete Cholesky and Cholesky-Infinity factorizations
`cholupdate`	Rank 1 update to Cholesky factorization
`gmres`	Generalized Minimum Residual method (with restarts)
`luinc`	Incomplete LU matrix factorizations
`pcg`	Preconditioned Conjugate Gradients method
`qmr`	Quasi-Minimal Residual method
`qr`	Orthogonal-triangular decomposition
`qrdelete`	Delete column from QR factorization
`qrinsert`	Insert column in QR factorization
`qrupdate`	Rank 1 update to QR factorization

Sparse Eigenvalues and Singular Values

`eigs`	Find eigenvalues and eigenvectors
`svds`	Find singular values

Miscellaneous

`spparms`	Set parameters for sparse matrix routines

Sound Processing Functions

General Sound Functions

`lin2mu`	Convert linear audio signal to mu-law
`mu2lin`	Convert mu-law audio signal to linear
`sound`	Convert vector into sound
`soundsc`	Scale data and play as sound

SPARCstation-Specific Sound Functions

`auread`	Read NeXT/SUN (.au) sound file
`auwrite`	Write NeXT/SUN (.au) sound file

.WAV Sound Functions

`wavread`	Read Microsoft WAVE (.wav) sound file
`wavwrite`	Write Microsoft WAVE (.wav) sound file

Character String Functions

General

`abs`	Absolute value and complex magnitude
`eval`	Interpret strings containing MATLAB expressions
`real`	Real part of complex number
`strings`	MATLAB string handling

String Manipulation

`deblank`	Strip trailing blanks from the end of a string
`findstr`	Find one string within another
`lower`	Convert string to lower case
`strcat`	String concatenation
`strcmp`	Compare strings
`strcmpi`	Compare strings ignoring case
`strjust`	Justify a character array
`strmatch`	Find possible matches for a string
`strncmp`	Compare the first `n` characters of two strings
`strrep`	String search and replace
`strtok`	First token in string
`strvcat`	Vertical concatenation of strings
`symvar`	Determine symbolic variables in an expression
`texlabel`	Produce the TeX format from a character string
`upper`	Convert string to upper case

String to Number Conversion

`char`	Create character array (string)
`int2str`	Integer to string conversion
`mat2str`	Convert a matrix into a string
`num2str`	Number to string conversion
`sprintf`	Write formatted data to a string
`sscanf`	Read string under format control
`str2double`	Convert string to double-precision value
`str2num`	String to number conversion

Radix Conversion

`bin2dec`	Binary to decimal number conversion
`dec2bin`	Decimal to binary number conversion
`dec2hex`	Decimal to hexadecimal number conversion

`hex2dec`	IEEE hexadecimal to decimal number conversion
`hex2num`	Hexadecimal to double number conversion

Low-Level File I/O Functions

File Opening and Closing

`fclose`	Close one or more open files
`fopen`	Open a file or obtain information about open files

Unformatted I/O

`fread`	Read binary data from file
`fwrite`	Write binary data to a file

Formatted I/O

`fgetl`	Return the next line of a file as a string without line terminator(s)
`fgets`	Return the next line of a file as a string with line terminator(s)
`fprintf`	Write formatted data to file
`fscanf`	Read formatted data from file

File Positioning

`feof`	Test for end-of-file
`ferror`	Query MATLAB about errors in file input or output
`frewind`	Rewind an open file
`fseek`	Set file position indicator
`ftell`	Get file position indicator

String Conversion

`sprintf`	Write formatted data to a string
`sscanf`	Read string under format control

Specialized File I/O

`dlmread`	Read an ASCII delimited file into a matrix
`dlmwrite`	Write a matrix to an ASCII delimited file
`hdf`	HDF interface
`imfinfo`	Return information about a graphics file
`imread`	Read image from graphics file

`imwrite`	Write an image to a graphics file
`textread`	Read formatted data from text file
`wk1read`	Read a Lotus123 WK1 spreadsheet file into a matrix
`wk1write`	Write a matrix to a Lotus123 WK1 spreadsheet file

Bitwise Functions

`bitand`	Bit-wise AND
`bitcmp`	Complement bits
`bitor`	Bit-wise OR
`bitmax`	Maximum floating-point integer
`bitset`	Set bit
`bitshift`	Bit-wise shift
`bitget`	Get bit
`bitxor`	Bit-wise XOR

Structure Functions

`fieldnames`	Field names of a structure
`getfield`	Get field of structure array
`rmfield`	Remove structure fields
`setfield`	Set field of structure array
`struct`	Create structure array
`struct2cell`	Structure to cell array conversion

Object Functions

`class`	Create object or return class of object
`isa`	Detect an object of a given class

Cell Array Functions

`cell`	Create cell array
`cellfun`	Apply a function to each element in a cell array
`cellstr`	Create cell array of strings from character array
`cell2struct`	Cell array to structure array conversion
`celldisp`	Display cell array contents
`cellplot`	Graphically display the structure of cell arrays
`num2cell`	Convert a numeric array into a cell array

Multidimensional Array Functions

`cat`	Concatenate arrays
`flipdim`	Flip array along a specified dimension
`ind2sub`	Subscripts from linear index
`ipermute`	Inverse permute the dimensions of a multidimensional array
`ndgrid`	Generate arrays for multidimensional functions and interpolation
`ndims`	Number of array dimensions
`permute`	Rearrange the dimensions of a multidimensional array
`reshape`	Reshape array
`shiftdim`	Shift dimensions
`squeeze`	Remove singleton dimensions
`sub2ind`	Single index from subscripts

Plotting and Data Visualization

Basic Plots and Graphs

`bar`	Vertical bar chart
`barh`	Horizontal bar chart
`hist`	Plot histograms
`hold`	Hold current graph
`loglog`	Plot using log-log scales
`pie`	Pie plot
`plot`	Plot vectors or matrices.
`polar`	Polar coordinate plot
`semilogx`	Semi-log scale plot
`semilogy`	Semi-log scale plot
`subplot`	Create axes in tiled positions

Three-Dimensional Plotting

`bar3`	Vertical 3-D bar chart
`bar3h`	Horizontal 3-D bar chart
`comet3`	3-D comet plot
`cylinder`	Generate cylinder
`fill3`	Draw filled 3-D polygons in 3-space
`plot3`	Plot lines and points in 3-D space
`quiver3`	3-D quiver (or velocity) plot
`slice`	Volumetric slice plot
`sphere`	Generate sphere
`stem3`	Plot discrete surface data

`waterfall`	Waterfall plot

Plot Annotation and Grids

`clabel`	Add contour labels to a contour plot
`datetick`	Date formatted tick labels
`grid`	Grid lines for 2-D and 3-D plots
`gtext`	Place text on a 2-D graph using a mouse
`legend`	Graph legend for lines and patches
`plotyy`	Plot graphs with Y tick labels on the left and right
`title`	Titles for 2-D and 3-D plots
`xlabel`	X-axis labels for 2-D and 3-D plots
`ylabel`	Y-axis labels for 2-D and 3-D plots
`zlabel`	Z-axis labels for 3-D plots

Surface, Mesh, and Contour Plots

`contour`	Contour (level curves) plot
`contourc`	Contour computation
`contourf`	Filled contour plot
`hidden`	Mesh hidden line removal mode
`meshc`	Combination mesh/contourplot
`mesh`	3-D mesh with reference plane
`peaks`	A sample function of two variables
`surf`	3-D shaded surface graph
`surface`	Create surface low-level objects
`surfc`	Combination surf/contourplot
`surfl`	3-D shaded surface with lighting
`trimesh`	Triangular mesh plot
`trisurf`	Triangular surface plot

Volume Visualization

`coneplot`	Plot velocity vectors as cones in 3-D vector field
`contourslice`	Draw contours in volume slice plane
`isocaps`	Compute isosurface end-cap geometry
`isonormals`	Compute normals of isosurface vertices
`isosurface`	Extract isosurface data from volume data
`reducepatch`	Reduce the number of patch faces
`reducevolume`	Reduce number of elements in volume data set
`shrinkfaces`	Reduce the size of patch faces
`smooth3`	Smooth 3-D data
`stream2`	Compute 2-D stream line data

`stream3`	Compute 3-D stream line data
`streamline`	Draw stream lines from 2- or 3-D vector data
`surf2patch`	Convert srface data to patch data
`subvolume`	Extract subset of volume data set

Domain Generation

`griddata`	Data gridding and surface fitting
`meshgrid`	Generation of X and Y arrays for 3-D plots

Specialized Plotting

`area`	Area plot
`box`	Axis box for 2-D and 3-D plots
`comet`	Comet plot
`compass`	Compass plot
`errorbar`	Plot graph with error bars
`ezcontour`	Easy to use contour plotter
`ezcontourf`	Easy to use filled contour plotter
`ezmesh`	Easy to use 3-D mesh plotter
`ezmeshc`	Easy to use combination mesh/contour plotter
`ezplot`	Easy to use function plotter
`ezplot3`	Easy to use 3-D parametric curve plotter
`ezpolar`	Easy to use polar coordinate plotter
`ezsurf`	Easy to use 3-D colored surface plotter
`ezsurfc`	Easy to use combination surface/contour plotter
`feather`	Feather plot
`fill`	Draw filled 2-D polygons
`fplot`	Plot a function
`pareto`	Pareto char
`pie3`	3-D pie plot
`plotmatrix`	Scatter plot matrix
`pcolor`	Pseudocolor (checkerboard) plot
`rose`	Plot rose or angle histogram
`quiver`	Quiver (or velocity) plot
`ribbon`	Ribbon plot
`stairs`	Stairstep graph
`scatter`	Scatter plot
`scatter3`	3-D scatter plot
`stem`	Plot discrete sequence data
`convhull`	Convex hull
`delaunay`	Delaunay triangulation
`dsearch`	Search Delaunay triangulation for nearest point

`inpolygon`	True for points inside a polygonal region
`polyarea`	Area of polygon
`tsearch`	Search for enclosing Delaunay triangle
`voronoi`	Voronoi diagram

View Control

`camdolly`	Move camera position and target
`camlookat`	View specific objects
`camorbit`	Orbit about camera target
`campan`	Rotate camera target about camera position
`campos`	Set or get camera position
`camproj`	Set or get projection type
`camroll`	Rotate camera about viewing axis
`camtarget`	Set or get camera target
`camup`	Set or get camera up-vector
`camva`	Set or get camera view angle
`camzoom`	Zoom camera in or out
`daspect`	Set or get data aspect ratio
`pbaspect`	Set or get plot box aspect ratio
`view`	3-D graph viewpoint specification.
`viewmtx`	Generate view transformation matrices
`xlim`	Set or get the current *x*-axis limits
`ylim`	Set or get the current *y*-axis limits
`zlim`	Set or get the current *z*-axis limits

Lighting

`camlight`	Cerate or position Light
`diffuse`	Diffuse reflectance
`lighting`	Lighting mode
`lightingangle`	Position light in sphereical coordinates
`material`	Material reflectance mode
`specular`	Specular reflectance

Color Operations

`brighten`	Brighten or darken color map
`bwcontr`	Contrasting black and/or color
`caxis`	Pseudocolor axis scaling
`colorbar`	Display color bar (color scale)
`colorcube`	Enhanced color-cube color map
`colordef`	Set up color defaults

`colormap`	Set the color look-up table
`graymon`	Graphics figure defaults set for grayscale monitor
`hsv2rgb`	Hue-saturation-value to red-green-blue conversion
`rgb2hsv`	RGB to HSVconversion
`rgbplot`	Plot color map
`shading`	Color shading mode
`spinmap`	Spin the colormap
`surfnorm`	3-D surface normals
`whitebg`	Change axes background color for plots

Colormaps

`autumn`	Shades of red and yellow color map
`bone`	Gray-scale with a tinge of blue color map
`contrast`	Gray color map to enhance image contrast
`cool`	Shades of cyan and magenta color map
`copper`	Linear copper-tone color map
`flag`	Alternating red, white, blue, and black color map
`gray`	Linear gray-scale color map
`hot`	Black-red-yellow-white color map
`hsv`	Hue-saturation-value (HSV) color map
`jet`	Variant of HSV
`lines`	Line color colormap
`prism`	Colormap of prism colors
`spring`	Shades of magenta and yellow color map
`summer`	Shades of green and yellow colormap
`winter`	Shades of blue and green color map

Printing

`orient`	Hardcopy paper orientation
`print`	Print graph or save graph to file
`printopt`	Configure local printer defaults
`saveas`	Save figure to graphic file

Handle Graphics, General

`copyobj`	Make a copy of a graphics object and its children
`findobj`	Find objects with specified property values
`gcbo`	Return object whose callback is currently executing
`gco`	Return handle of current object
`get`	Get object properties
`rotate`	Rotate objects about specified origin and direction

`ishandle`	True for graphics objects
`set`	Set object properties

Handle Graphics, Object Creation

`axes`	Create Axes object
`figure`	Create Figure (graph) windows
`image`	Create Image (2-D matrix)
`light`	Create Light object (illuminates Patch and Surface)
`line`	Create Line object (3-D polylines)
`patch`	Create Patch object (polygons)
`rectangle`	Create Rectangle object (2-D rectangle)
surface	Create Surface (quadrilaterals)
`text`	Create Text object (character strings)
`uicontext`	Create context menu (popup associated with object)

Handle Graphics, Figure Windows

`capture`	Screen capture of the current figure
`clc`	Clear figure window
`clf`	Clear figure
`clg`	Clear figure (graph window)
`close`	Close specified window
`gcf`	Get current figure handle
`newplot`	Graphics M-file preamble for `NextPlot` property
`refresh`	Refresh figure
`saveas`	Save figure or model to desired output format

Handle Graphics, Axes

`axis`	Plot axis scaling and appearance
`cla`	Clear Axes
`gca`	Get current Axes handle

Object Manipulation

`propedit`	Edit all properties of any selected object
`reset`	Reset axis or figure
`rotate3d`	Interactively rotate the view of a 3-D plot
`selectmoveresize`	Interactively select, move, or resize objects
`shg`	Show graph window

Interactive User Input

`ginput`	Graphical input from a mouse or cursor
`zoom`	Zoom in and out on a 2-D plot

Region of Interest

`dragrect`	Drag XOR rectangles with mouse
`drawnow`	Complete any pending drawing
`rbbox`	Rubberband box

Graphical User Interface Creation

Dialog Boxes

`dialog`	Create a dialog box
`errordlg`	Create error dialog box
`helpdlg`	Display help dialog box
`inputdlg`	Create input dialog box
`listdlg`	Create list selection dialog box
`msgbox`	Create message dialog box
`pagedlg`	Display page layout dialog box
`printdlg`	Display print dialog box
`questdlg`	Create question dialog box
`uigetfile`	Display dialog box to retrieve name of file for reading
`uiputfile`	Display dialog box to retrieve name of file for writing
`uisetcolor`	Interactively set a `ColorSpec` using a dialog box
`uisetfont`	Interactively set a font using a dialog box
`warndlg`	Create warning dialog box

User Interface Objects

`menu`	Generate a menu of choices for user input
`menuedit`	Menu editor
`uicontextmenu`	Create context menu
`uicontrol`	Create user interface control
`uimenu`	Create user interface menu

Other Functions

`dragrect`	Drag rectangles with mouse
`findfigs`	Display off-screen visible figure windows
`gcbo`	Return handle of object whose callback is executing

`rbbox`	Create rubberband box for area selection
`selectmoveresize`	Select, move, resize, or copy Axes and Uicontrol graphics objects
`textwrap`	Return wrapped string matrix for given Uicontrol
`uiresume`	Used with `uiwait`, controls program execution
`uiwait`	Used with `uiresume`, controls program execution
`waitbar`	Display wait bar
`waitforbuttonpress`	Wait for key/buttonpress over figure

2

Reference

This chapter describes all MATLAB operators, commands, and functions in alphabetical order.

Purpose

Matrix and array arithmetic

Syntax

```
A+B
A–B
A*B       A.*B
A/B       A./B
A\B       A.\B
A^B       A.^B
A'        A.'
```

Description

+
-
*
/
\
^
'

MATLAB has two different types of arithmetic operations. Matrix arithmetic operations are defined by the rules of linear algebra. Array arithmetic operations are carried out element-by-element. The period character (.) distinguishes the array operations from the matrix operations. However, since the matrix and array operations are the same for addition and subtraction, the character pairs .+ and .– are not used.

+ Addition or unary plus. A+B adds A and B. A and B must have the same size, unless one is a scalar. A scalar can be added to a matrix of any size.

– Subtraction or unary minus. A–B subtracts B from A. A and B must have the same size, unless one is a scalar. A scalar can be subtracted from a matrix of any size.

* Matrix multiplication. C = A*B is the linear algebraic product of the matrices A and B. More precisely,

$$C(i, j) = \sum_{k=1}^{n} A(i, k)B(k, j)$$

For nonscalar A and B, the number of columns of A must equal the number of rows of B. A scalar can multiply a matrix of any size.

`.*` Array multiplication. `A.*B` is the element-by-element product of the arrays `A` and `B`. `A` and `B` must have the same size, unless one of them is a scalar.

`/` Slash or matrix right division. `B/A` is roughly the same as `B*inv(A)`. More precisely, `B/A = (A'\B')'`. See `\`.

`./` Array right division. `A./B` is the matrix with elements `A(i,j)/B(i,j)`. `A` and `B` must have the same size, unless one of them is a scalar.

`\` Backslash or matrix left division. If `A` is a square matrix, `A\B` is roughly the same as `inv(A)*B`, except it is computed in a different way. If `A` is an `n`-by-`n` matrix and `B` is a column vector with `n` components, or a matrix with several such columns, then `X = A\B` is the solution to the equation $AX = B$ computed by Gaussian elimination (see "Algorithm" for details). A warning message prints if `A` is badly scaled or nearly singular.

If `A` is an `m`-by-`n` matrix with `m ~= n` and `B` is a column vector with `m` components, or a matrix with several such columns, then `X = A\B` is the solution in the least squares sense to the under- or overdetermined system of equations $AX = B$. The effective rank, `k`, of `A`, is determined from the QR decomposition with pivoting (see "Algorithm" for details). A solution `X` is computed which has at most `k` nonzero components per column. If `k < n`, this is usually not the same solution as `pinv(A)*B`, which is the least squares solution with the smallest norm, $||X||$.

`.\` Array left division. `A.\B` is the matrix with elements `B(i,j)/A(i,j)`. `A` and `B` must have the same size, unless one of them is a scalar.

`^` Matrix power. `X^p` is `X` to the power `p`, if `p` is a scalar. If `p` is an integer, the power is computed by repeated multiplication. If the integer is negative, `X` is inverted first. For other values of `p`, the calculation involves eigenvalues and eigenvectors, such that if `[V,D] = eig(X)`, then `X^p = V*D.^p/V`.

If `x` is a scalar and `P` is a matrix, `x^P` is `x` raised to the matrix power `P` using eigenvalues and eigenvectors. `X^P`, where `X` and `P` are both matrices, is an error.

`.^` Array power. `A.^B` is the matrix with elements `A(i,j)` to the `B(i,j)` power. `A` and `B` must have the same size, unless one of them is a scalar.

' Matrix transpose. `A'` is the linear algebraic transpose of `A`. For complex matrices, this is the complex conjugate transpose.

.' Array transpose. `A.'` is the array transpose of `A`. For complex matrices, this does not involve conjugation.

Remarks

The arithmetic operators have M-file function equivalents, as shown:

Binary addition	`A+B`	`plus(A,B)`
Unary plus	`+A`	`uplus(A)`
Binary subtraction	`A–B`	`minus(A,B)`
Unary minus	`–A`	`uminus(A)`
Matrix multiplication	`A*B`	`mtimes(A,B)`
Array-wise multiplication	`A.*B`	`times(A,B)`
Matrix right division	`A/B`	`mrdivide(A,B)`
Array-wise right division	`A./B`	`rdivide(A,B)`
Matrix left division	`A\B`	`mldivide(A,B)`
Array-wise left division	`A.\B`	`ldivide(A,B)`
Matrix power	`A^B`	`mpower(A,B)`
Array-wise power	`A.^B`	`power(A,B)`
Complex transpose	`A'`	`ctranspose(A)`
Matrix transpose	`A.'`	`transpose(A)`

Examples

Here are two vectors, and the results of various matrix and array operations on them, printed with `format rat`.

Matrix Operations		Array Operations	
x	1 2 3	y	4 5 6
x'	1 2 3	y'	4 5 6

Matrix Operations		Array Operations	
x+y	5 7 9	x–y	–3 –3 –3
x + 2	3 4 5	x–2	–1 0 1
x * y	Error	x.*y	4 10 18
x'*y	32	x'.*y	Error
x*y'	4 5 6 8 10 12 12 15 18	x.*y'	Error
x*2	2 4 6	x.*2	2 4 6
x\y	16/7	x.\y	4 5/2 2
2\x	1/2 1 3/2	2./x	2 1 2/3
x/y	0 0 1/6 0 0 1/3 0 0 1/2	x./y	1/4 2/5 1/2
x/2	1/2 1 3/2	x./2	1/2 1 3/2
x^y	Error	x.^y	1 32 729

Matrix Operations		Array Operations	
x^2	Error	x.^2	1 4 9
2^x	Error	2.^x	2 4 8
(x+i*y)'	1 - 4i 2 - 5i 3 - 6i		
(x+i*y).'	1 + 4i 2 + 5i 3 + 6i		

Algorithm

The specific algorithm used for solving the simultaneous linear equations denoted by `X = A\B` and `X = B/A` depends upon the structure of the coefficient matrix `A`.

- If `A` is a triangular matrix, or a permutation of a triangular matrix, then `X` can be computed quickly by a permuted backsubstitution algorithm. The check for triangularity is done for full matrices by testing for zero elements and for sparse matrices by accessing the sparse data structure. Most nontriangular matrices are detected almost immediately, so this check requires a negligible amount of time.
- If `A` is symmetric, or Hermitian, and has positive diagonal elements, then a Cholesky factorization is attempted (see `chol`). If `A` is sparse, a symmetric minimum degree preordering is applied (see `symmmd` and `spparms`). If `A` is found to be positive definite, the Cholesky factorization attempt is successful and requires less than half the time of a general factorization. Nonpositive definite matrices are usually detected almost immediately, so this check also requires little time. If successful, the Cholesky factorization is

  ```
  A = R'*R
  ```

  where `R` is upper triangular. The solution `X` is computed by solving two triangular systems,

  ```
  X = R\(R'\B)
  ```

- If `A` is square, but not a permutation of a triangular matrix, or is not Hermitian with positive elements, or the Cholesky factorization fails, then a general triangular factorization is computed by Gaussian elimination with partial pivoting (see `lu`). If `A` is sparse, a non-

symmetric minimum degree preordering is applied (see `colmmd` and `spparms`). This results in

```
A = L*U
```

where `L` is a permutation of a lower triangular matrix and `U` is an upper triangular matrix. Then `X` is computed by solving two permuted triangular systems.

```
X = U\(L\B)
```

- If `A` is not square and is full, then Householder reflections are used to compute an orthogonal-triangular factorization.

  ```
  A*P = Q*R
  ```

  where `P` is a permutation, `Q` is orthogonal and `R` is upper triangular (see `qr`). The least squares solution `X` is computed with

  ```
  X = P*(R\(Q'*B)
  ```

- If `A` is not square and is sparse, then the augmented matrix is formed by:

  ```
  S = [c*I A; A' 0]
  ```

  The default for the residual scaling factor is `c = max(max(abs(A)))/1000` (see `spparms`). The least squares solution `X` and the residual `R = B-A*X` are computed by

  ```
  S * [R/c; X] = [B; 0]
  ```

  with minimum degree preordering and sparse Gaussian elimination with numerical pivoting.

The various matrix factorizations are computed by MATLAB implementations of the algorithms employed by LINPACK routines `ZGECO`, `ZGEFA` and `ZGESL` for square matrices and `ZQRDC` and `ZQRSL` for rectangular matrices. See the *LINPACK Users' Guide* for details.

Diagnostics

From matrix division, if a square `A` is singular:

```
Matrix is singular to working precision.
```

From element-wise division, if the divisor has zero elements:

```
Divide by zero.
```

On machines without IEEE arithmetic, like the VAX, the above two operations generate the error messages shown. On machines with IEEE arithmetic, only warning messages are generated. The matrix division returns a matrix with each element set to `Inf`; the element-wise division produces `NaN`s or `Inf`s where appropriate.

If the inverse was found, but is not reliable:

```
Warning: Matrix is close to singular or badly scaled.
    Results may be inaccurate.  RCOND = xxx
```

From matrix division, if a nonsquare `A` is rank deficient:

```
Warning: Rank deficient, rank = xxx tol = xxx
```

See Also

`det`, `inv`, `lu`, `orth`, `permute`, `ipermute`, `qr`, `rref`

References

[1] Dongarra, J.J., J.R. Bunch, C.B. Moler, and G.W. Stewart, *LINPACK Users' Guide*, SIAM, Philadelphia, 1979.

Relational Operators < > <= >= == ~=

Purpose

Relational operations

Syntax

```
A < B
A > B
A <= B
A >= B
A == B
A ~= B
```

Description

The relational operators are <, ≤, >, ≥, ==, and ~=. Relational operators perform element-by-element comparisons between two arrays. They return an array of the same size, with elements set to logical true (`1`) where the relation is true, and elements set to logical false (`0`) where it is not.

The operators <, ≤, >, and ≥ use only the real part of their operands for the comparison. The operators == and ~= test real and imaginary parts.

To test if two strings are equivalent, use `strcmp`, which allows vectors of dissimilar length to be compared.

Examples

If one of the operands is a scalar and the other a matrix, the scalar expands to the size of the matrix. For example, the two pairs of statements:

```
X = 5; X >= [1 2 3; 4 5 6; 7 8 10]
X = 5*ones(3,3); X >= [1 2 3; 4 5 6; 7 8 10]
```

produce the same result:

```
ans =

     1     1     1
     1     1     0
     0     0     0
```

See Also

`all`, `any`, `find`, `strcmp`

The logical operators `&`, `|`, `~`

Logical Operators & | ~

Purpose

Logical operations

Syntax

```
A & B
A | B
~A
```

Description

The symbols &, |, and ~ are the logical operators AND, OR, and NOT. They work element-wise on arrays, with 0 representing logical false (F), and anything nonzero representing logical true (T). The & operator does a logical AND, the | operator does a logical OR, and ~A complements the elements of A. The function xor(A,B) implements the exclusive OR operation. Truth tables for these operators and functions follow.

Inputs A	B	and A&B	or A|B	xor xor(A,B)	NOT ~A
0	0	0	0	0	1
0	1	0	1	1	1
1	0	0	1	1	0
1	1	1	1	0	0

The precedence for the logical operators with respect to each other is:

1. not has the highest precedence.
2. and and or have equal precedence, and are evaluated from left to right.

Remarks

The logical operators have M-file function equivalents, as shown:

and	A&B	and(A,B)
or	A|B	or(A,B)
not	~A	not(A)

Precedence of & and |

MATLAB's left to right execution precedence causes a|b&c to be equivalent to (a|b)&c. However, in most programming languages, a|b&c is equivalent to

`a|(b&c)`, that is, & takes precedence over |. To ensure compatibility with future versions of MATLAB, you should use parentheses to explicity specify the intended precedence of statements containing combinations of & and |.

Examples

Here are two examples that illustrate the precedence of the logical operators to each other:

```
1 | 0 & 0 = 0
0 & 0 | 1 = 1
```

See Also

`all`, `any`, `find`, `logical`, `xor`

The relational operators: `<`, `<=`, `>`, `>=`, `==`, `~=ì`

Special Characters [ ] ( ) {} = ' . ... , ; % !

Purpose

Special characters

Syntax

```
[ ] ( ) {} = ' . ... , ; % !
```

Description

`[ ]` Brackets are used to form vectors and matrices. `[6.9 9.64 sqrt(-1)]` is a vector with three elements separated by blanks. `[6.9, 9.64, i]` is the same thing. `[1+j 2-j 3]` and `[1 +j 2 -j 3]` are not the same. The first has three elements, the second has five.

`[11 12 13; 21 22 23]` is a 2-by-3 matrix. The semicolon ends the first row.

Vectors and matrices can be used inside `[ ]` brackets. `[A B;C]` is allowed if the number of rows of `A` equals the number of rows of `B` and the number of columns of `A` plus the number of columns of `B` equals the number of columns of `C`. This rule generalizes in a hopefully obvious way to allow fairly complicated constructions.

`A = [ ]` stores an empty matrix in `A`. `A(m,:) = [ ]` deletes row `m` of `A`. `A(:,n) = [ ]` deletes column `n` of `A`. `A(n) = [ ]` reshapes `A` into a column vector and deletes the third element.

`[A1,A2,A3...] = function` assigns function output to multiple variables.

For the use of `[` and `]` on the left of an "=" in multiple assignment statements, see `lu`, `eig`, `svd`, and so on.

`{ }` Curly braces are used in cell array assignment statements. For example.,

`A(2,1) = {[1 2 3; 4 5 6]}`, or `A{2,2} = ('str')`. See `help paren` for more information about `{ }`.

( ) Parentheses are used to indicate precedence in arithmetic expressions in the usual way. They are used to enclose arguments of functions in the usual way. They are also used to enclose subscripts of vectors and matrices in a manner somewhat more general than usual. If `X` and `V` are vectors, then `X(V)` is `[X(V(1)), X(V(2)), ..., X(V(n))]`. The components of `V` must be integers to be used as subscripts. An error occurs if any such subscript is less than 1 or greater than the size of `X`. Some examples are

- `X(3)` is the third element of `X`.
- `X([1 2 3])` is the first three elements of `X`.

See `help paren` for more information about `( )`.

If `X` has `n` components, `X(n:-1:1)` reverses them. The same indirect subscripting works in matrices. If `V` has `m` components and `W` has `n` components, then `A(V,W)` is the m-by-n matrix formed from the elements of `A` whose subscripts are the elements of `V` and `W`. For example, `A([1,5],:) = A([5,1],:)` interchanges rows 1 and 5 of `A`.

= Used in assignment statements. `B = A` stores the elements of `A` in `B`. == is the relational equals operator. See the Relational Operators page.

' Matrix transpose. `X'` is the complex conjugate transpose of `X`. `X.'` is the nonconjugate transpose.

Quotation mark. `'any text'` is a vector whose components are the ASCII codes for the characters. A quotation mark within the text is indicated by two quotation marks.

. Decimal point. `314/100`, `3.14` and `.314e1` are all the same. Element-by-element operations. These are obtained using `.*`, `.^`, `./`, or `.\`. See the Arithmetic Operators page.

. Field access. `A.(field)` and `A(i).field`, when `A` is a structure, access the contents of `field`.

.. Parent directory. See `cd`.

... Continuation. Three or more points at the end of a line indicate continuation.

`,` Comma. Used to separate matrix subscripts and function arguments. Used to separate statements in multistatement lines. For multi-statement lines, the comma can be replaced by a semicolon to suppress printing.

`;` Semicolon. Used inside brackets to end rows. Used after an expression or statement to suppress printing or to separate statements.

`%` Percent. The percent symbol denotes a comment; it indicates a logical end of line. Any following text is ignored. MATLAB displays the first contiguous comment lines in a M-file in response to a `help` command.

`!` Exclamation point. Indicates that the rest of the input line is issued as a command to the operating system.

Remarks

Some uses of special characters have M-file function equivalents, as shown:

Horizontal concatenation	`[A,B,C...]`	`horzcat(A,B,C...)`
Vertical concatenation	`[A;B;C...]`	`vertcat(A,B,C...)`
Subscript reference	`A(i,j,k...)`	`subsref(A,S)`. See `help subsref`.
Subscript assignment	`A(i,j,k...)= B`	`subsasgn(A,S,B)`. See `help subsasgn`.

See Also

The arithmetic operators +, –, *, /, \, ^, '

The relational operators: <, <=, >, >=, ==, ~=

The logical operators &, |, ~

Purpose

Create vectors, array subscripting, and `for` loop iterations

Description

The colon is one of the most useful operators in MATLAB. It can create vectors, subscript arrays, and specify `for` iterations.

The colon operator uses the following rules to create regularly spaced vectors:

`j:k`	is the same as `[j,j+1,...,k]`
`j:k`	is empty if `j > k`
`j:i:k`	is the same as `[j,j+i,j+2i, ...,k]`
`j:i:k`	is empty if `i > 0` and `j > k` or if `i < 0` and `j < k`

where `i`,`j`, and `k` are all scalars.

Below are the definitions that govern the use of the colon to pick out selected rows, columns, and elements of vectors, matrices, and higher-dimensional arrays:

`A(:,j)`	is the `j`-th column of `A`
`A(i,:)`	is the `i`-th row of `A`
`A(:,:)`	is the equivalent two-dimensional array. For matrices this is the same as `A`.
`A(j:k)`	is `A(j), A(j+1),...,A(k)`
`A(:,j:k)`	is `A(:,j), A(:,j+1),...,A(:,k)`
`A(:,:,k)`	is the `k`th page of three-dimensional array `A`.
`A(i,j,k,:)`	is a vector in four-dimensional array `A`. The vector includes `A(i,j,k,1)`, `A(i,j,k,2)`, `A(i,j,k,3)`, and so on.
`A(:)`	is all the elements of `A`, regarded as a single column. On the left side of an assignment statement, `A(:)` fills `A`, preserving its shape from before. In this case, the right side must contain the same number of elements as `A`.

Colon :

Examples

Using the colon with integers,

```
D = 1:4
```

results in

```
D =
    1    2    3    4
```

Using two colons to create a vector with arbitrary real increments between the elements,

```
E = 0:.1:.5
```

results in

```
E =
    0    0.1000    0.2000    0.3000    0.4000    0.5000
```

The command

```
A(:,:,2) = pascal(3)
```

generates a three-dimensional array whose first page is all zeros.

```
A(:,:,1) =
     0     0     0
     0     0     0
     0     0     0

A(:,:,2) =
     1     1     1
     1     2     3
     1     3     6
```

See Also

`for`, `linspace`, `logspace`, `reshape`

Purpose

Absolute value and complex magnitude

Syntax

```
Y = abs(X)
```

Description

`abs(X)` returns the absolute value, $|X|$, for each element of `X`.

If `X` is complex, `abs(X)` returns the complex modulus (magnitude):

```
abs(X) = sqrt(real(X).^2 + imag(X).^2)
```

Examples

```
abs(–5) = 5
abs(3+4i) = 5
```

See Also

`angle`, `sign`, `unwrap`

acos, acosh

Purpose

Inverse cosine and inverse hyperbolic cosine

Syntax

```
Y = acos(X)
Y = acosh(X)
```

Description

The acos and acosh functions operate element-wise on arrays. The functions' domains and ranges include complex values. All angles are in radians.

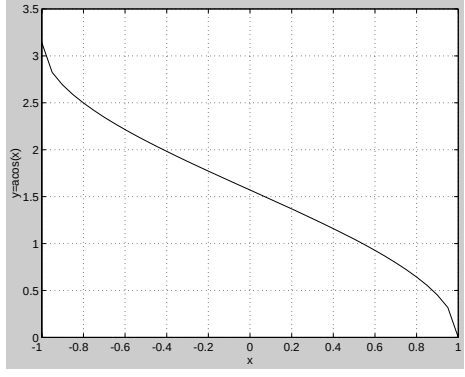
`Y = acos(X)` returns the inverse cosine (arccosine) for each element of `X`. For real elements of `X` in the domain [–1, 1], `acos(X)` is real and in the range [0, π]. For real elements of `X` outside the domain [–1, 1], `acos(X)` is complex.

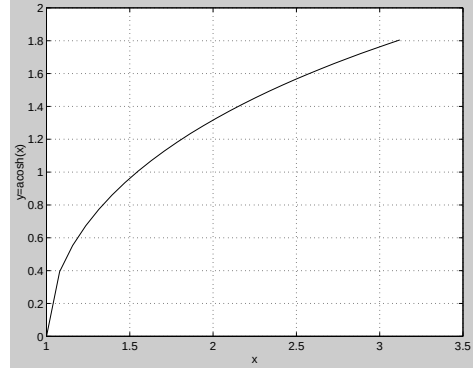
`Y = acosh(X)` returns the inverse hyperbolic cosine for each element of `X`.

Examples

Graph the inverse cosine function over the domain $-1 \le x \le 1$, and the inverse hyperbolic cosine function over the domain $1 \le x \le \pi$.

```
x = -1:.05:1; plot(x,acos(x))
x = 1:pi/40:pi; plot(x,acosh(x))
```





Algorithm

$$\cos^{-1}(z) = -i \log\left[z + i\,(1 - z^2)^{\frac{1}{2}}\right]$$

$$\cosh^{-1}(z) = \log\left[z + (z^2 - 1)^{\frac{1}{2}}\right]$$

See Also

cos, cosh

Purpose

Inverse cotangent and inverse hyperbolic cotangent

Syntax

```
Y = acot(X)
Y = acoth(X)
```

Description

The acot and acoth functions operate element-wise on arrays. The functions' domains and ranges include complex values. All angles are in radians.

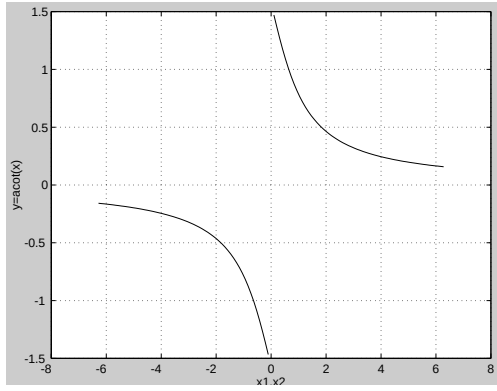
`Y = acot(X)` returns the inverse cotangent (arccotangent) for each element of `X`.

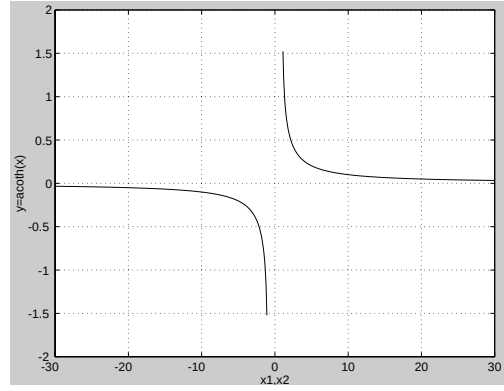
`Y = acoth(X)` returns the inverse hyperbolic cotangent for each element of `X`.

Examples

Graph the inverse cotangent over the domains $-2\pi \le x < 0$ and $0 < x \le 2\pi$, and the inverse hyperbolic cotangent over the domains $-30 \le x < -1$ and $1 < x \le 30$.

```
x1 = -2*pi:pi/30:-0.1; x2 = 0.1:pi/30:2*pi;
plot(x1,acot(x1),x2,acot(x2))
x1 = -30:0.1:-1.1; x2 = 1.1:0.1:30;
plot(x1,acoth(x1),x2,acoth(x2))
```





Algorithm

$$\cot^{-1}(z) = \tan^{-1}\left(\frac{1}{z}\right)$$

$$\coth^{-1}(z) = \tanh^{-1}\left(\frac{1}{z}\right)$$

See Also `cot`, `coth`

Purpose

Inverse cosecant and inverse hyperbolic cosecant

Syntax

```
Y = acsc(X)
Y = acsch(X)
```

Description

The acsc and acsch functions operate element-wise on arrays. The functions' domains and ranges include complex values. All angles are in radians.

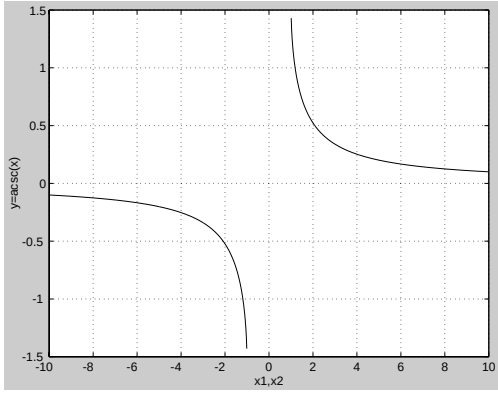
`Y = acsc(X)` returns the inverse cosecant (arccosecant) for each element of `X`.

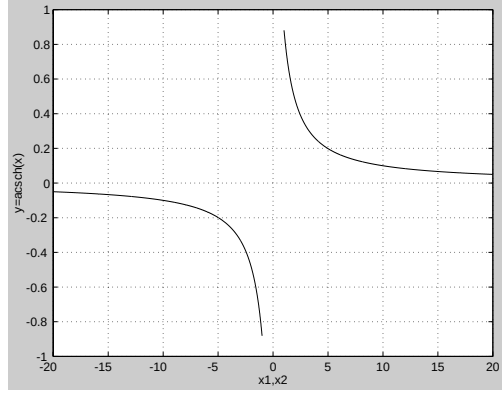
`Y = acsch(X)` returns the inverse hyperbolic cosecant for each element of `X`.

Examples

Graph the inverse cosecant over the domains $-10 \le x < -1$ and $1 < x \le 10$, and the inverse hyperbolic cosecant over the domains $-20 \le x \le -1$ and $1 \le x \le 20$.

```
x1 = -10:0.01:-1.01; x2 = 1.01:0.01:10;
plot(x1,acsc(x1),x2,acsc(x2))
x1 = -20:0.01:-1; x2 = 1:0.01:20;
plot(x1,acsch(x1),x2,acsch(x2))
```





Algorithm

$$\csc^{-1}(z) = \sin^{-1}\left(\frac{1}{z}\right)$$

$$\operatorname{csch}^{-1}(z) = \sinh^{-1}\left(\frac{1}{z}\right)$$

See Also csc, csch

Purpose

Add directories to MATLAB's search path

Syntax

```
addpath('directory')
addpath('dir1','dir2','dir3',...)
addpath(...,'-flag')
```

Description

`addpath('directory')` prepends the specified directory to MATLAB's current search path.

`addpath('dir1','dir2','dir3',...)` prepends all the specified directories to the path.

`addpath(...,'-flag')` either prepends or appends the specified directories to the path depending the value of `flag`:

`0` or `begin`	Prepend specified directories
`1` or `end`	Append specified directories

Examples

```
path
                MATLABPATH
       c:\matlab\toolbox\general
       c:\matlab\toolbox\ops
       c:\matlab\toolbox\strfun

addpath('c:\matlab\myfiles')

path
              MATLABPATH
       c:\matlab\myfiles
       c:\matlab\toolbox\general
       c:\matlab\toolbox\ops
       c:\matlab\toolbox\strfun
```

See Also

`path`, `rmpath`

airy

Purpose

Airy functions

Syntax

```
W = airy(Z)
W = airy(k,Z)
[W,ierr] = airy(k,Z)
```

Definition

The Airy functions form a pair of linearly independent solutions to:

$$\frac{d^2W}{dZ^2} - ZW = 0$$

The relationship between the Airy and modified Bessel functions is:

$$Ai(Z) = \left[\frac{1}{\pi}\sqrt{Z/3}\right] K_{1/3}(\zeta)$$

$$Bi(Z) = \sqrt{Z/3}\,[I_{-1/3}(\zeta) + I_{1/3}(\zeta)]$$

where,

$$\zeta = \frac{2}{3}Z^{3/2}$$

Description

`W = airy(Z)` returns the Airy function, $Ai(Z)$, for each element of the complex array `Z`.

`W = airy(k,Z)` returns different results depending on the value of `k`:

k	Returns
`0`	The same result as `airy(Z)`.
`1`	The derivative, $Ai'(Z)$.
`2`	The Airy function of the second kind, $Bi(Z)$.
`3`	The derivative, $Bi'(Z)$.

`[W,ierr] = airy(k,Z)` also returns an array of error flags.

`ierr = 1`	Illegal arguments.
`ierr = 2`	Overflow. Return `Inf`.
`ierr = 3`	Some loss of accuracy in argument reduction.
`ierr = 4`	Unacceptable loss of accuracy, `Z` too large.
`ierr = 5`	No convergence. Return `NaN`.

See Also

`besseli`, `besselj`, `besselk`, `bessely`

References

[1] Amos, D. E., "A Subroutine Package for Bessel Functions of a Complex Argument and Nonnegative Order," *Sandia National Laboratory Report*, SAND85-1018, May, 1985.

[2] Amos, D. E., "A Portable Package for Bessel Functions of a Complex Argument and Nonnegative Order," *Trans. Math. Software*, 1986.

all

Purpose

Test to determine if all elements are nonzero

Syntax

```
B = all(A)
B = all(A,dim)
```

Description

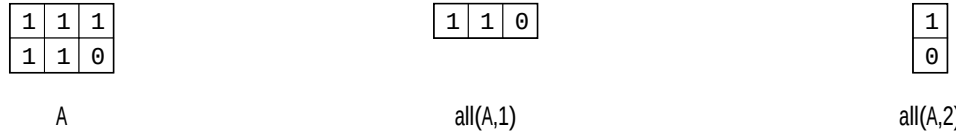
`B = all(A)` tests whether *all* the elements along various dimensions of an array are nonzero or logical true (`1`).

If `A` is a vector, `all(A)` returns logical true (`1`) if all of the elements are nonzero, and returns logical false (`0`) if one or more elements are zero.

If `A` is a matrix, `all(A)` treats the columns of `A` as vectors, returning a row vector of `1`s and `0`s.

If `A` is a multidimensional array, `all(A)` treats the values along the first non-singleton dimension as vectors, returning a logical condition for each vector.

`B = all(A,dim)` tests along the dimension of `A` specified by scalar *dim*.



Examples

Given,

```
A = [0.53 0.67 0.01 0.38 0.07 0.42 0.69]
```

then `B = (A < 0.5)` returns logical true (`1`) only where `A` is less than one half:

```
0   0   1   1   1   1   0
```

The `all` function reduces such a vector of logical conditions to a single condition. In this case, `all(B)` yields `0`.

This makes `all` particularly useful in `if` statements,

```
if all(A < 0.5)
    do something
end
```

where code is executed depending on a single condition, not a vector of possibly conflicting conditions.

Applying the `all` function twice to a matrix, as in `all(all(A))`, always reduces it to a scalar condition.

```
all(all(eye(3)))
ans =
   0
```

See Also

any

The logical operators &, |, ~

The relational operators <, <=, >, >=, ==, ~=

The colon operator :

Other functions that collapse an array's dimensions include:

`max`, `mean`, `median`, `min`, `prod`, `std`, `sum`, `trapz`

angle

Purpose

Phase angle

Syntax

```
P = angle(Z)
```

Description

`P = angle(Z)` returns the phase angles, in radians, for each element of complex array `Z`. The angles lie between $\pm\pi$.

For complex `Z`, the magnitude and phase angle are given by

```
R = abs(Z)        % magnitude
theta = angle(Z)  % phase angle
```

and the statement

```
Z = R.*exp(i*theta)
```

converts back to the original complex `Z`.

Examples

```
Z =
1.0000 - 1.0000i   2.0000 + 1.0000i   3.0000 - 1.0000i   4.0000 + 1.0000i
1.0000 + 2.0000i   2.0000 - 2.0000i   3.0000 + 2.0000i   4.0000 - 2.0000i
1.0000 - 3.0000i   2.0000 + 3.0000i   3.0000 - 3.0000i   4.0000 + 3.0000i
1.0000 + 4.0000i   2.0000 - 4.0000i   3.0000 + 4.0000i   4.0000 - 4.0000i

P = angle(Z)
P =

   -0.7854    0.4636   -0.3218    0.2450
    1.1071   -0.7854    0.5880   -0.4636
   -1.2490    0.9828   -0.7854    0.6435
    1.3258   -1.1071    0.9273   -0.7854
```

Algorithm

`angle` can be expressed as:

```
angle(z) = imag(log(z)) = atan2(imag(z),real(z))
```

See Also

`abs`, `unwrap`

Purpose

The most recent answer

Syntax

```
ans
```

Description

The ans variable is created automatically when no output argument is specified.

Examples

The statement

```
2+2
```

is the same as

```
ans = 2+2
```

any

Purpose

Test for any nonzeros

Syntax

```
B = any(A)
B = any(A,dim)
```

Description

`B = any(A)` tests whether *any* of the elements along various dimensions of an array are nonzero or logical true (`1`).

If `A` is a vector, `any(A)` returns logical true (`1`) if any of the elements of `A` are nonzero, and returns logical false (`0`) if all the elements are zero.

If `A` is a matrix, `any(A)` treats the columns of `A` as vectors, returning a row vector of `1`s and `0`s.

If `A` is a multidimensional array, `any(A)` treats the values along the first non-singleton dimension as vectors, returning a logical condition for each vector.

`B = any(A,dim)` tests along the dimension of `A` specified by scalar *dim*.

1	0	1
0	0	0

A

1	0	1

any(A,1)

1
0

any(A,2)

Examples

Given,

```
A = [0.53 0.67 0.01 0.38 0.07 0.42 0.69]
```

then `B = (A < 0.5)` returns logical true (`1`) only where `A` is less than one half:

```
0   0   1   1   1   1   0
```

The `any` function reduces such a vector of logical conditions to a single condition. In this case, `any(B)` yields `1`.

This makes `any` particularly useful in `if` statements,

```
if any(A < 0.5)
    do something
end
```

where code is executed depending on a single condition, not a vector of possibly conflicting conditions.

Applying the any function twice to a matrix, as in `any(any(A))`, always reduces it to a scalar condition.

```
any(any(eye(3)))
ans =
   1
```

See Also

`all`

The logical operators `&`, `|`, `~`

The relational operators `<`, `<=`, `>`, `>=`, `==`, `~=`

The colon operator `:`

Other functions that collapse an array's dimensions include:

`max`, `mean`, `median`, `min`, `prod`, `std`, `sum`, `trapz`

asec, asech

Purpose

Inverse secant and inverse hyperbolic secant

Syntax

```
Y = asec(X)
Y = asech(X)
```

Description

The asec and asech functions operate element-wise on arrays. The functions' domains and ranges include complex values. All angles are in radians.

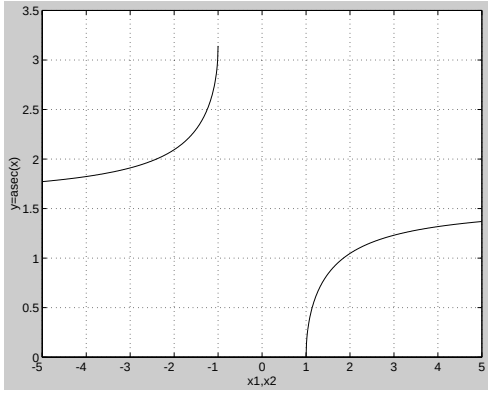
`Y = asec(X)` returns the inverse secant (arcsecant) for each element of `X`.

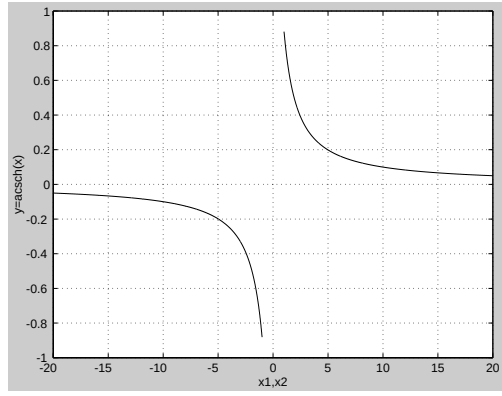
`Y = asech(X)` returns the inverse hyperbolic secant for each element of `X`.

Examples

Graph the inverse secant over the domains $1 \le x \le 5$ and $-5 \le x \le -1$, and the inverse hyperbolic secant over the domain $0 < x \le 1$.

```
x1 = -5:0.01:-1; x2 = 1:0.01:5;
plot(x1,asec(x1),x2,asec(x2))
x = 0.01:0.001:1; plot(x,asech(x))
```





Algorithm

$$\sec^{-1}(z) = \cos^{-1}\left(\frac{1}{z}\right)$$

$$\operatorname{sech}^{-1}(z) = \cosh^{-1}\left(\frac{1}{z}\right)$$

See Also

sec, sech

Purpose

Inverse sine and inverse hyperbolic sine

Syntax

```
Y = asin(X)
Y = asinh(X)
```

Description

The `asin` and `asinh` functions operate element-wise on arrays. The functions' domains and ranges include complex values. All angles are in radians.

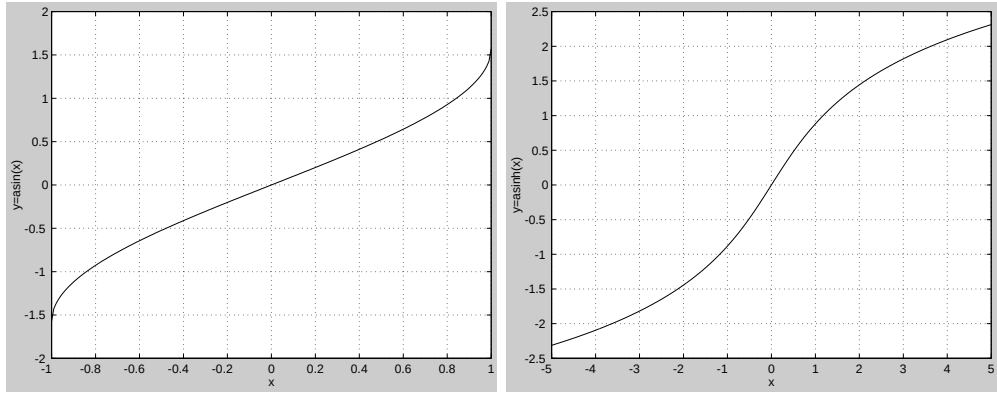
`Y = asin(X)` returns the inverse sine (arcsine) for each element of `X`. For real elements of `X` in the domain $[-1, 1]$, `asin(X)` is in the range $[-\pi/2, \pi/2]$. For real elements of `x` outside the range $[-1, 1]$, `asin(X)` is complex.

`Y = asinh(X)` returns the inverse hyperbolic sine for each element of `X`.

Examples

Graph the inverse sine function over the domain $-1 \le x \le 1$, and the inverse hyperbolic sine function over the domain $-5 \le x \le 5$.

```
x = -1:.01:1; plot(x,asin(x))
x = -5:.01:5; plot(x,asinh(x))
```



Algorithm

$$\sin^{-1}(z) = -i \log\left[iz + (1 - z^2)^{\frac{1}{2}} \right]$$

$$\sinh^{-1}(z) = \log\left[z + (z^2 + 1)^{\frac{1}{2}} \right]$$

See Also

`sin`, `sinh`

assignin

Purpose

Assign a value to a workspace variable

Syntax

```
assignin(ws,'var',val)
```

Description

`assignin(ws,'var',val)` assigns the value `val` to the variable *var* in the workspace `ws`. *var* is created if it doesn't exist. `ws` can have a value of `'base'` or `'caller'` to denote the MATLAB base workspace or the workspace of the caller function.

The `assignin` function is particularly useful for these tasks:

- Exporting data from a function to the MATLAB workspace
- Within a function, changing the value of a variable that is defined in the workspace of the caller function (such as a variable in the function argument list)

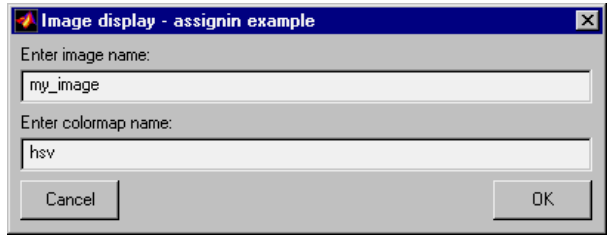
Remarks

The MATLAB base workspace is the workspace that is seen from the MATLAB command line (when not in the debugger). The caller workspace is the workspace of the function that called the M-file. Note the base and caller workspaces are equivalent in the context of an M-file that is invoked from the MATLAB command line.

Examples

This example creates a dialog box for the image display function, prompting a user for an image name and a colormap name. The `assignin` function is used to export the user–entered values to the MATLAB workspace variables `imfile` and `cmap`.

```
prompt = {'Enter image name:','Enter colormap name:'};
title = 'Image display - assignin example';
lines = 1;
def = {'my_image','hsv'};
answer = inputdlg(prompt,title,lines,def);
assignin('base','imfile',answer{1});
assignin('base','cmap',answer{2});
```



See Also `evalin`

atan, atanh

Purpose

Inverse tangent and inverse hyperbolic tangent

Syntax

```
Y = atan(X)
Y = atanh(X)
```

Description

The atan and atanh functions operate element-wise on arrays. The functions' domains and ranges include complex values. All angles are in radians.

`Y = atan(X)` returns the inverse tangent (arctangent) for each element of `X`.

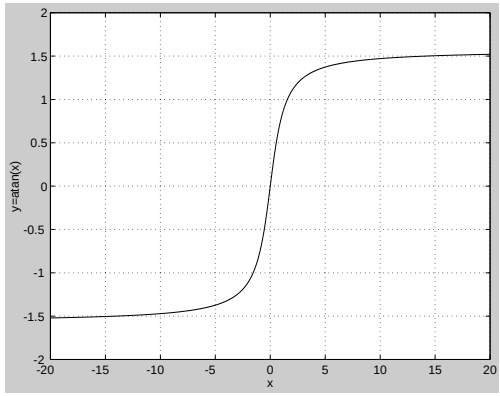
For real elements of `X`, `atan(X)` is in the range $[-\pi/2, \pi/2]$.

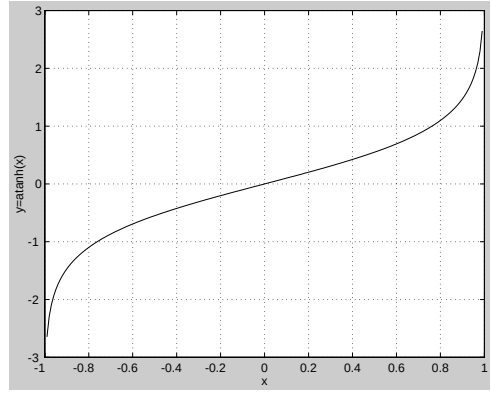
`Y = atanh(X)` returns the inverse hyperbolic tangent for each element of `X`.

Examples

Graph the inverse tangent function over the domain $-20 \le x \le 20$, and the inverse hyperbolic tangent function over the domain $-1 < x < 1$.

```
x = -20:0.01:20; plot(x,atan(x))
x = -0.99:0.01:0.99; plot(x,atanh(x))
```





Algorithm

$$\tan^{-1}(z) = \frac{i}{2}\log\left(\frac{i+z}{i-z}\right)$$

$$\tanh^{-1}(z) = \frac{1}{2}\log\left(\frac{1+z}{1-z}\right)$$

See Also

atan2, tan, tanh

Purpose

Four-quadrant inverse tangent

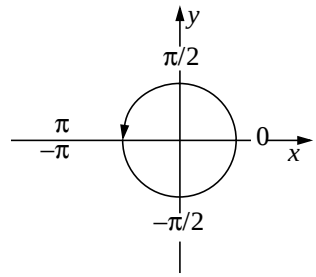
Syntax

```
P = atan2(Y,X)
```

Description

`P = atan2(Y,X)` returns an array `P` the same size as `X` and `Y` containing the element-by-element, four-quadrant inverse tangent (arctangent) of the real parts of `Y` and `X`. Any imaginary parts are ignored.

Elements of `P` lie in the closed interval [–`pi`,`pi`], where `pi` is MATLAB's floating- point representation of π. The specific quadrant is determined by `sign(Y)` and `sign(X)`:



This contrasts with the result of `atan(Y/X)`, which is limited to the interval $[-\pi/2, \pi/2]$, or the right side of this diagram.

Examples

Any complex number $z = x+iy$ is converted to polar coordinates with

```
r = abs(z)
theta = atan2(imag(z),real(z))
```

To convert back to the original complex number:

```
z = r *exp(i *theta)
```

This is a common operation, so MATLAB provides a function, `angle(z)`, that simply computes `atan2(imag(z),real(z))`.

See Also

`atan`, `atanh`, `tan`, `tanh`

auread

Purpose

Read NeXT/SUN (.au) sound file

Syntax

```
y = auread('aufile')
[y,Fs,bits] = auread('aufile')
[...] = auread('aufile',N)
[...] = auread('aufile',[N1,N2])
siz = auread('aufile','size')
```

Description

Supports multi-channel data in the following formats:

- 8-bit mu-law
- 8-, 16-, and 32-bit linear
- floating-point

`y = auread('aufile')` loads a sound file specified by the string `aufile`, returning the sampled data in `y`. The `.au` extension is appended if no extension is given. Amplitude values are in the range `[-1,+1]`.

`[y,Fs,bits] = auread('aufile')` returns the sample rate (`Fs`) in Hertz and the number of bits per sample (`bits`) used to encode the data in the file.

`[...] = auread('aufile',N)` returns only the first `N` samples from each channel in the file.

`[...] = auread('aufile',[N1 N2])` returns only samples `N1` through `N2` from each channel in the file.

`siz = auread('aufile','size')` returns the size of the audio data contained in the file in place of the actual audio data, returning the vector `siz = [samples channels]`.

See Also

`auwrite`, `wavread`

Purpose

Write NeXT/SUN (.au) sound file

Syntax

```
auwrite(y,'aufile')
auwrite(y,Fs,'aufile')
auwrite(y,Fs,N,'aufile')
auwrite(y,Fs,N,'method','aufile')
```

Description

`auwrite` supports multi-channel data for 8-bit mu-law, and 8- and 16-bit linear formats.

`auwrite(y,'aufile')` writes a sound file specified by the string `aufile`. The data should be arranged with one channel per column. Amplitude values outside the range `[-1,+1]` are clipped prior to writing.

`auwrite(y,Fs,'aufile')` specifies the sample rate of the data in Hertz.

`auwrite(y,Fs,N,'aufile')` selects the number of bits in the encoder. Allowable settings are `N = 8` and `N = 16`.

`auwrite(y,Fs,N,'method','aufile')` allows selection of the encoding method, which can be either `mu` or `linear`. Note that mu-law files must be 8-bit. By default, `method = 'mu'`.

See Also

`auread`, `wavwrite`

balance

Purpose

Improve accuracy of computed eigenvalues

Syntax

```
[D,B] = balance(A)
B = balance(A)
```

Description

`[D,B] = balance(A)` returns a diagonal matrix `D` whose elements are integer powers of two, and a balanced matrix `B` so that `B = D\A*D`. If `A` is symmetric, then `B == A` and `D` is the identity matrix.

`B = balance(A)` returns just the balanced matrix `B`.

Remarks

Nonsymmetric matrices can have poorly conditioned eigenvalues. Small perturbations in the matrix, such as roundoff errors, can lead to large perturbations in the eigenvalues. The quantity which relates the size of the matrix perturbation to the size of the eigenvalue perturbation is the condition number of the eigenvector matrix,

```
cond(V) = norm(V)*norm(inv(V))
```

where

```
[V,D] = eig(A)
```

(The condition number of `A` itself is irrelevant to the eigenvalue problem.)

Balancing is an attempt to concentrate any ill conditioning of the eigenvector matrix into a diagonal scaling. Balancing usually cannot turn a nonsymmetric matrix into a symmetric matrix; it only attempts to make the norm of each row equal to the norm of the corresponding column. Furthermore, the diagonal scale factors are limited to powers of two so they do not introduce any roundoff error.

MATLAB's eigenvalue function, `eig(A)`, automatically balances `A` before computing its eigenvalues. Turn off the balancing with `eig(A,'nobalance')`.

Examples

This example shows the basic idea. The matrix A has large elements in the upper right and small elements in the lower left. It is far from being symmetric.

```
A = [1  100  10000; .01  1  100; .0001  .01  1]
A =
   1.0e+04 *
    0.0001    0.0100    1.0000
    0.0000    0.0001    0.0100
    0.0000    0.0000    0.0001
```

Balancing produces a diagonal D matrix with elements that are powers of two and a balanced matrix B that is closer to symmetric than A.

```
[D,B] = balance(A)
D =
   1.0e+03 *
    2.0480         0         0
         0    0.0320         0
         0         0    0.0003
B =
    1.0000    1.5625    1.2207
    0.6400    1.0000    0.7812
    0.8192    1.2800    1.0000
```

To see the effect on eigenvectors, first compute the eigenvectors of A.

```
[V,E] = eig(A); V
V =
   -1.0000    0.9999   -1.0000
    0.0050    0.0100    0.0034
    0.0000    0.0001    0.0001
```

Note that all three vectors have the first component the largest. This indicates V is badly conditioned; in fact cond(V) is 1.7484e+05. Next, look at the eigenvectors of B.

```
[V,E] = eig(B); V
V =
   -0.8873    0.6933    0.8919
    0.2839    0.4437   -0.3264
    0.3634    0.5679   -0.3129
```

Now the eigenvectors are well behaved and `cond(V)` is `31.9814`. The ill conditioning is concentrated in the scaling matrix; `cond(D)` is `8192`.

This example is small and not really badly scaled, so the computed eigenvalues of `A` and `B` agree within roundoff error; balancing has little effect on the computed results.

Algorithm

`balance` is built into the MATLAB interpreter. It uses the algorithm in [1] originally published in Algol, but popularized by the Fortran routines `BALANC` and `BALBAK` from EISPACK.

Successive similarity transformations via diagonal matrices are applied to `A` to produce `B`. The transformations are accumulated in the transformation matrix `D`.

The `eig` function automatically uses balancing to prepare its input matrix.

Limitations

Balancing can destroy the properties of certain matrices; use it with some care. If a matrix contains small elements that are due to roundoff error, balancing may scale them up to make them as significant as the other elements of the original matrix.

Diagnostics

If `A` is not a square matrix:

```
Matrix must be square.
```

See Also

`condeig`, `eig`, `hess`, `schur`

References

[1] Parlett, B. N. and C. Reinsch, “Balancing a Matrix for Calculation of Eigenvalues and Eigenvectors,” *Handbook for Auto. Comp.*, Vol. II, Linear Algebra, 1971,pp. 315-326.

Purpose

Base to decimal number conversion

Syntax

```
d = base2dec('strn',base)
```

Description

`d = base2dec('strn',base)` converts the string number *strn* of the specified base into its decimal (base 10) equivalent. `base` must be an integer between 2 and 36. If *'strn'* is a character array, each row is interpreted as a string in the specified `base`.

Examples

The expression `base2dec('212',3)` converts 212_3 to decimal, returning 23.

See Also

`dec2base`

besselh

Purpose

Bessel functions of the third kind (Hankel functions)

Syntax

```
H = besselh(nu,K,Z)
H = besselh(nu,Z)
H = besselh(nu,1,Z,1)
H = besselh(nu,2,Z,1)
[H,ierr] = besselh(...)
```

Definitions

The differential equation

$$z^2 \frac{d^2y}{dz^2} + z\frac{dy}{dz} + (z^2 - \nu^2)y = 0$$

where ν is a nonnegative constant, is called *Bessel's equation*, and its solutions are known as *Bessel functions*. $J_\nu(z)$ and $J_{-\nu}(z)$ form a fundamental set of solutions of Bessel's equation for noninteger ν. $Y_\nu(z)$ is a second solution of Bessel's equation—linearly independent of $J_\nu(z)$— defined by:

$$Y_\nu(z) = \frac{J_\nu(z)\cos(\nu\pi) - J_{-\nu}(z)}{\sin(\nu\pi)}$$

The relationship between the Hankel and Bessel functions is:

$$H_\nu^{(1)}(z) = J_\nu(z) + i\ Y_\nu(z)$$

Description

`H = besselh(nu,K,Z)` for `K` = 1 or 2 computes the Hankel functions $H_\nu^{(1)}(z)$ or $H_\nu^{(2)}(z)$ for each element of the complex array `Z`. If `nu` and `Z` are arrays of the same size, the result is also that size. If either input is a scalar, it is expanded to the other input's size. If one input is a row vector and the other is a column vector, the result is a two-dimensional table of function values.

`H = besselh(nu,Z)` uses `K` = 1.

`H = besselh(nu,1,Z,1)` scales $H_\nu^{(1)}(z)$ by `exp(-i*z)`.

`H = besselh(nu,2,Z,1)` scales $H_\nu^{(2)}(z)$ by `exp(+i*z)`.

`[H,ierr] = besselh(...)` also returns an array of error flags:

`ierr = 1`	Illegal arguments.
`ierr = 2`	Overflow. Return `Inf`.
`ierr = 3`	Some loss of accuracy in argument reduction.
`ierr = 4`	Unacceptable loss of accuracy, `Z` or `nu` too large.
`ierr = 5`	No convergence. Return `NaN`.

besseli, besselk

Purpose

Modified Bessel functions

Syntax

```
I = besseli(nu,Z)      Modified Bessel function of the 1st kind
K = besselk(nu,Z)      Modified Bessel function of the 2nd kind
I = besseli(nu,Z,1)
K = besselk(nu,Z,1)
[I,ierr] = besseli(...)
[K,ierr] = besselk(...)
```

Definitions

The differential equation

$$z^2 \frac{d^2y}{dz^2} + z\frac{dy}{dz} - (z^2 + \nu^2)y = 0$$

where ν is a real constant, is called the *modified Bessel's equation*, and its solutions are known as *modified Bessel functions*.

$I_\nu(z)$ and $I_{-\nu}(z)$ form a fundamental set of solutions of the modified Bessel's equation for noninteger ν. $K_\nu(z)$ is a second solution, independent of $I_\nu(z)$.

$I_\nu(z)$ and $K_\nu(z)$ are defined by:

$$I_\nu(z) = \left(\frac{z}{2}\right)^\nu \sum_{k=0}^{\infty} \frac{\left(\frac{z^2}{4}\right)^k}{k!\ \Gamma(\nu + k + 1)}, \quad \text{where } \Gamma(a) \text{ is the gamma function}$$

$$K_\nu(z) = \left(\frac{\pi}{2}\right) \frac{I_{-\nu}(z) - I_\nu(z)}{\sin(\nu\pi)}$$

Description

`I = besseli(nu,Z)` computes modified Bessel functions of the first kind, $I_\nu(z)$, for each element of the array `Z`. The order `nu` need not be an integer, but must be real. The argument `Z` can be complex. The result is real where `Z` is positive.

If `nu` and `Z` are arrays of the same size, the result is also that size. If either input is a scalar, it is expanded to the other input's size. If one input is a row vector and the other is a column vector, the result is a two-dimensional table of function values.

`K = besselk(nu,Z)` computes modified Bessel functions of the second kind, $K_\nu(z)$, for each element of the complex array `Z`.

`I = besseli(nu,Z,1)` computes `besseli(nu,Z).*exp(-real(Z))`.

`K = besselk(nu,Z,1)` computes `besselk(nu,Z).*exp(real(Z))`.

`[I,ierr] = besseli(...)` and `[K,ierr] = besselk(...)` also return an array of error flags.

`ierr = 1`	Illegal arguments.
`ierr = 2`	Overflow. Return `Inf`.
`ierr = 3`	Some loss of accuracy in argument reduction.
`ierr = 4`	Unacceptable loss of accuracy, `Z` or `nu` too large.
`ierr = 5`	No convergence. Return `NaN`.

Examples

```
format long
z = (0:0.2:1)';

besseli(1,z)

ans =
                   0
   0.10050083402813
   0.20402675573357
   0.31370402560492
   0.43286480262064
   0.56515910399249

besselk(1,z)

ans =
                 Inf
   4.77597254322047
   2.18435442473269
   1.30283493976350
   0.86178163447218
   0.60190723019723
```

`besseli(3:9,(0:.2,10)',1)` generates the entire table on page 423 of Abramowitz and Stegun, *Handbook of Mathematical Functions*.

`besselk(3:9,(0:.2:10)',1)` generates part of the table on page 424 of Abramowitz and Stegun, *Handbook of Mathematical Functions*.

Algorithm

The `besseli` and `besselk` functions use a Fortran MEX-file to call a library developed by D. E. Amos [3] [4].

See Also

`airy`, `besselj`, `bessely`

References

[1] Abramowitz, M. and I.A. Stegun, *Handbook of Mathematical Functions*, National Bureau of Standards, Applied Math. Series #55, Dover Publications, 1965, sections 9.1.1, 9.1.89 and 9.12, formulas 9.1.10 and 9.2.5.

[2] Carrier, Krook, and Pearson, *Functions of a Complex Variable: Theory and Technique*, Hod Books, 1983, section 5.5.

[3] Amos, D. E., "A Subroutine Package for Bessel Functions of a Complex Argument and Nonnegative Order," *Sandia National Laboratory Report*, SAND85-1018, May, 1985.

[4] Amos, D. E., "A Portable Package for Bessel Functions of a Complex Argument and Nonnegative Order," *Trans. Math. Software*, 1986.

Purpose

Bessel functions

Syntax

```
J = besselj(nu,Z)      Bessel function of the 1st kind
Y = bessely(nu,Z)      Bessel function of the 2nd kind
J = besselj(nu,Z,1)
Y = bessely(nu,Z,1)
[J,ierr] = besselj(nu,Z)
[Y,ierr] = bessely(nu,Z)
```

Definition

The differential equation

$$z^2 \frac{d^2y}{dz^2} + z\frac{dy}{dz} + (z^2 - \nu^2)y = 0$$

where ν is a real constant, is called *Bessel's equation*, and its solutions are known as *Bessel functions*.

$J_\nu(z)$ and $J_{-\nu}(z)$ form a fundamental set of solutions of Bessel's equation for noninteger ν. $J_\nu(z)$ is defined by:

$$J_\nu(z) = \left(\frac{z}{2}\right)^\nu \sum_{k=0}^{\infty} \frac{\left(-\frac{z^2}{4}\right)^k}{k!\ \Gamma(\nu + k + 1)},$$

where $\Gamma(a)$ is the gamma function

$Y_\nu(z)$is a second solution of Bessel's equation that is linearly independent of $J_\nu(z)$ and defined by:

$$Y_\nu(z) = \frac{J_\nu(z)\cos(\nu\pi) - J_{-\nu}(z)}{\sin(\nu\pi)}$$

Description

`J = besselj(nu,Z)` computes Bessel functions of the first kind, $J_\nu(z)$, for each element of the complex array `Z`. The order `nu` need not be an integer, but must be real. The argument `Z` can be complex. The result is real where `Z` is positive.

If nu and Z are arrays of the same size, the result is also that size. If either input is a scalar, it is expanded to the other input's size. If one input is a row vector and the other is a column vector, the result is a two-dimensional table of function values.

`Y = bessely(nu,Z)` computes Bessel functions of the second kind, $Y_\nu(z)$, for real, nonnegative order nu and argument Z.

`J = besselj(nu,Z,1)` computes `besselj(nu,Z).*exp(-imag(Z))`.

`Y = bessely(nu,Z,1)` computes `bessely(nu,Z).*exp(-imag(Z))`.

`[J,ierr] = besselj(nu,Z)` and `[Y,ierr] = bessely(nu,Z)` also return an array of error flags.

`ierr = 1`	Illegal arguments.
`ierr = 2`	Overflow. Return `Inf`.
`ierr = 3`	Some loss of accuracy in argument reduction.
`ierr = 4`	Unacceptable loss of accuracy, Z or nu too large.
`ierr = 5`	No convergence. Return `NaN`.

Remarks

The Bessel functions are related to the Hankel functions, also called Bessel functions of the third kind:

$$H_\nu^{(1)}(z) = J_\nu(z) + i\ Y_\nu(z)$$

$$H_\nu^{(2)}(z) = J_\nu(z) - i\ Y_\nu(z)$$

where $J_\nu(z)$ is `besselj`, and $Y_\nu(z)$ is `bessely`. The Hankel functions also form a fundamental set of solutions to Bessel's equation (see `besselh`).

Examples

```
format long
z = (0:0.2:1)';

besselj(1,z)

ans =
                   0
   0.09950083263924
   0.19602657795532
   0.28670098806392
   0.36884204609417
   0.44005058574493

bessely(1,z)

ans =
                -Inf
  -3.32382498811185
  -1.78087204427005
  -1.26039134717739
  -0.97814417668336
  -0.78121282130029
```

`besselj(3:9,(0:.2,10)')` generates the entire table on page 398 of Abramowitz and Stegun, *Handbook of Mathematical Functions.*

`bessely(3:9,(0:.2,10)')` generates the entire table on page 399 of Abramowitz and Stegun, *Handbook of Mathematical Functions.*

Algorithm

The `besselj` and `bessely` functions use a Fortran MEX-file to call a library developed by D. E. Amos [3] [4].

See Also

`airy`, `besseli`, `besselk`

References

[1] Abramowitz, M. and I.A. Stegun, *Handbook of Mathematical Functions*, National Bureau of Standards, Applied Math. Series #55, Dover Publications, 1965, sections 9.1.1, 9.1.89 and 9.12, formulas 9.1.10 and 9.2.5.

[2] Carrier, Krook, and Pearson, *Functions of a Complex Variable: Theory and Technique*, Hod Books, 1983, section 5.5.

[3] Amos, D. E., “A Subroutine Package for Bessel Functions of a Complex Argument and Nonnegative Order,” *Sandia National Laboratory Report*, SAND85-1018, May, 1985.

[4] Amos, D. E., “A Portable Package for Bessel Functions of a Complex Argument and Nonnegative Order,” *Trans. Math. Software*, 1986.

Purpose

Beta functions

Syntax

```
B = beta(Z,W)
I = betainc(X,Z,W)
L = betaln(Z,W)
```

Definition

The beta function is:

$$B(z, w) = \int_0^1 t^{z-1}(1-t)^{w-1}\, dt = \frac{\Gamma(z)\Gamma(w)}{\Gamma(z+w)}$$

where $\Gamma(z)$ is the gamma function. The incomplete beta function is:

$$I_x(z, w) = \frac{1}{B(z, w)}\int_0^x t^{z-1}(1-t)^{w-1}\, dt$$

Description

`B = beta(Z,W)` computes the beta function for corresponding elements of the complex arrays `Z` and `W`. The arrays must be the same size (or either can be scalar).

`I = betainc(X,Z,W)` computes the incomplete beta function. The elements of `X` must be in the closed interval [0,1].

`L = betaln(Z,W)` computes the natural logarithm of the beta function, `log(beta(Z,W))`, without computing `beta(Z,W)`. Since the `beta` function can range over very large or very small values, its logarithm is sometimes more useful.

Examples

```
format rat
beta((0:10)',3)

ans =

     1/0
     1/3
     1/12
     1/30
     1/60
     1/105
     1/168
     1/252
     1/360
     1/495
     1/660
```

In this case, with integer arguments,

```
beta(n,3)
= (n-1)!*2!/(n+2)!
= 2/(n*(n+1)*(n+2))
```

is the ratio of fairly small integers and the rational format is able to recover the exact result.

For `x = 510`, `betaln(x,x) = -708.8616`, which, on a computer with IEEE arithmetic, is slightly less than `log(realmin)`. Here `beta(x,x)` would underflow (or be denormal).

Algorithm

```
beta(z,w) = exp(gammaln(z)+gammaln(w)-gammaln(z+w))
betaln(z,w) = gammaln(z)+gammaln(w)-gammaln(z+w)
```

Purpose

BiConjugate Gradients method

Syntax

```
x = bicg(A,b)
bicg(A,b,tol)
bicg(A,b,tol,maxit)
bicg(A,b,tol,maxit,M)
bicg(A,b,tol,maxit,M1,M2)
bicg(A,b,tol,maxit,M1,M2,x0)
x = bicg(A,b,tol,maxit,M1,M2,x0)
[x,flag] = bicg(A,b,tol,maxit,M1,M2,x0)
[x,flag,relres] = bicg(A,b,tol,maxit,M1,M2,x0)
[x,flag,relres,iter] = bicg(A,b,tol,maxit,M1,M2,x0)
[x,flag,relres,iter,resvec] = bicg(A,b,tol,maxit,M1,M2,x0)
```

Description

`x = bicg(A,b)` attempts to solve the system of linear equations `A*x = b` for `x`. The coefficient matrix `A` must be square and the column vector `b` must have length `n`, where `A` is `n`-by-`n`. When `A` is not explicitly available as a matrix, you can express `A` as an operator `afun` where `afun(x)` returns the matrix-vector product `A*x` and `afun(x,'transp')` returns `A'*x`. This operator can be the name of an M-file or an inline object. In this case `n` is taken to be the length of the column vector `b`.

`bicg` will start iterating from an initial estimate that, by default, is an all zero vector of length `n`. Iterates are produced until the method either converges, fails, or has computed the maximum number of iterations. Convergence is achieved when an iterate `x` has relative residual `norm(b-A*x)/norm(b)` less than or equal to the tolerance of the method. The default tolerance is `1e-6`. The default maximum number of iterations is the minimum of `n` and 20. No preconditioning is used.

`bicg(A,b,tol)` specifies the tolerance of the method, `tol`.

`bicg(A,b,tol,maxit)` additionally specifies the maximum number of iterations, `maxit`.

`bicg(A,b,tol,maxit,M)` and `bicg(A,b,tol,maxit,M1,M2)` use left preconditioner `M` or `M = M1*M2` and effectively solve the system `inv(M)*A*x = inv(M)*b` for `x`. You can replace the matrix `M` with a function `mfun` such that `mfun(x)` returns either `M\x` or `M'\x`, depending upon the last

argument. If M1 or M2 is given as the empty matrix ([]), it is considered to be the identity matrix, equivalent to no preconditioning at all. Since systems of equations of the form M*y = r are solved using backslash within bicg, it is wise to factor preconditioners into their LU factors first. For example, replace bicg(A,b,tol,maxit,M) with:

```
[M1,M2] = lu(M);
bicg(A,b,tol,maxit,M1,M2).
```

bicg(A,b,tol,maxit,M1,M2,x0) specifies the initial estimate x0. If x0 is given as the empty matrix ([]), the default all zero vector is used.

x = bicg(A,b,tol,maxit,M1,M2,x0) returns a solution x. If bicg converged, a message to that effect is displayed. If bicg failed to converge after the maximum number of iterations or halted for any reason, a warning message is printed displaying the relative residual norm(b–A*x)/norm(b) and the iteration number at which the method stopped or failed.

[x,flag] = bicg(A,b,tol,maxit,M1,M2,x0) returns a solution x and a flag that describes the convergence of bicg.

Flag	Convergence
0	bicg converged to the desired tolerance tol within maxit iterations without failing for any reason.
1	bicg iterated maxit times but did not converge.
2	One of the systems of equations of the form M*y = r involving the preconditioner was ill-conditioned and did not return a useable result when solved by \ (backslash).
3	The method stagnated. (Two consecutive iterates were the same.)
4	One of the scalar quantities calculated during bicg became too small or too large to continue computing.

Whenever `flag` is not `0`, the solution `x` returned is that with minimal norm residual computed over all the iterations. No messages are displayed if the `flag` output is specified.

`[x,flag,relres] = bicg(A,b,tol,maxit,M1,M2,x0)` also returns the relative residual `norm(b-A*x)/norm(b)`. If `flag` is `0`, then `relres` ≤ `tol`.

`[x,flag,relres,iter] = bicg(A,b,tol,maxit,M1,M2,x0)` also returns the iteration number at which `x` was computed. This always satisfies `0` ≤ `iter` ≤ `maxit`.

`[x,flag,relres,iter,resvec] = bicg(A,b,tol,maxit,M1,M2,x0)` also returns a vector of the residual norms at each iteration, starting from `resvec(1) = norm(b-A*x0)`. If `flag` is `0`, `resvec` is of length `iter+1` and `resvec(end)` ≤ `tol*norm(b)`.

Examples

Start with `A = west0479` and make the true solution the vector of all ones.

```
load west0479
A = west0479
b = sum(A,2)
```

We could accurately solve `A*x = b` using backslash since `A` is not so large.

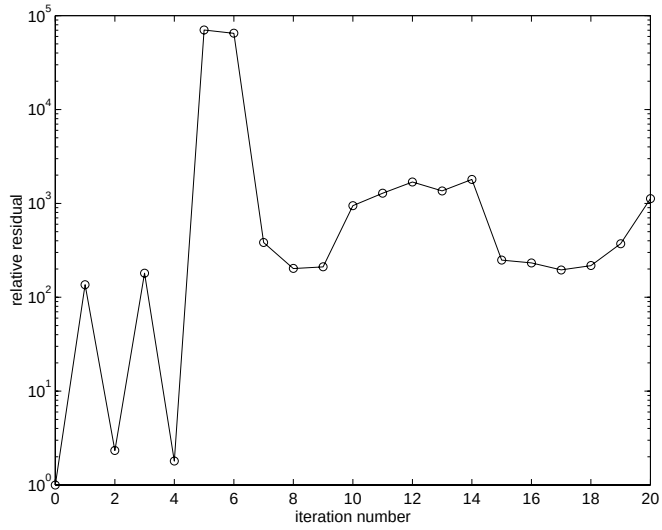
```
x = A \ b
norm(b-A*x) / norm(b) =
6.8476e-18
```

Now try to solve `A*x = b` with `bicg`.

```
[x,flag,relres,iter,resvec] = bicg(A,b)
flag =
1
relres =
1
iter =
0
```

The value of `flag` indicates that `bicg` iterated the default 20 times without converging. The value of `iter` shows that the method behaved so badly that the initial all zero guess was better than all the subsequent iterates. The value of `relres` supports this: `relres = norm(b-A*x)/norm(b)` = `norm(b)/norm(b)` = `1`.

The plot `semilogy(0:20,resvec/norm(b),'-o')` below confirms that the unpreconditioned method oscillated rather wildly.



Try an incomplete LU factorization with a drop tolerance of `1e-5` for the preconditioner.

```
[L1,U1] = luinc(A,1e-5)
nnz(A) =
1887
nnz(L1) =
5562
nnz(U1) =
4320
```

A warning message indicates a zero on the main diagonal of the upper triangular `U1`. Thus it is singular. When we try to use it as a preconditioner

```
[x,flag,relres,iter,resvec] = bicg(A,b,1e-6,20,L1,U1)
flag =
2
relres =
1
iter =
0
resvec =
7.0557e+005
```

the method fails in the very first iteration when it tries to solve a system of equations involving the singular `U1` with backslash. It is forced to return the initial estimate since no other iterates were produced.

Try again with a slightly less sparse preconditioner.

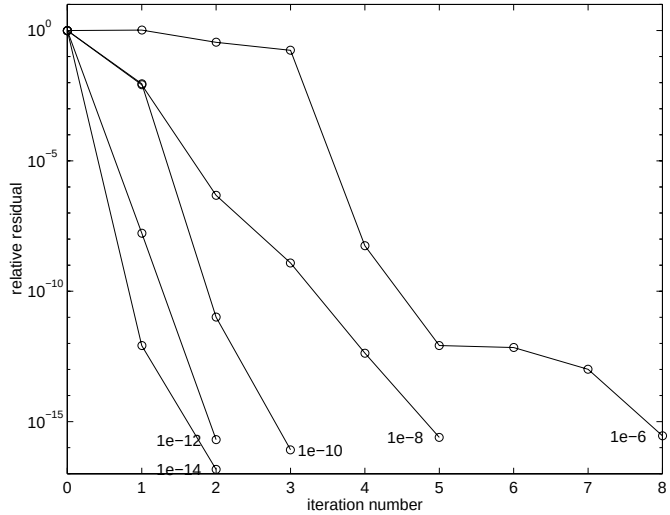
```
[L2,U2] = luinc(A,1e-6)
nnz(L2) =
6231
nnz(U2) =
4559
```

This time `U2` is nonsingular and may be an appropriate preconditioner.

```
[x,flag,relres,iter,resvec] = bicg(A,b,1e-15,10,L2,U2)
flag =
0
relres =
2.8664e-16
iter =
8
```

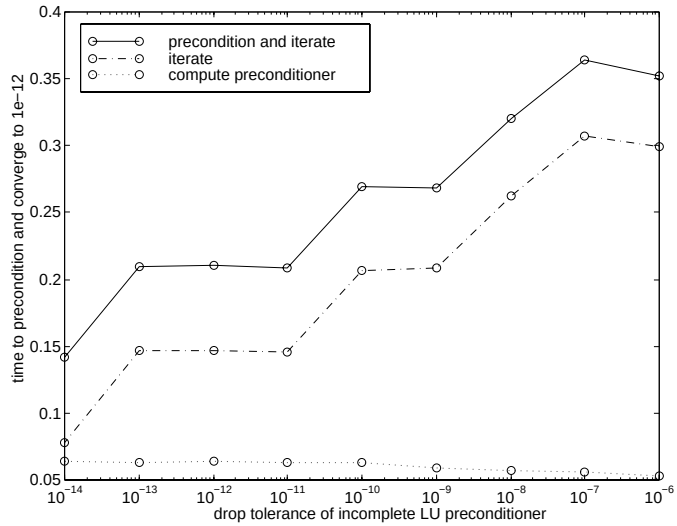
and `bicg` converges to within the desired tolerance at iteration number 8. Decreasing the value of the drop tolerance increases the fill-in of the incomplete factors but also increases the accuracy of the approximation to the original matrix. Thus, the preconditioned system becomes closer to `inv(U)*inv(L)*L*U*x = inv(U)*inv(L)*b`, where `L` and `U` are the true LU factors, and closer to being solved within a single iteration.

The next graph shows the progress of `bicg` using six different incomplete LU factors as preconditioners. Each line in the graph is labeled with the drop tolerance of the preconditioner used in `bicg`.



This does not give us any idea of the time involved in creating the incomplete factors and then computing the solution. The following graph plots drop tolerance of the incomplete LU factors against the time to compute the preconditioner, the time to iterate once the preconditioner has been computed, and their sum, the total time to solve the problem. The time to produce the factors does not increase very quickly with the fill-in, but it does slow down the average time for an iteration. Since fewer iterations are performed, the total

time to solve the problem decreases. `west0479` is quite a small matrix, only 139-by-139, and preconditioned `bicg` still takes longer than backslash.



See Also

`bicgstab`, `cgs`, `gmres`, `luinc`, `pcg`, `qmr`

The arithmetic operator \

References

"Templates for the Solution of Linear Systems: Building Blocks for Iterative Methods", *SIAM*, Philadelphia, 1994.

bicgstab

Purpose

BiConjugate Gradients Stabilized method

Syntax

```
x = bicgstab(A,b)
bicgstab(A,b,tol)
bicgstab(A,b,tol,maxit)
bicgstab(A,b,tol,maxit,M)
bicgstab(A,b,tol,maxit,M1,M2)
bicgstab(A,b,tol,maxit,M1,M2,x0)
x = bicgstab(A,b,tol,maxit,M1,M2,x0)
[x,flag] = bicgstab(A,b,tol,maxit,M1,M2,x0)
[x,flag,relres] = bicgstab(A,b,tol,maxit,M1,M2,x0)
[x,flag,relres,iter] = bicgstab(A,b,tol,maxit,M1,M2,x0)
[x,flag,relres,iter,resvec] = bicgstab(A,b,tol,maxit,M1,M2,x0)
```

Description

`x = bicgstab(A,b)` attempts to solve the system of linear equations `A*x = b` for `x`. The coefficient matrix `A` must be square and the column vector `b` must have length `n`, where `A` is `n`-by-`n`. When `A` is not explicitly available as a matrix, you can express `A` as an operator `afun` that returns the matrix-vector product `A*x` for `afun(x)`. This operator can be the name of an M-file, a string expression, or an inline object. In this case `n` is taken to be the length of the column vector `b`.

`bicgstab` will start iterating from an initial estimate that, by default, is an all zero vector of length `n`. Iterates are produced until the method either converges, fails, or has computed the maximum number of iterations. Convergence is achieved when an iterate `x` has relative residual `norm(b-A*x)/norm(b)` less than or equal to the tolerance of the method. The default tolerance is `1e-6`. The default maximum number of iterations is the minimum of `n` and 20. No preconditioning is used.

`bicgstab(A,b,tol)` specifies the tolerance of the method, `tol`.

`bicgstab(A,b,tol,maxit)` additionally specifies the maximum number of iterations, `maxit`.

`bicgstab(A,b,tol,maxit,M)` and `bicgstab(A,b,tol,maxit,M1,M2)` use left preconditioner `M` or `M = M1*M2` and effectively solve the system `inv(M)*A*x = inv(M)*b` for `x`. You can replace the matrix `M` with a function `mfun` such that `mfun(x)` returns `M\x`. If `M1` or `M2` is given as the empty matrix (`[]`), it is considered to be the identity matrix, equivalent to no preconditioning

at all. Since systems of equations of the form `M*y = r` are solved using backslash within `bicgstab`, it is wise to factor preconditioners into their LU factors first. For example, replace `bicgstab(A,b,tol,maxit,M)` with:

```
[M1,M2] = lu(M);
bicgstab(A,b,tol,maxit,M1,M2).
```

`bicgstab(A,b,tol,maxit,M1,M2,x0)` specifies the initial estimate `x0`. If `x0` is given as the empty matrix (`[]`), the default all zero vector is used.

`x = bicgstab(A,b,tol,maxit,M1,M2,x0)` returns a solution `x`. If `bicgstab` converged, a message to that effect is displayed. If `bicgstab` failed to converge after the maximum number of iterations or halted for any reason, a warning message is printed displaying the relative residual `norm(b–A*x)/norm(b)` and the iteration number at which the method stopped or failed.

`[x,flag] = bicgstab(A,b,tol,maxit,M1,M2,x0)` returns a solution `x` and a flag that describes the convergence of `bicgstab`.

Flag	Convergence
`0`	`bicgstab` converged to the desired tolerance `tol` within `maxit` iterations without failing for any reason.
`1`	`bicgstab` iterated `maxit` times but did not converge.
`2`	One of the systems of equations of the form `M*y = r` involving the preconditioner was ill-conditioned and did not return a useable result when solved by \ (backslash).
`3`	The method stagnated. (Two consecutive iterates were the same.)
`4`	One of the scalar quantities calculated during `bicgstab` became too small or too large to continue computing.

Whenever `flag` is not `0`, the solution `x` returned is that with minimal norm residual computed over all the iterations. No messages are displayed if the `flag` output is specified.

`[x,flag,relres] = bicgstab(A,b,tol,maxit,M1,M2,x0)` also returns the relative residual `norm(b-A*x)/norm(b)`. If `flag` is `0`, then `relres` ≤ `tol`.

`[x,flag,relres,iter] = bicgstab(A,b,tol,maxit,M1,M2,x0)` also returns the iteration number at which `x` was computed. This always satisfies `0` ≤ `iter` ≤ `maxit`. `iter` may be an integer or an integer + 0.5, since `bicgstab` may converge halfway through an iteration.

`[x,flag,relres,iter,resvec] = bicgstab(A,b,tol,maxit,M1,M2,x0)` also returns a vector of the residual norms at each iteration, starting from `resvec(1) = norm(b-A*x0)`. If `flag` is `0`, `resvec` is of length `2*iter+1`, whether `iter` is an integer or not. In this case, `resvec(end)` ≤ `tol*norm(b)`.

Example

```
load west0479
A = west0479
b = sum(A,2)
[x,flag] = bicgstab(A,b)
```

`flag` is `1` since `bicgstab` will not converge to the default tolerance `1e-6` within the default 20 iterations.

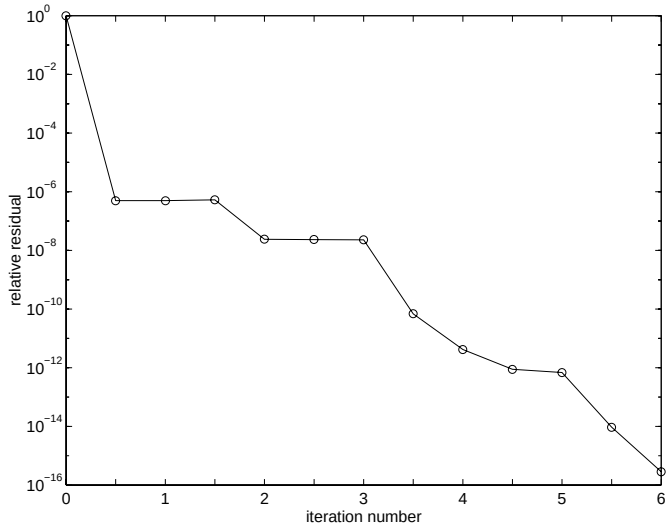
```
[L1,U1] = luinc(A,1e-5)
[x1,flag1] = bicgstab(A,b,1e-6,20,L1,U1)
```

`flag1` is 2 since the upper triangular `U1` has a zero on its diagonal so `bicgstab` fails in the first iteration when it tries to solve a system such as `U1*y = r` with backslash.

```
[L2,U2] = luinc(A,1e-6)
[x2,flag2,relres2,iter2,resvec2] = bicgstab(A,b,1e-15,10,L2,U2)
```

`flag2` is `0` since `bicgstab` will converge to the tolerance of `2.9e-16` (the value of `relres2`) at the sixth iteration (the value of `iter2`) when preconditioned by the incomplete LU factorization with a drop tolerance of `1e-6`.
`resvec2(1) = norm(b)` and `resvec2(13) = norm(b-A*x2)`. You can follow the progress of `bicgstab` by plotting the relative residuals at the halfway point and

end of each iteration starting from the intial estimate (iterate number 0) with `semilogy(0:0.5:iter2,resvec2/norm(b),'-o')`



See Also

`bicg`, `cgs`, `gmres`, `luinc`, `pcg`, `qmr`

The arithmetic operator \

References

van der Vorst, H. A., "BI-CGSTAB: A fast and smoothly converging variant of BI-CG for the solution of nonsymmetric linear systems", *SIAM J. Sci. Stat. Comput.*, March 1992,Vol. 13, No. 2, pp. 631-644.

"Templates for the Solution of Linear Systems: Building Blocks for Iterative Methods", *SIAM*, Philadelphia, 1994.

bin2dec

Purpose Binary to decimal number conversion

Syntax `bin2dec(`*`binarystr`*`)`

Description `bin2dec(`*`binarystr`*`)` interprets the binary string *`binarystr`* and returns the equivalent decimal number.

Examples `bin2dec('010111')` returns 23.

See Also `dec2bin`

Purpose

Bit-wise AND

Syntax

```
C = bitand(A,B)
```

Description

`C = bitand(A,B)` returns the bit-wise AND of two nonnegative integer arguments `A` and `B`. To ensure the operands are integers, use the `ceil`, `fix`, `floor`, and `round` functions.

Examples

The five-bit binary representations of the integers 13 and 27 are 01101 and 11011, respectively. Performing a bit-wise AND on these numbers yields 01001, or 9.

```
C = bitand(13,27)

C =

     9
```

See Also

`bitcmp`, `bitget`, `bitmax`, `bitor`, `bitset`, `bitshift`, `bitxor`

bitcmp

Purpose

Complement bits

Syntax

```
C = bitcmp(A,n)
```

Description

`C = bitcmp(A,n)` returns the bit-wise complement of `A` as an `n`-bit floating-point integer (flint).

Example

With eight-bit arithmetic, the ones' complement of 01100011 (99, decimal) is 10011100 (156, decimal).

```
C = bitcmp(99,8)

C =

   156
```

See Also

`bitand`, `bitget`, `bitmax`, `bitor`, `bitset`, `bitshift`, `bitxor`

Purpose

Get bit

Syntax

```
C = bitget(A,bit)
```

Description

`C = bitget(A,bit)` returns the value of the bit at position *bit* in `A`. Operand `A` must be a nonnegative integer, and *bit* must be a number between 1 and the number of bits in the floating-point integer (flint) representation of `A` (52 for IEEE flints). To ensure the operand is an integer, use the `ceil`, `fix`, `floor`, and `round` functions.

Example

The `dec2bin` function converts decimal numbers to binary. However, you can also use the `bitget` function to show the binary representation of a decimal number. Just test successive bits from most to least significant:

```
disp(dec2bin(13))
1101
C = bitget(13,4:-1:1)

C =
     1     1     0     1
```

See Also

`bitand`, `bitcmp`, `bitmax`, `bitor`, `bitset`, `bitshift`, `bitxor`

bitmax

Purpose

Maximum floating-point integer

Syntax

```
bitmax
```

Description

`bitmax` returns the maximum unsigned floating-point integer for your computer. It is the value when all bits are set. On IEEE machines, this is the value $2^{53} - 1$.

See Also

`bitand`, `bitcmp`, `bitget`, `bitor`, `bitset`, `bitshift`, `bitxor`

Purpose

Bit-wise OR

Syntax

```
C = bitor(A,B)
```

Description

`C = bitor(A,B)` returns the bit-wise OR of two nonnegative integer arguments `A` and `B`. To ensure the operands are integers, use the `ceil`, `fix`, `floor`, and `round` functions.

Examples

The five-bit binary representations of the integers 13 and 27 are 01101 and 11011, respectively. Performing a bit-wise OR on these numbers yields 11111, or 31.

```
C = bitor(13,27)

C =

    31
```

See Also

`bitand`, `bitcmp`, `bitget`, `bitmax`, `bitset`, `bitshift`, `bitxor`

bitset

Purpose

Set bit

Syntax

```
C = bitset(A,bit)
C = bitset(A,bit,v)
```

Description

`C = bitset(A,bit)` sets bit position *bit* in `A` to 1 (on). `A` must be a nonnegative integer and *bit* must be a number between 1 and the number of bits in the floating-point integer (flint) representation of `A` (52 for IEEE flints). To ensure the operand is an integer, use the `ceil`, `fix`, `floor`, and `round` functions.

`C = bitset(A,bit,v)` sets the bit at position *bit* to the value `v`, which must be either 0 or 1.

Examples

Setting the fifth bit in the five-bit binary representation of the integer 9 (01001) yields 11001, or 25.

```
C = bitset(9,5)

C =

    25
```

See Also

`bitand`, `bitcmp`, `bitget`, `bitmax`, `bitor`, `bitshift`, `bitxor`

Purpose

Bit-wise shift

Syntax

```
C = bitshift(A,k,n)
C = bitshift(A,k)
```

Description

`C = bitshift(A,k,n)` returns the value of `A` shifted by `k` bits. If `k>0`, this is same as a multiplication by 2^k (left shift). If `k<0`, this is the same as a division by 2^k (right shift). An equivalent computation for this function is `C = fix(A*2^k)`.

If the shift causes `C` to overflow `n` bits, the overflowing bits are dropped. `A` must contain nonnegative integers between `0` and `BITMAX`, which you can ensure by using the `ceil`, `fix`, `floor`, and `round` functions.

`C = bitshift(A,k)` uses the default value of `n = 53`.

Examples

Shifting 1100 (12, decimal) to the left two bits yields 110000 (48, decimal).

```
C = bitshift(12,2)

C =

    48
```

See Also

`bitand`, `bitcmp`, `bitget`, `bitmax`, `bitor`, `bitset`, `bitxor`, `fix`

bitxor

Purpose

Bit-wise XOR

Syntax

```
C = bitxor(A,B)
```

Description

`C = bitxor(A,B)` returns the bit-wise XOR of the two arguments `A` and `B`. Both `A` and `B` must be integers. You can ensure this by using the `ceil`, `fix`, `floor`, and `round` functions.

Examples

The five-bit binary representations of the integers 13 and 27 are 01101 and 11011, respectively. Performing a bit-wise XOR on these numbers yields 10110, or 22.

```
C = bitxor(13,27)

C =
    22
```

See Also

`bitand`, `bitcmp`, `bitget`, `bitmax`, `bitor`, `bitset`, `bitshift`

Purpose

A string of blanks

Syntax

```
blanks(n)
```

Description

`blanks(n)` is a string of `n` blanks.

Examples

`blanks` is useful with the `display` function. For example,

```
disp(['xxx' blanks(20) 'yyy'])
```

displays twenty blanks between the strings `'xxx'` and `'yyy'`.

`disp(blanks(n)')` moves the cursor down `n` lines.

See Also

`clc`, `format`, `home`

blkdiag

Purpose

Construct a block diagonal matrix from input arguments

Syntax

```
out = blkdiag(a,b,c,d,...)
```

Description

`out = blkdiag(a,b,c,d,...)` where `a`, `b`, ... are matrices outputs a block diagonal matrix of the form:

$$\begin{bmatrix} a & 0 & 0 & 0 & 0 \\ 0 & b & 0 & 0 & 0 \\ 0 & 0 & c & 0 & 0 \\ 0 & 0 & 0 & d & 0 \\ 0 & 0 & 0 & 0 & \ldots \end{bmatrix}$$

The input matrics do not have to be square, nor do they have to be of equal size.

`blkdiag` works not only for matrices, but for any MATLAB objects which support `horzcat` and `vertcat` operations.

See Also

`diag`

Purpose

Terminate execution of a `for` loop or `while` loop

Syntax

```
break
```

Description

`break` terminates the execution of a `for` loop or `while` loop. In nested loops, `break` exits from the innermost loop only.

Examples

The example below shows a `while` loop that reads the contents of the file `fft.m` into a MATLAB character array. A `break` statement is used to exit the `while` loop when the first empty line is encountered. The resulting character array contains the M-file help for the `fft` program.

```
fid = fopen('fft.m','r');
s = '';
while ~feof(fid)
   line = fgetl(fid);
   if isempty(line), break, end
   s = strvcat(s,line);
end
disp(s)
```

See Also

`end`, `for`, `return`, `while`

builtin

Purpose

Execute builtin function from overloaded method

Syntax

```
builtin(function,x1,...,xn)
[y1,..,yn] = builtin(function,x1,...,xn)
```

Description

`builtin` is used in methods that overload builtin functions to execute the original builtin function. If *function* is a string containing the name of a builtin function,then:

`builtin(`*function*`,x1,...,xn)` evaluates that function at the given arguments.

`[y1,..,yn] = builtin(`*function*`,x1,...,xn)` returns multiple output arguments.

Remarks

`builtin`(...) is the same as `feval`(...) except that it calls the original builtin version of the function even if an overloaded one exists. (For this to work you must never overload `builtin`.)

See Also

`feval`

Purpose

Calendar

Syntax

```
c = calendar
c = calendar(d)
c = calendar(y,m)

calendar(...)
```

Description

`c = calendar` returns a 6-by-7 matrix containing a calendar for the current month. The calendar runs Sunday (first column) to Saturday.

`c = calendar(d)`, where `d` is a serial date number or a date string, returns a calendar for the specified month.

`c = calendar(y,m)`, where `y` and `m` are integers, returns a calendar for the specified month of the specified year.

`calendar(...)` displays the calendar on the screen.

Examples

The command:

```
calendar(1957,10)
```

reveals that the Space Age began on a Friday (on October 4, 1957, when Sputnik 1 was launched).

```
                Oct 1957
   S     M     Tu     W     Th     F     S
   0     0      1     2      3     4     5
   6     7      8     9     10    11    12
  13    14     15    16     17    18    19
  20    21     22    23     24    25    26
  27    28     29    30     31     0     0
   0     0      0     0      0     0     0
```

See Also

`datenum`

cart2pol

Purpose

Transform Cartesian coordinates to polar or cylindrical

Syntax

```
[THETA,RHO,Z] = cart2pol(X,Y,Z)
[THETA,RHO] = cart2pol(X,Y)
```

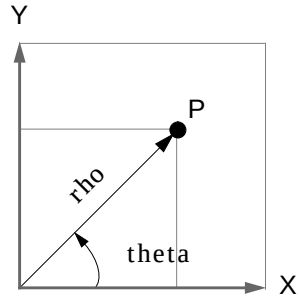
Description

`[THETA,RHO,Z] = cart2pol(X,Y,Z)` transforms three-dimensional Cartesian coordinates stored in corresponding elements of arrays `X`, `Y`, and `Z`, into cylindrical coordinates. `THETA` is a counterclockwise angular displacement in radians from the positive *x*-axis, `RHO` is the distance from the origin to a point in the *x-y* plane, and `Z` is the height above the *x-y* plane. Arrays `X`, `Y`, and `Z` must be the same size (or any can be scalar).

`[THETA,RHO] = cart2pol(X,Y)` transforms two-dimensional Cartesian coordinates stored in corresponding elements of arrays `X` and `Y` into polar coordinates.

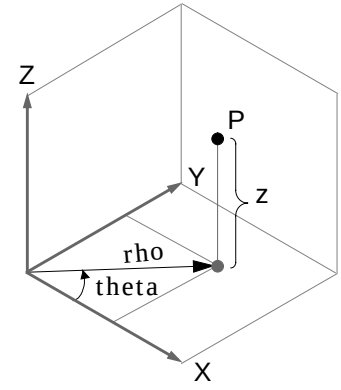
Algorithm

The mapping from two-dimensional Cartesian coordinates to polar coordinates, and from three-dimensional Cartesian coordinates to cylindrical coordinates is:



Two-Dimensional Mapping

```
theta = atan2(y,x)
rho = sqrt(x.^2 + y.^2)
```



Three-Dimensional Mapping

```
theta = atan2(y,x)
rho = sqrt(x.^2 + y.^2)
z = z
```

See Also `cart2sph`, `pol2cart`, `sph2cart`

cart2sph

Purpose

Transform Cartesian coordinates to spherical

Syntax

```
[THETA,PHI,R] = cart2sph(X,Y,Z)
```

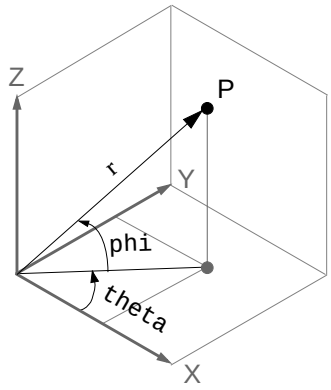
Description

`[THETA,PHI,R] = cart2sph(X,Y,Z)` transforms Cartesian coordinates stored in corresponding elements of arrays `X`, `Y`, and `Z` into spherical coordinates. Azimuth `THETA` and elevation `PHI` are angular displacements in radians measured from the positive *x*-axis, and the *x-y* plane, respectively; and `R` is the distance from the origin to a point.

Arrays `X`, `Y`, and `Z` must be the same size.

Algorithm

The mapping from three-dimensional Cartesian coordinates to spherical coordinates is:




```
        theta = atan2(y,x)
phi = atan2(z, sqrt(x.^2 + y.^2))
    r = sqrt(x.^2+y.^2+z.^2)
```

See Also

`cart2pol`, `pol2cart`, `sph2cart`

Purpose

Case switch

Description

case is part of the switch statement syntax, which allows for conditional execution.

A particular case consists of the case statement itself, followed by a case expression, and one or more statements.

A case is executed only if its associated case expression (case_expr) is the first to match the switch expression (switch_expr).

Examples

The general form of the switch statement is:

```
switch switch_expr
    case case_expr
      statement,...,statement
    case {case_expr1,case_expr2,case_expr3,...}
      statement,...,statement
...
    otherwise
      statement,...,statement
 end
```

See switch for more details.

See Also

switch

cat

Purpose

Concatenate arrays

Syntax

```
C = cat(dim,A,B)
C = cat(dim,A1,A2,A3,A4...)
```

Description

`C = cat(dim,A,B)` concatenates the arrays `A` and `B` along `dim`.

`C = cat(dim,A1,A2,A3,A4,...)` concatenates all the input arrays (`A1`, `A2`, `A3`, `A4`, and so on) along `dim`.

`cat(2,A,B)` is the same as `[A,B]` and `cat(1,A,B)` is the same as `[A;B]`.

Remarks

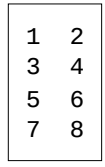
When used with comma separated list syntax, `cat(dim,C{:})` or `cat(dim,C.field)` is a convenient way to concatenate a cell or structure array containing numeric matrices into a single matrix.

Examples

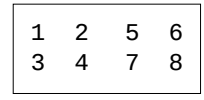
Given,

```
A =                B =
     1     2              5     6
     3     4              7     8
```

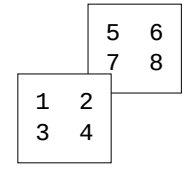
concatenating along different dimensions produces:



`C = cat(1,A,B)`



`C = cat(2,A,B)`



`C = cat(3,A,B)`

The commands

```
A = magic(3); B = pascal(3);
C = cat(4,A,B);
```

produce a 3-by-3-by-1-by-2 array.

See Also

`num2cell`

The special character `[]`

Purpose

Begin `catch` block

Description

The general form of a `try` statement is:

`try` statement, ..., statement, `catch` statement, ..., statement `end`

Normally, only the statements between the `try` and `catch` are executed. However, if an error occurs while executing any of the statements, the error is captured into `lasterr`, and the statements between the `catch` and `end` are executed. If an error occurs within the `catch` statements, execution stops unless caught by another `try...catch` block. The error string produced by a failed `try` block can be obtained with `lasterr`.

See Also

`end`, `eval`, `evalin`, `try`

cd

Purpose

Change working directory

Syntax

```
cd
cd directory
cd ..
```

Description

`cd` prints out the current directory.

`cd directory` sets the current directory to `directory`. On UNIX platforms, the character ~ is interpreted as the user's root directory.

`cd ..` changes to the directory above the current one.

Examples

UNIX: `cd /usr/local/matlab/toolbox/demos`

DOS: `cd C:MATLAB\DEMOS`

VMS: `cd DISK1:[MATLAB.DEMOS]`

See Also

`dir`, `path`, `what`

Purpose

Convert complex diagonal form to real block diagonal form

Syntax

```
[V,D] = cdf2rdf(V,D)
```

Description

If the eigensystem `[V,D] = eig(X)` has complex eigenvalues appearing in complex-conjugate pairs, `cdf2rdf` transforms the system so `D` is in real diagonal form, with 2-by-2 real blocks along the diagonal replacing the complex pairs originally there. The eigenvectors are transformed so that

```
X = V*D/V
```

continues to hold. The individual columns of `V` are no longer eigenvectors, but each pair of vectors associated with a 2-by-2 block in `D` spans the corresponding invariant vectors.

Examples

The matrix

```
X =
    1     2     3
    0     4     5
    0    -5     4
```

has a pair of complex eigenvalues.

```
[V,D] = eig(X)

V =
    1.0000     0.4002 - 0.0191i       0.4002 + 0.0191i
         0     0.6479                 0.6479
         0          0 + 0.6479i            0 - 0.6479i

D =
    1.0000           0                  0
         0      4.0000 + 5.0000i        0
         0           0            4.0000 - 5.0000i
```

Converting this to real block diagonal form produces

```
[V,D] = cdf2rdf(V,D)

V =
    1.0000     0.4002     -0.0191
         0     0.6479           0
         0          0      0.6479
D =
    1     0     0
    0     4     5
    0    -5     4
```

Algorithm

The real diagonal form for the eigenvalues is obtained from the complex form using a specially constructed similarity transformation.

See Also

`eig`, `rsf2csf`

Purpose

Round toward infinity

Syntax

```
B = ceil(A)
```

Description

`B = ceil(A)` rounds the elements of `A` to the nearest integers greater than or equal to `A`. For complex `A`, the imaginary and real parts are rounded independently.

Examples

```
a =

  Columns 1 through 4

 -1.9000         -0.2000          3.4000          5.6000

  Columns 5 through 6

   7.0000             2.4000 + 3.6000i

ceil(a)

ans =

  Columns 1 through 4

  -1.0000          0             4.0000             6.0000

  Columns 5 through 6

   7.0000             3.0000 + 4.0000i
```

See Also

`fix`, `floor`, `round`

cell

Purpose

Create cell array

Syntax

```
c = cell(n)
c = cell(m,n)
c = cell([m n])
c = cell(m,n,p,...)
c = cell([m n p ...])
c = cell(size(A))
```

Description

`c = cell(n)` creates an n-by-n cell array of empty matrices. An error message appears if `n` is not a scalar.

`c = cell(m,n)` or `c = cell([m,n])` creates an `m`-by-`n` cell array of empty matrices. Arguments `m` and `n` must be scalars.

`c = cell(m,n,p,...)` or `c = cell([m n p ...])` creates an `m`-by-`n`-by-`p`-... cell array of empty matrices. Arguments `m`, `n`, `p`,... must be scalars.

`c = cell(size(A))` creates a cell array the same size as `A` containing all empty matrices.

Examples

```
A = ones(2,2)

A =
     1     1
     1     1

c = cell(size(A))

c =

     []     []
     []     []
```

See Also

ones, rand, randn, zeros

Purpose

Convert cell array to structure array

Syntax

```
s = cell2struct(c,fields,dim)
```

Description

`s = cell2struct(c,fields,dim)` converts the cell array `c` into the structure `s` by folding the dimension `dim` of `c` into fields of `s`. The length of `c` along the specified dimension (`size(c,dim)`) must match the number of fields names in `fields`. Argument `fields` can be a character array or a cell array of strings.

Examples

```
c = {'tree',37.4,'birch'};
f = {'category','height','name'};
s = cell2struct(c,f,2)

s =

    category: 'tree'
      height: 37.4000
        name: 'birch'
```

See Also

`fieldnames`, `struct2cell`

celldisp

Purpose

Display cell array contents.

Syntax

```
celldisp(C)
celldisp(C,name)
```

Description

`celldisp(C)` recursively displays the contents of a cell array.

`celldisp(C,`*name*`)` uses the string *name* for the display instead of the name of the first input (or ans).

Example

Use `celldisp` to display the contents of a 2-by-3 cell array:

```
C = {[1 2] 'Tony' 3+4i; [1 2;3 4] –5 'abc'};
celldisp(C)

C{1,1} =

     1     2

C{2,1} =

     1     2
     3     4

C{1,2} =

Tony

C{2,2} =

    –5

C{1,3} =

   3.0000+ 4.0000i


C{2,3} =

abc
```

See Also `cellplot`

cellfun

Purpose

Apply a function to each element in a cell array

Syntax

```
D = cellfun('fname',C)
D = cellfun('size',C,k)
D = cellfun('isclass',C,classname)
```

Description

`D = cellfun('fname',C)` applies the function `fname` to the elements of the cell array `C` and returns the results in the double array `D`. Each element of `D` contains the value returned by `fname` for the corresponding element in `C`. The output array `D` is the same size as the cell array `C`.

These functions are supported:

Function	Return Value
`isempty`	`true` for an empty cell element
`islogical`	`true` for a logical cell element
`isreal`	`true` for a real cell element
`length`	Length of the cell element
`ndims`	Number of dimensions of the cell element
`prodofsize`	Number of elements in the cell element

`D = cellfun('size',C,k)` returns the size along the `k`-th dimension of each element of `C`.

`D = cellfun('isclass',C,'classname')` returns `true` for each element of `C` that matches `classname`. This function syntax returns `false` for objects that are a subclass of `classname`.

Limitations

If the cell array contains objects, `cellfun` does not call overloaded versions of the function `fname`.

Example

Consider this 2-by-3 cell array:

```
C{1,1} = [1 2; 4 5];
C{1,2} = 'Name';
C{1,3} = pi;
C{2,1} = 2 + 4i;
C{2,2} = 7;
C{2,3} = magic(3);
```

`cellfun` returns a 2-by-3 double array:

```
D = cellfun('isreal',C)

D =

     1     1     1
     0     1     1

len = cellfun('length',C)

len =

     2     4     1
     1     1     3

isdbl = cellfun('isclass',C,'double')

isdbl =

     1     0     1
     1     1     1
```

See Also

`isempty`, `islogical`, `isreal`, `length`, `ndims`, `size`

cellplot

Purpose

Graphically display the structure of cell arrays

Syntax

```
cellplot(c)
cellplot(c,'legend')
handles = cellplot(...)
```

Description

`cellplot(c)` displays a figure window that graphically represents the contents of `c`. Filled rectangles represent elements of vectors and arrays, while scalars and short text strings are displayed as text.

`cellplot(c,'legend')` also puts a legend next to the plot.

`handles = cellplot(c)` displays a figure window and returns a vector of surface handles.

Limitations

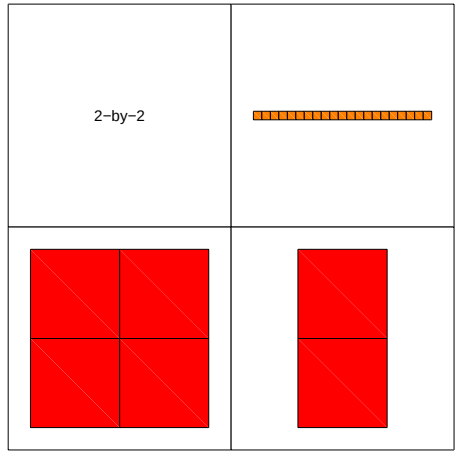
The `cellplot` function can display only two-dimensional cell arrays.

Examples

Consider a 2-by-2 cell array containing a matrix, a vector, and two text strings:

```
c{1,1} = '2-by-2';
c{1,2} = 'eigenvalues of eye(2)';
c{2,1} = eye(2);
c{2,2} = eig(eye(2));
```

The command `cellplot(c)` produces:



Purpose

Create cell array of strings from character array

Syntax

```
c = cellstr(S)
```

Description

`c = cellstr(S)` places each row of the character array `S` into separate cells of `c`. Use the `string` function to convert back to a string matrix.

Examples

Given the string matrix

```
S =
abc
defg
hi
```

The command `c = cellstr(S)` returns the 3-by-1 cell array:

```
c =
    'abc'
    'defg'
    'hi'
```

See Also

`iscellstr`, `strings`

cgs

Purpose

Conjugate Gradients Squared method

Syntax

```
x = cgs(A,b)
cgs(A,b,tol)
cgs(A,b,tol,maxit)
cgs(A,b,tol,maxit,M)
cgs(A,b,tol,maxit,M1,M2)
cgs(A,b,tol,maxit,M1,M2,x0)
x = cgs(A,b,tol,maxit,M1,M2,x0)
[x,flag] = cgs(A,b,tol,maxit,M1,M2,x0)
[x,flag,relres] = cgs(A,b,tol,maxit,M1,M2,x0)
[x,flag,relres,iter] = cgs(A,b,tol,maxit,M1,M2,x0)
[x,flag,relres,iter,resvec] = cgs(A,b,tol,maxit,M1,M2,x0)
```

Description

`x = cgs(A,b)` attempts to solve the system of linear equations `A*x = b` for `x`. The coefficient matrix `A` must be square and the column vector `b` must have length `n`, where `A` is `n`-by-`n`. When `A` is not explicitly available as a matrix, you can express `A` as an operator `afun` that returns the matrix-vector product `A*x` for `afun(x)`. This operator can be the name of an M-file, a string expression, or an inline object. In this case `n` is taken to be the length of the column vector `b`

`cgs` will start iterating from an initial estimate that, by default, is an all zero vector of length `n`. Iterates are produced until the method either converges, fails, or has computed the maximum number of iterations. Convergence is achieved when an iterate `x` has relative residual `norm(b-A*x)/norm(b)` less than or equal to the tolerance of the method. The default tolerance is `1e-6`. The default maximum number of iterations is the minimum of `n` and 20. No preconditioning is used.

`cgs(A,b,tol)` specifies the tolerance of the method, `tol`.

`cgs(A,b,tol,maxit)` additionally specifies the maximum number of iterations, `maxit`.

`cgs(A,b,tol,maxit,M)` and `cgs(A,b,tol,maxit,M1,M2)` use left preconditioner `M` or `M = M1*M2` and effectively solve the system `inv(M)*A*x = inv(M)*b` for `x`. You can replace the matrix `M` with a function `mfun` such that `mfun(x)` returns `M\x`. If `M1` or `M2` is given as the empty matrix (`[]`), it is considered to be the identity matrix, equivalent to no preconditioning

at all. Since systems of equations of the form `M*y = r` are solved using backslash within `cgs`, it is wise to factor preconditioners into their LU factors first. For example, replace `cgs(A,b,tol,maxit,M)` with:

```
[M1,M2] = lu(M);
cgs(A,b,tol,maxit,M1,M2).
```

`cgs(A,b,tol,maxit,M1,M2,x0)` specifies the initial estimate `x0`. If `x0` is given as the empty matrix (`[]`), the default all zero vector is used.

`x = cgs(A,b,tol,maxit,M1,M2,x0)` returns a solution `x`. If `cgs` converged, a message to that effect is displayed. If `cgs` failed to converge after the maximum number of iterations or halted for any reason, a warning message is printed displaying the relative residual `norm(b-A*x)/norm(b)` and the iteration number at which the method stopped or failed.

`[x,flag] = cgs(A,b,tol,maxit,M1,M2,x0)` returns a solution `x` and a flag that describes the convergence of `cgs`.

Flag	Convergence
`0`	`cgs` converged to the desired tolerance `tol` within `maxit` iterations without failing for any reason.
`1`	`cgs` iterated `maxit` times but did not converge.
`2`	One of the systems of equations of the form `M*y = r` involving the preconditioner was ill-conditioned and did not return a useable result when solved by \ (backslash).
`3`	The method stagnated. (Two consecutive iterates were the same.)
`4`	One of the scalar quantities calculated during `cgs` became too small or too large to continue computing.

Whenever `flag` is not `0`, the solution `x` returned is that with minimal norm residual computed over all the iterations. No messages are displayed if the `flag` output is specified.

`[x,flag,relres] = cgs(A,b,tol,maxit,M1,M2,x0)` also returns the relative residual `norm(b-A*x)/norm(b)`. If `flag` is `0`, then `relres` ≤ `tol`.

`[x,flag,relres,iter] = cgs(A,b,tol,maxit,M1,M2,x0)` also returns the iteration number at which `x` was computed. This always satisfies `0` ≤ `iter` ≤ `maxit`.

`[x,flag,relres,iter,resvec] = cgs(A,b,tol,maxit,M1,M2,x0)` also returns a vector of the residual norms at each iteration, starting from `resvec(1) = norm(b-A*x0)`. If `flag` is `0`, `resvec` is of length `iter+1` and `resvec(end)` ≤ `tol*norm(b)`.

Examples

```
load west0479
A = west0479
b = sum(A,2)
[x,flag] = cgs(A,b)
```

`flag` is `1` since `cgs` will not converge to the default tolerance `1e-6` within the default 20 iterations.

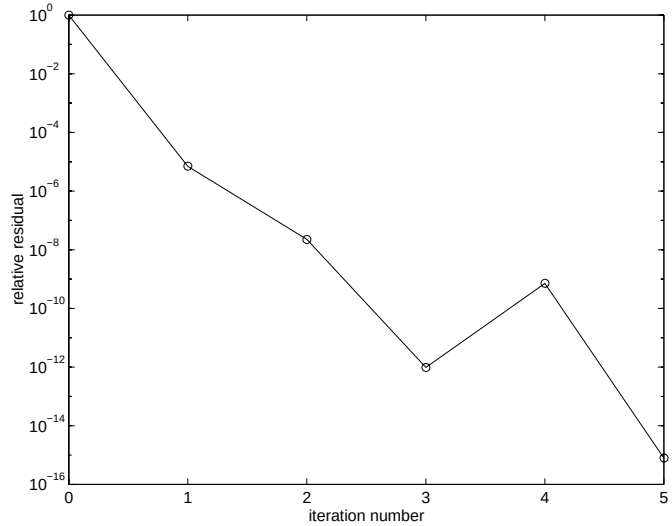
```
[L1,U1] = luinc(A,1e-5)
[x1,flag1] = cgs(A,b,1e-6,20,L1,U1)
```

`flag1` is `2` since the upper triangular `U1` has a zero on its diagonal so `cgs` fails in the first iteration when it tries to solve a system such as `U1*y = r` for `y` with backslash.

```
[L2,U2] = luinc(A,1e-6)
[x2,flag2,relres2,iter2,resvec2] = cgs(A,b,1e-15,10,L2,U2)
```

`flag2` is `0` since `cgs` will converge to the tolerance of `7.9e-16` (the value of `relres2`) at the fifth iteration (the value of `iter2`) when preconditioned by the incomplete LU factorization with a drop tolerance of `1e-6`. `resvec2(1) = norm(b)` and `resvec2(6) = norm(b-A*x2)`. You can follow the progress of `cgs` by plotting the relative residuals at each iteration

starting from the initial estimate (iterate number 0) with `semilogy(0:iter2,res2/norm(b),'-o')`.



See Also

`bicg`, `bicgstab`, `gmres`, `luinc`, `pcg`, `qmr`

The arithmetic operator \

References

Sonneveld, Peter, "CGS: A fast Lanczos-type solver for nonsymmetric linear systems", *SIAM* J. Sci. Stat. Comput., January 1989, Vol. 10, No. 1, pp. 36-52.

"Templates for the Solution of Linear Systems: Building Blocks for Iterative Methods", *SIAM*, Philadelphia, 1994.

char

Purpose

Create character array (string)

Syntax

```
S = char(X)
S = char(C)
S = char(t1,t2.t3...)
```

Description

`S = char(X)` converts the array `X` that contains positive integers representing character codes into a MATLAB character array (the first 127 codes are ASCII). The actual characters displayed depend on the character set encoding for a given font. The result for any elements of `X` outside the range from 0 to 65535 is not defined (and may vary from platform to platform). Use `double` to convert a character array into its numeric codes.

`S = char(C)` when `C` is a cell array of strings, places each element of `C` into the rows of the character array `s`. Use `cellstr` to convert back.

`S = char(t1,t2,t3,..)` forms the character array `S` containing the text strings `T1`,`T2`,`T3`,... as rows, automatically padding each string with blanks to form a valid matrix. Each text parameter,`T`*i*, can itself be a character array. This allows the creation of arbitarily large character arrays. Empty strings are significant.

Remarks

Ordinarily, the elements of `A` are integers in the range 32:127, which are the printable ASCII characters, or in the range 0:255, which are all 8-bit values. For noninteger values, or values outside the range 0:255, the characters printed are determined by `fix(rem(A,256))`.

Examples

To print a 3-by-32 display of the printable ASCII characters:

```
ascii = char(reshape(32:127,32,3)')
ascii =
! " # $ % & ' ( ) * + , - . / 0 1 2 3 4 5 6 7 8 9 : ; < = > ?
@ 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 [ \ ] ^ _
' 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 { | } ~
```

See Also cellstr, double, get, set, strings, strvcat, text

chol

Purpose

Cholesky factorization

Syntax

```
R = chol(X)
[R,p] = chol(X)
```

Description

The `chol` function uses only the diagonal and upper triangle of `X`. The lower triangular is assumed to be the (complex conjugate) transpose of the upper. That is, `X` is Hermitian.

`R = chol(X)`, where `X` is positive definite produces an upper triangular `R` so that `R'*R = X`. If `X` is not positive definite, an error message is printed.

`[R,p] = chol(X)`, with two output arguments, never produces an error message. If `X` is positive definite, then `p` is 0 and `R` is the same as above. If `X` is not positive definite, then `p` is a positive integer and `R` is an upper triangular matrix of order `q = p-1` so that `R'*R = X(1:q,1:q)`.

Examples

The binomial coefficients arranged in a symmetric array create an interesting positive definite matrix.

```
n = 5;
X = pascal(n)
X =
     1     1     1     1     1
     1     2     3     4     5
     1     3     6    10    15
     1     4    10    20    35
     1     5    15    35    70
```

It is interesting because its Cholesky factor consists of the same coefficients, arranged in an upper triangular matrix.

```
R = chol(X)
R =
     1     1     1     1     1
     0     1     2     3     4
     0     0     1     3     6
     0     0     0     1     4
     0     0     0     0     1
```

Destroy the positive definiteness (and actually make the matrix singular) by subtracting 1 from the last element.

```
X(n,n) = X(n,n)-1
X =
     1     1     1     1     1
     1     2     3     4     5
     1     3     6    10    15
     1     4    10    20    35
     1     5    15    35    69
```

Now an attempt to find the Cholesky factorization fails.

Algorithm

`chol` uses the algorithm from the LINPACK subroutine `ZPOFA`. For a detailed description of the use of the Cholesky decomposition, see Chapter 8 of the *LINPACK Users' Guide*.

References

[1] Dongarra, J.J., J.R. Bunch, C.B. Moler, and G.W. Stewart, *LINPACK Users' Guide*, SIAM, Philadelphia, 1979.

See Also

`cholinc`, `cholupdate`

cholinc

Purpose

Sparse incomplete Cholesky and Cholesky-Infinity factorizations

Syntax

```
R = cholinc(X,droptol)
R = cholinc(X,options)
R = cholinc(X,'0')
[R,p] = cholinc(X,'0')
R = cholinc(X,'inf')
```

Description

`cholinc` produces two different kinds of incomplete Cholesky factorizations: the drop tolerance and the 0 level of fill-in factorizations. These factors may be useful as preconditioners for a symmetric positive definite system of linear equations being solved by an iterative method such as `pcg` (Preconditioned Conjugate Gradients). `cholinc` works only for sparse matrices.

`R = cholinc(X,droptol)` performs the incomplete Cholesky factorization of `X`, with drop tolerance `droptol`.

`R = cholinc(X,options)` allows additional options to the incomplete Cholesky factorization. `options` is a structure with up to three fields:

`droptol`	Drop tolerance of the incomplete factorization
`michol`	Modified incomplete Cholesky
`rdiag`	Replace zeros on the diagonal of `R`

Only the fields of interest need to be set.

`droptol` is a non-negative scalar used as the drop tolerance for the incomplete Cholesky factorization. This factorization is computed by performing the incomplete LU factorization with the pivot threshold option set to `0` (which forces diagonal pivoting) and then scaling the rows of the incomplete upper triangular factor, `U`, by the square root of the diagonal entries in that column. Since the nonzero entries `U(i,j)` are bounded below by `droptol*norm(X(:,j))` (see `luinc`), the nonzero entries `R(i,j)` are bounded below by the local drop tolerance `droptol*norm(X(:,j))/R(i,i)`.

Setting `droptol = 0` produces the complete Cholesky factorization, which is the default.

`michol` stands for modified incomplete Cholesky factorization. Its value is either `0` (unmodified, the default) or `1` (modified). This performs the modified incomplete LU factorization of `X` and scales the returned upper triangular factor as described above.

`rdiag` is either `0` or `1`. If it is `1`, any zero diagonal entries of the upper triangular factor R are replaced by the square root of the local drop tolerance in an attempt to avoid a singular factor. The default is `0`.

`R = cholinc(X,'0')` produces the incomplete Cholesky factor of a real sparse matrix that is symmetric and positive definite using no fill-in. The upper triangular `R` has the same sparsity pattern as `triu(X)`, although `R` may be zero in some positions where `X` is nonzero due to cancellation. The lower triangle of `X` is assumed to be the transpose of the upper. Note that the positive definiteness of `X` does not guarantee the existence of a factor with the required sparsity. An error message results if the factorization is not possible. If the factorization is successful, `R'*R` agrees with `X` over its sparsity pattern.

`[R,p] = cholinc(X,'0')` with two output arguments, never produces an error message. If `R` exists, `p` is `0`. If `R` does not exist, then `p` is a positive integer and `R` is an upper triangular matrix of size `q`-by-`n` where `q = p-1`. In this latter case, the sparsity pattern of `R` is that of the `q`-by-`n` upper triangle of `X`. `R'*R` agrees with `X` over the sparsity pattern of its first `q` rows and first `q` columns.

`R = cholinc(X,'inf')` produces the Cholesky-Infinity factorization. This factorization is based on the Cholesky factorization, and additionally handles real positive semi-definite matrices. It may be useful for finding a solution to systems which arise in interior-point methods. When a zero pivot is encountered in the ordinary Cholesky factorization, the diagonal of the Cholesky-Infinity factor is set to `Inf` and the rest of that row is set to `0`. This forces a `0` in the corresponding entry of the solution vector in the associated system of linear equations. In practice, `X` is assumed to be positive semi-definite so even negative pivots are replaced with a value of `Inf`.

Remarks

The incomplete factorizations may be useful as preconditioners for solving large sparse systems of linear equations. A single `0` on the diagonal of the upper triangular factor makes it singular. The incomplete factorization with a drop tolerance prints a warning message if the upper triangular factor has zeros on the diagonal. Similarly, using the `rdiag` option to replace a zero diagonal only

gets rid of the symptoms of the problem, but it does not solve it. The preconditioner may not be singular, but it probably is not useful, and a warning message is printed.

The Cholesky-Infinity factorization is meant to be used within interior-point methods. Otherwise, its use is not recommended.

Examples

Example 1.

Start with a symmetric positive definite matrix, `S`.

```
S = delsq(numgrid('C',15));
```

`S` is the two-dimensional, five-point discrete negative Lapacian on the grid generated by `numgrid('C',15)`.

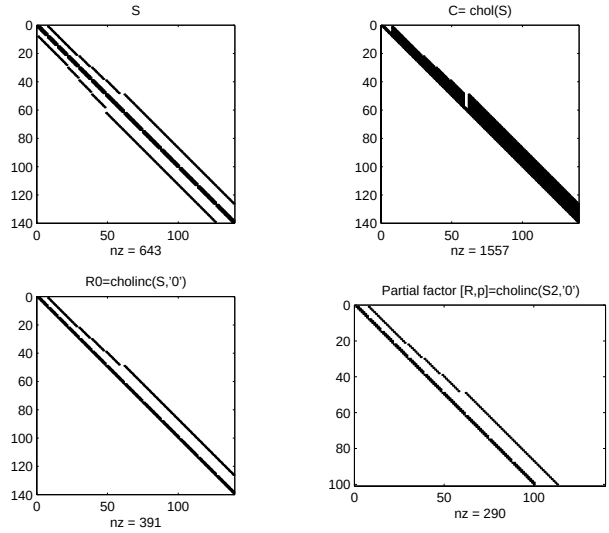
Compute the Cholesky factorization and the incomplete Cholesky factorization of level 0 to compare the fill-in. Make `S` singular by zeroing out a diagonal entry and compute the (partial) incomplete Cholesky factorization of level `0`.

```
C = chol(S);
R0 = cholinc(S,'0');
S2 = S; S2(101,101) = 0;
[R,p] = cholinc(S2,'0');
```

Fill-in occurs within the bands of `S` in the complete Cholesky factor, but none in the incomplete Cholesky factor. The incomplete factorization of the singular `S2` stopped at row `p = 101` resulting in a 100-by-139 partial factor.

```
D1 = (R0'*R0).*spones(S)–S;
D2 = (R'*R).*spones(S2)–S2;
```

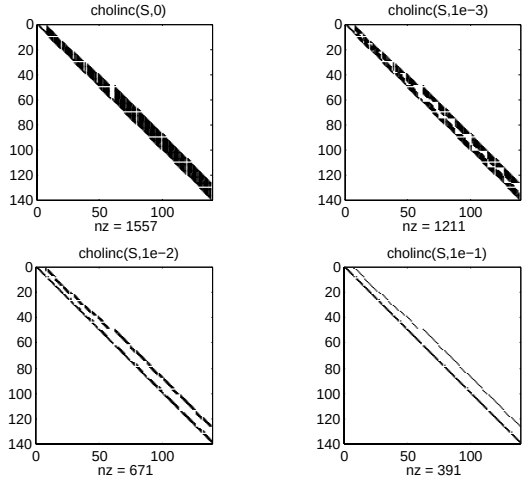
`D1` has elements of the order of `eps`, showing that `R0'*R0` agrees with `S` over its sparsity pattern. `D2` has elements of the order of `eps` over its first 100 rows and first 100 columns, `D2(1:100,:)` and `D2(:,1:100)`.



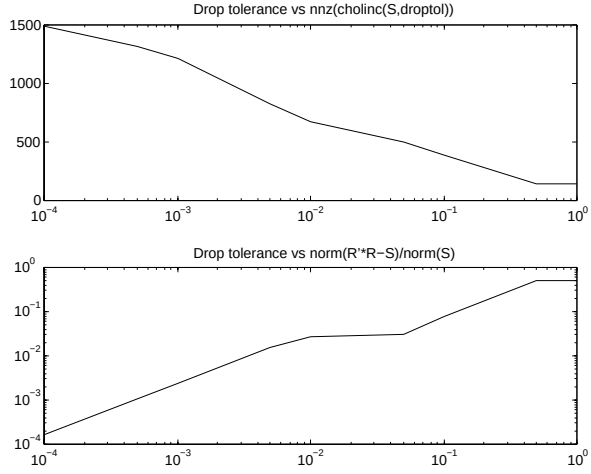
Example 2.

The first subplot below shows that `cholinc(S,0)`, the incomplete Cholesky factor with a drop tolerance of `0`, is the same as the Cholesky factor of `S`.

Increasing the drop tolerance increases the sparsity of the incomplete factors, as seen below.



Unfortunately, the sparser factors are poor approximations, as is seen by the plot of drop tolerance versus `norm(R'*R-S,1)/norm(S,1)` in the next figure.



Example 3.

The Hilbert matrices have (i,j) entries 1/(i+j-1) and are theoretically positive definite:

```
H3 = hilb(3)
H3 =
    1.0000    0.5000    0.3333
    0.5000    0.3333    0.2500
    0.3333    0.2500    0.2000

R3 = chol(H3)
R3 =
    1.0000    0.5000    0.3333
         0    0.2887    0.2887
         0         0    0.0745
```

In practice, the Cholesky factorization breaks down for larger matrices:

```
H20 = sparse(hilb(20));
[R,p] = chol(H20);
p =
    14
```

For `hilb(20)`, the Cholesky factorization failed in the computation of row 14 because of a numerically zero pivot. You can use the Cholesky-Infinity factorization to avoid this error. When a zero pivot is encountered, `cholinc` places an `Inf` on the main diagonal, zeros out the rest of the row, and continues with the computation:

```
Rinf = cholinc(H20,'inf');
```

In this case, all subsequent pivots are also too small, so the remainder of the upper triangular factor is:

```
full(Rinf(14:end,14:end))
ans =
   Inf     0     0     0     0     0     0
     0   Inf     0     0     0     0     0
     0     0   Inf     0     0     0     0
     0     0     0   Inf     0     0     0
     0     0     0     0   Inf     0     0
     0     0     0     0     0   Inf     0
     0     0     0     0     0     0   Inf
```

Limitations

`cholinc` works on square sparse matrices only. For `cholinc(X,'0')` and `cholinc(X,'inf')`, `X` must be real.

Algorithm

`R = cholinc(X,droptol)` is obtained from `[L,U] = luinc(X,options)`, where `options.droptol = droptol` and `options.thresh = 0`. The rows of the uppertriangular `U` are scaled by the square root of the diagonal in that row, and this scaled factor becomes `R`.

`R = cholinc(X,options)` is produced in a similar manner, except the `rdiag` option translates into the `udiag` option and the `milu` option takes the value of the `michol` option.

`R = cholinc(X,'0')` is based on the "KJI" variant of the Cholesky factorization. Updates are made only to positions which are nonzero in the upper triangle of `X`.

`R = cholinc(X,'inf')` is based on the algorithm in Zhang ([2]).

See Also

`chol`, `luinc`, `pcg`

References

[1] Saad, Yousef, *Iterative Methods for Sparse Linear Systems*, PWS Publishing Company, 1996, Chapter 10 - Preconditioning Techniques.

[2] Zhang, Yin, *Solving Large-Scale Linear Programs by Interior-Point Methods Under the MATLAB Environment*, Department of Mathematics and Statistics, University of Maryland Baltimore County, Technical Report TR96-01

cholupdate

Purpose

Rank 1 update to Cholesky factorization

Syntax

```
R1 = cholupdate(R,x)
R1 = cholupdate(R,x,'+')
R1 = cholupdate(R,x,'-')
[R1,p] = cholupdate(R,x,'-')
```

Description

`R1 = cholupdate(R,x)` where `R = chol(A)` is the original Cholesky factorization of `A`, returns the upper triangular Cholesky factor of `A + x*x'`, where `x` is a column vector of appropriate length. `cholupdate` uses only the diagonal and upper triangle of `R`. The lower triangle of `R` is ignored.

`R1 = cholupdate(R,x,'+')` is the same as `R1 = cholupdate(R,x)`.

`R1 = cholupdate(R,x,'-')` returns the Cholesky factor of `A - x*x'`. An error message reports when R is not a valid Cholesky factor or when the downdated matrix is not positive definite and so does not have a Cholesky factoriza- tion.

`[R1,p] = cholupdate(R,x,'-')` will not return an error message. If `p` is `0`, `R1` is the Cholesky factor of `A - x*x'`. If `p` is greater than `0`, `R1` is the Cholesky factor of the original `A`. If `p` is `1`, `cholupdate` failed because the downdated matrix is not positive definite. If `p` is `2`, `cholupdate` failed because the upper triangle of `R` was not a valid Cholesky factor.

Remarks

`cholupdate` works only for full matrices.

Example

```
A = pascal(4)
A =

     1     1     1     1
     1     2     3     4
     1     3     6    10
     1     4    10    20
```

```
R = chol(A)
R =

     1     1     1     1
     0     1     2     3
     0     0     1     3
     0     0     0     1

x = [0 0 0 1]';
```

This is called a rank one update to `A` since `rank(x*x')` is `1`:

```
A + x*x'
ans =

     1     1     1     1
     1     2     3     4
     1     3     6    10
     1     4    10    21
```

Instead of computing the Cholesky factor with `R1 = chol(A + x*x')`, we can use `cholupdate`:

```
R1 = cholupdate(R,x)
R1 =

    1.0000    1.0000    1.0000    1.0000
         0    1.0000    2.0000    3.0000
         0         0    1.0000    3.0000
         0         0         0    1.4142
```

Next destroy the positive definiteness (and actually make the matrix singular) by subtracting `1` from the last element of `A`. The downdated matrix is:

```
A - x*x'
ans =


     1     1     1     1
     1     2     3     4
     1     3     6    10
     1     4    10    19
```

Compare `chol` with `cholupdate`:

```
R1 = chol(A-x*x')
??? Error using ==> chol
Matrix must be positive definite.

R1 = cholupdate(R,x,'-')
??? Error using ==> cholupdate
Downdated matrix must be positive definite.
```

However, subtracting `0.5` from the last element of `A` produces a positive definite matrix, and we can use `cholupdate` to compute its Cholesky factor:

```
x = [0 0 0 1/sqrt(2)]';
R1 = cholupdate(R,x,'-')
R1 =
    1.0000    1.0000    1.0000    1.0000
         0    1.0000    2.0000    3.0000
         0         0    1.0000    3.0000
         0         0         0    0.7071
```

Algorithm

`cholupdate` uses the algorithms from the LINPACK subroutines `ZCHUD` and `ZCHDD`. `cholupdate` is useful since computing the new Cholesky factor from scratch is an $O(\mathtt{N}^3)$ algorithm, while simply updating the existing factor in this way is an $O(\mathtt{N}^2)$ algorithm.

References

Dongarra, J.J., J.R. Bunch, C.B. Moler, and G.W. Stewart, *LINPACK Users' Guide*, SIAM, Philadelphia, 1979.

See Also

`chol`, `qrupdate`

Purpose

Create object or return class of object

Syntax

```
str = class(object)
obj = class(s,'class_name')
obj = class(s,'class_name',parent1,parent2...)
```

Description

`str = class(object)` returns a string specifying the class of *object*.

The possible object classes are:

`cell`	Multidimensional cell array
`double`	Multidimensional double precision array
`sparse`	Two-dimensional real (or complex) sparse array
`char`	Array of alphanumeric characters
`struct`	Structure
`'class_name'`	User-defined object class

`obj = class(s,'class_name')` creates an object of class `'class_name'` using structure `s` as a template. This syntax is only valid in a function named `class_name.m` in a directory named `@class_name` (where `'class_name'` is the same as the string passed into `class`).

NOTE On VMS, the method directory is named `#class_name`.

`obj = class(s,'class_name',parent1,parent2,...)` creates an object of class `'class_name'` using structure `s` as a template, and also ensures that the newly created object inherits the methods and fields of the parent objects *parent1*, *parent2*, and so on.

See Also

`inferiorto`, `isa`, `superiorto`

Limitations

`clear` doesn't affect the amount of memory allocated to the MATLAB process under UNIX.

clc

Purpose Clear command window

Syntax `clc`

Description `clc` clears the command window.

Remarks After using `clc`, you still can use the up arrow to see the history of the commands, one at a time.

Examples Display a sequence of random matrices at the same location in the command window:

```
clc
for i =1:25
   home
   A = rand(5)
end
```

See Also `clf`, `home`

Purpose

Remove items from memory

Syntax

```
clear
clear name
clear name1 name2 name3…
clear global name
clear keyword
```

Description

`clear` clears all variables from the workspace.

`clear name` removes just the M-file or MEX-file function or variable `name` from the workspace. A `MATLABPATH` relative partial pathname is permitted. If `name` is global, it is removed from the current workspace, but left accessible to any functions declaring it global. If `name` has been locked by `mlock`, it will remain in memory.

`clear name1 name2 name3` removes `name1`, `name2`, and `name3` from the workspace.

`clear global name` removes the global variable `name`.

`clear keyword` clears the items indicated by `keyword`.

Keyword	Items Cleared
`functions`	Clears all the currently compiled M-functions from memory.
`variables`	Clears all variables from the workspace.
`mex`	Clears all MEX-files from memory.
`global`	Clears all global variables.

`all`	Removes all variables, functions, and MEX-files from memory, leaving the workspace empty.
`classes`	Works the same as `clear all`, but also clears class definitions. If any objects exist outside the workspace (e.g., in userdata or persistent in a locked m-file), a warning will be issued and the class definition will not be cleared. `clear classes` must be used if the number or names of fields in a class are changed.

Remarks

You can use wildcards (*) to remove items selectively. For instance, `clear my*` removes any variables whose names begin with the string "my." The function form of the syntax, `clear('name')`, is also permitted.

Limitations

`clear` does not affect the amount of memory allocated to the MATLAB process under UNIX.

See Also

`mlock`, `munlock`, `pack`

Purpose

Current time as a date vector

Syntax

```
c = clock
```

Description

`c = clock` returns a 6-element date vector containing the current date and time in decimal form:

```
c = [year month day hour minute seconds]
```

The first five elements are integers. The seconds element is accurate to several digits beyond the decimal point. The statement `fix(clock)` rounds to integer display format.

See Also

`cputime`, `datenum`, `datevec`, `etime`, `tic`, `toc`

colmmd

Purpose

Sparse column minimum degree permutation

Syntax

```
p = colmmd(S)
```

Description

`p = colmmd(S)` returns the column minimum degree permutation vector for the sparse matrix `S`. For a nonsymmetric matrix `S`, this is a column permutation `p` such that `S(:,p)` tends to have sparser LU factors than `S`.

The `colmmd` permutation is automatically used by `\` and `/` for the solution of nonsymmetric and symmetric indefinite sparse linear systems.

Use `spparms` to change some options and parameters associated with heuristics in the algorithm.

Algorithm

The minimum degree algorithm for symmetric matrices is described in the review paper by George and Liu [1]. For nonsymmetric matrices, MATLAB's minimum degree algorithm is new and is described in the paper by Gilbert, Moler, and Schreiber [2]. It is roughly like symmetric minimum degree for `A'*A`, but does not actually form `A'*A`.

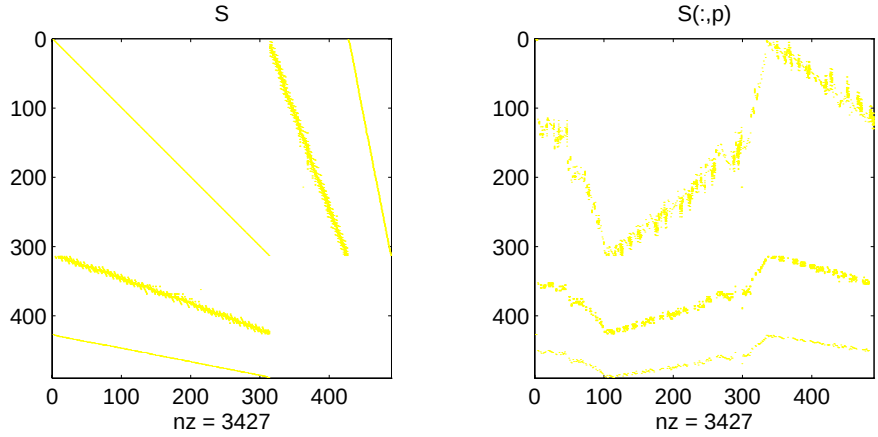
Each stage of the algorithm chooses a vertex in the graph of `A'*A` of lowest degree (that is, a column of `A` having nonzero elements in common with the fewest other columns), eliminates that vertex, and updates the remainder of the graph by adding fill (that is, merging rows). If the input matrix `S` is of size `m`-by-`n`, the columns are all eliminated and the permutation is complete after `n` stages. To speed up the process, several heuristics are used to carry out multiple stages simultaneously.

Examples

The Harwell-Boeing collection of sparse matrices includes a test matrix ABB313. It is a rectangular matrix, of order 313-by-176, associated with least squares adjustments of geodesic data in the Sudan. Since this is a least squares problem, form the augmented matrix (see `spaugment`), which is square and of order 489. The `spy` plot shows that the nonzeros in the original matrix are concentrated in two stripes, which are reflected and supplemented with a scaled identity in the augmented matrix. The `colmmd` ordering scrambles this

structure. (Note that this example requires the Harwell-Boeing collection of software.)

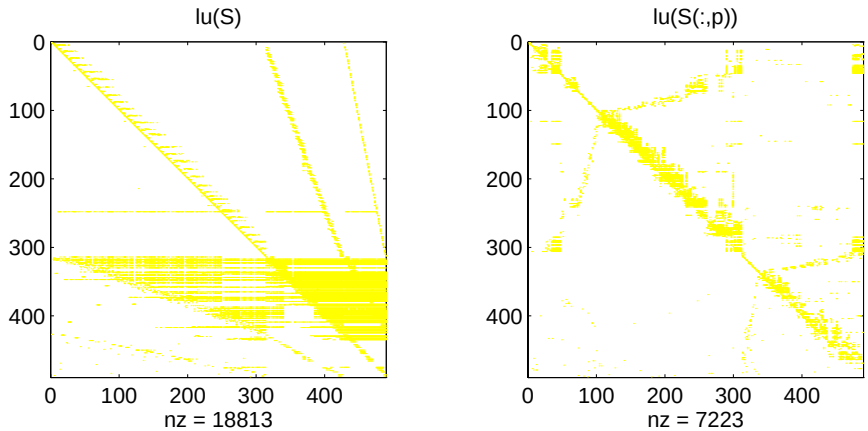
```
load('abb313.mat')
S = spaugment(A);
p = colmmd(S);
spy(S)
spy(S(:,p))
```



Comparing the spy plot of the LU factorization of the original matrix with that of the reordered matrix shows that minimum degree reduces the time and

storage requirements by better than a factor of 2.6. The nonzero counts are 18813 and 7223, respectively.

```
spy(lu(S))
spy(lu(S(:,p)))
```



See Also

`colperm`, `lu`, `spparms`, `symmmd`, `symrcm`

The arithmetic operator \

References

[1] George, Alan and Liu, Joseph, "The Evolution of the Minimum Degree Ordering Algorithm," *SIAM Review*, 1989, 31:1-19,.

[2] Gilbert, John R., Cleve Moler, and Robert Schreiber, "Sparse Matrices in MATLAB: Design and Implementation," *SIAM Journal on Matrix Analysis and Applications 13*, 1992, pp. 333-356.

Purpose

Sparse column permutation based on nonzero count

Syntax

```
j = colperm(S)
```

Description

`j = colperm(S)` generates a permutation vector `j` such that the columns of `S(:,j)` are ordered according to increasing count of nonzero entries. This is sometimes useful as a preordering for LU factorization; in this case use `lu(S(:,j))`.

If `S` is symmetric, then `j = colperm(S)` generates a permutation `j` so that both the rows and columns of `S(j,j)` are ordered according to increasing count of nonzero entries. If `S` is positive definite, this is sometimes useful as a preordering for Cholesky factorization; in this case use `chol(S(j,j))`.

Algorithm

The algorithm involves a sort on the counts of nonzeros in each column.

Examples

The n-by-n *arrowhead* matrix

```
A = [ones(1,n); ones(n-1,1) speye(n-1,n-1)]
```

has a full first row and column. Its LU factorization, `lu(A)`, is almost completely full. The statement

```
j = colperm(A)
```

returns `j = [2:n 1]`. So `A(j,j)` sends the full row and column to the bottom and the rear, and `lu(A(j,j))` has the same nonzero structure as `A` itself.

On the other hand, the Bucky ball example, `B = bucky`,

has exactly three nonzero elements in each row and column, so `j = colperm(B)` is the identity permutation and is no help at all for reducing fill-in with subsequent factorizations.

See Also

`chol`, `colmmd`, `lu`, `symrcm`

compan

Purpose

Companion matrix

Syntax

```
A = compan(u)
```

Description

`A = compan(u)` returns the corresponding companion matrix whose first row is `-u(2:n)/u(1)`, where `u` is a vector of polynomial coefficients. The eigenvalues of `compan(u)` are the roots of the polynomial.

Examples

The polynomial $(x-1)(x-2)(x+3) = x^3 - 7x + 6$ has a companion matrix given by

```
u = [1  0  -7  6]
A = compan(u)
A =
    0    7   -6
    1    0    0
    0    1    0
```

The eigenvalues are the polynomial roots:

```
eig(compan(u))
ans =
    -3.0000
     2.0000
     1.0000
```

This is also `roots(u)`.

See Also

`eig`, `poly`, `polyval`, `roots`

Purpose

Construct complex data from real and imaginary components

Syntax

```
c = complex(a,b)
c = complex(a)
```

Description

`c = complex(a,b)` creates a complex output, `c`, from the two real inputs.

```
c = a + bi
```

The output is the same size as the inputs, which must be equally sized vectors, matrices, or multi-dimensional arrays.

The `complex` function provides a useful substitute for expressions such as

```
a + i*b    or    a + j*b
```

in cases when the names "`i`" and "`j`" may be used for other variables (and do not equal $\sqrt{-1}$), or when `a` and `b` are not double precision.

`c = complex(a)` uses input `a` as the real component of the complex output. The imaginary component is zero.

```
c = a + 0i
```

Example

Create complex `uint8` vector from two real `uint8` vectors.

```
a = uint8([1;2;3;4])
b = uint8([2;2;7;7])

c = complex(a,b)

c =
   1.0000 + 2.0000i
   2.0000 + 2.0000i
   3.0000 + 7.0000i
   4.0000 + 7.0000i
```

See Also

`imag`, `real`

computer

Purpose

Identify the computer on which MATLAB is running

Syntax

```
str = computer
[str,maxsize] = computer
```

Description

`str = computer` returns a string with the computer type on which MATLAB is running.

`[str,maxsize] = computer` returns the integer `maxsize`, which contains the maximum number of elements allowed in an array with this version of MATLAB.

The list of supported computers changes as new computers are added and others become obsolete.

String	Computer
ALPHA	DEC Alpha
AXP_VMSG	Alpha VMS G_float
AXP_VMSIEEE	Alpha VMS IEEE
HP700	HP 9000/700
IBM_RS	IBM RS6000 workstation
LNX86	Linux Intel
PCWIN	MS-Windows
SGI	Silicon Graphics (R4000)
SGI64	Silicon Graphics (R8000)
SOL2	Solaris 2 SPARC workstation
SUN4	Sun4 SPARC workstation
VAX_VMSD	VAX/VMS D_float
VAX_VMSG	VAX/VMS G_float

See Also `isieee`, `isunix`, `isvms`

cond

Purpose

Condition number with respect to inversion

Syntax

```
c = cond(X)
c = cond(X,p)
```

Description

The *condition number* of a matrix measures the sensitivity of the solution of a system of linear equations to errors in the data. It gives an indication of the accuracy of the results from matrix inversion and the linear equation solution. Values of `cond(X)` and `cond(X,p)` near 1 indicate a well-conditioned matrix.

`c = cond(X)` returns the 2-norm condition number, the ratio of the largest singular value of `X` to the smallest.

`c = cond(X,p)` returns the matrix condition number in `p`-norm:

```
norm(X,p) * norm(inv(X),p
```

If *p* is...	**Then `cond(X,p)` returns the...**
`1`	1-norm condition number
`2`	2-norm condition number
`'fro'`	Frobenius norm condition number
`inf`	Infinity norm condition number

Algorithm

The algorithm for `cond` (when `p = 2`) uses the singular value decomposition, `svd`.

See Also

`condeig`, `condest`, `norm`, `rank`, `svd`

References

[1] Dongarra, J.J., J.R. Bunch, C.B. Moler, and G.W. Stewart, *LINPACK Users' Guide*, SIAM, Philadelphia, 1979.

Purpose

Condition number with respect to eigenvalues

Syntax

```
c = condeig(A)
[V,D,s] = condeig(A)
```

Description

`c = condeig(A)` returns a vector of condition numbers for the eigenvalues of `A`. These condition numbers are the reciprocals of the cosines of the angles between the left and right eigenvectors.

`[V,D,s] = condeig(A)` is equivalent to: `[V,D] = eig(A); s = condeig(A);`.

Large condition numbers imply that `A` is near a matrix with multiple eigenvalues.

See Also

`balance`, `cond`, `eig`

condest

Purpose

1-norm matrix condition number estimate

Syntax

```
c = condest(A)
[c,v] = condest(A)
```

Description

`c = condest(A)` uses Higham's modification of Hager's method to estimate the condition number of a matrix. The computed `c` is a lower bound for the condition of `A` in the 1-norm.

`[c,v] = condest(A)` estimates the condition number and also computes a vector `v` such that $\|Av\| = \|A\|\|v\|/c$.

Thus, `v` is an approximate null vector of `A` if `c` is large.

This function handles both real and complex matrices. It is particularly useful for sparse matrices.

See Also

`cond`, `normest`

Reference

[1] Higham, N.J. "Fortran Codes for Estimating the One-Norm of a Real or Complex Matrix, with Applications to Condition Estimation." *ACM Trans. Math. Soft.*, 14, 1988, pp. 381-396.

Purpose Complex conjugate

Syntax `ZC = conj(Z)`

Description `ZC = conj(Z)` returns the complex conjugate of the elements of `Z`.

Algorithm If `Z` is a complex array:

```
conj(Z) = real(Z) – i*imag(Z)
```

See Also `i`, `j`, `imag`, `real`

conv

Purpose

Convolution and polynomial multiplication

Syntax

```
w = conv(u,v)
```

Description

`w = conv(u,v)` convolves vectors `u` and `v`. Algebraically, convolution is the same operation as multiplying the polynomials whose coefficients are the elements of `u` and `v`.

Definition

Let `m = length(u)` and `n = length(v)`. Then `w` is the vector of length `m+n-1` whose kth element is

$$w(k) = \sum_j u(j)v(k+1-j)$$

The sum is over all the values of `j` which lead to legal subscripts for `u(j)` and `v(k+1-j)`, specifically `j = max(1,k+1-n):min(k,m)`. When `m = n`, this gives

```
w(1) = u(1)*v(1)
w(2) = u(1)*v(2)+u(2)*v(1)
w(3) = u(1)*v(3)+u(2)*v(2)+u(3)*v(1)
...
w(n) = u(1)*v(n)+u(2)*v(n-1)+ ... +u(n)*v(1)
...
w(2*n-1) = u(n)*v(n)
```

Algorithm

The convolution theorem says, roughly, that convolving two sequences is the same as multiplying their Fourier transforms. In order to make this precise, it is necessary to pad the two vectors with zeros and ignore roundoff error. Thus, if

`X = fft([x zeros(1,length(y)-1)])` and `Y = fft([y zeros(1,length(x)-1)])`

then `conv(x,y) = ifft(X.*Y)`

See Also

`convmtx` and `xcorr` in the Signal Processing Toolbox, and:

`deconv`, `filter`

Purpose

Two-dimensional convolution

Syntax

```
C = conv2(A,B)
C = conv2(hcol,hrow,A)
C = conv2(...,'shape')
```

Description

`C = conv2(A,B)` computes the two-dimensional convolution of matrices `A` and `B`. If one of these matrices describes a two-dimensional FIR filter, the other matrix is filtered in two dimensions.

The size of `C` in each dimension is equal to the sum of the corresponding dimensions of the input matrices, minus one. That is, if the size of `A` is `[ma,na]` and the size of `B` is `[mb,nb]`, then the size of `C` is `[ma+mb-1,na+nb-1]`.

`C = conv2(hcol,hrow,A)` convolves `A` separably with `hcol` in the column direction and `hrow` in the row direction. `hcol` and `hrow` should both be vectors.

`C = conv2(...,'shape')` returns a subsection of the two-dimensional convolution, as specified by the *shape* parameter:

`full`	Returns the full two-dimensional convolution (default).
`same`	Returns the central part of the convolution of the same size as `A`.
`valid`	Returns only those parts of the convolution that are computed without the zero-padded edges. Using this option, `C` has size `[ma-mb+1,na-nb+1]` when `size(A)` > `size(B)`.

Examples

In image processing, the Sobel edge finding operation is a two-dimensional convolution of an input array with the special matrix

```
s = [1 2 1; 0 0 0; -1 -2 -1];
```

These commands extract the horizontal edges from a raised pedestal:

```
A = zeros(10);
A(3:7,3:7) = ones(5);
H = conv2(A,s);
mesh(H)
```

These commands display first the vertical edges of A, then both horizontal and vertical edges.

```
V = conv2(A,s');
mesh(V)
mesh(sqrt(H.^2+V.^2))
```

See Also

conv, deconv, filter2

Purpose

Convex hull

Syntax

```
K = convhull(x,y)
K = convhull(x,y,TRI)
```

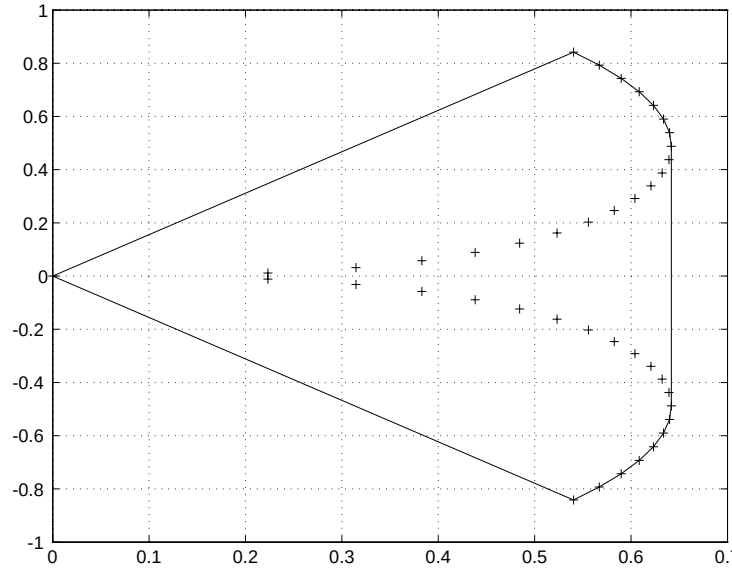
Description

`K = convhull(x,y)` returns indices into the x and y vectors of the points on the convex hull.

`K = convhull(x,y,TRI)` uses the triangulation (as obtained from `delaunay`) instead of computing it each time.

Examples

```
xx = –1:.05:1; yy = abs(sqrt(xx));
[x,y] = pol2cart(xx,yy);
k = convhull(x,y);
plot(x(k),y(k),'r–',x,y,'b+')
```



See Also

`delaunay`, `polyarea`, `voronoi`

convn

Purpose

N-dimensional convolution

Syntax

```
C = convn(A,B)
C = convn(A,B,'shape')
```

Description

`C = convn(A,B)` computes the N-dimensional convolution of the arrays `A` and `B`. The size of the result is `size(A)+size(B)-1`.

`C = convn(A,B,'shape')` returns a subsection of the N-dimensional convolution, as specified by the *shape* parameter:

- `'full'` returns the full N-dimensional convolution (default).
- `'same'` returns the central part of the result that is the same size as `A`.
- `'valid'` returns only those parts of the convolution that can be computed without assuming that the array `A` is zero-padded. The size of the result is

  `max(size(A)-size(B) + 1, 0)`.

See Also

conv, conv2

Purpose

Copy file

Syntax

```
copyfile('source','dest')
copyfile('source','dest','writable')
status = copyfile('source','dest')
[status,msg] = copyfile('source','dest')
```

Description

`copyfile('source','dest')` copies the file `source` to the new file `dest`. `source` and `dest` may be absolute pathnames or pathnames relative to the current directory. The pathname to `dest` must exist, but `dest` cannot be an existing filename in the current directory.

`copyfile('source','dest','writable')` checks that `dest` is writable.

`status = copyfile('source','dest')` returns 1 if the file is copied successfully and 0 otherwise.

`[status,msg] = copyfile('source','dest')` returns a nonempty error message string when an error occurs.

See Also

`delete`, `mkdir`

corrcoef

Purpose

Correlation coefficients

Syntax

```
S = corrcoef(X)
S = corrcoef(x,y)
```

Description

`S = corrcoef(X)` returns a matrix of correlation coefficients calculated from an input matrix whose rows are observations and whose columns are variables. The matrix `S = corrcoef(X)` is related to the covariance matrix `C = cov(X)` by

$$S(i, j) = \frac{C(i, j)}{\sqrt{C(i, i)C(j, j)}}$$

`corrcoef(X)` is the zeroth lag of the covariance function, that is, the zeroth lag of `xcov(x,'coeff')` packed into a square array.

`S = corrcoef(x,y)` where `x` and `y` are column vectors is the same as `corrcoef([x y])`.

See Also

`xcorr`, `xcov` in the Signal Processing Toolbox, and:

`cov`, `mean`, `std`

Purpose

Cosine and hyperbolic cosine

Syntax

```
Y = cos(X)
Y = cosh(X)
```

Description

The cos and cosh functions operate element-wise on arrays. The functions' domains and ranges include complex values. All angles are in radians.

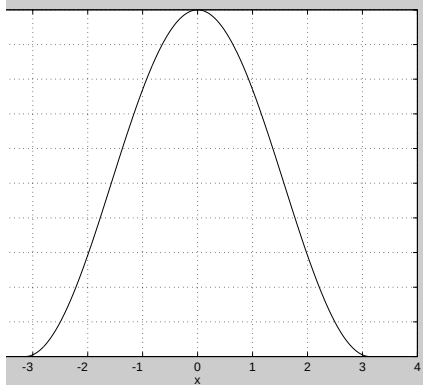
`Y = cos(X)` returns the circular cosine for each element of `X`.

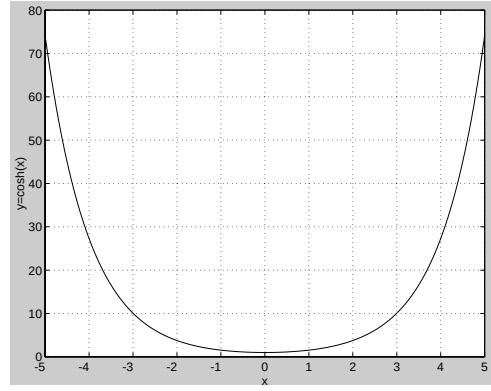
`Y = cosh(X)` returns the hyperbolic cosine for each element of `X`.

Examples

Graph the cosine function over the domain $-\pi \le x \le \pi$, and the hyperbolic cosine function over the domain $-5 \le x \le 5$.

```
x = -pi:0.01:pi; plot(x,cos(x))
x = -5:0.01:5; plot(x,cosh(x))
```





The expression `cos(pi/2)` is not exactly zero but a value the size of the floating-point accuracy, `eps`, because `pi` is only a floating-point approximation to the exact value of π.

Algorithm

$$\cos(x + iy) = \cos(x)\cosh(y) - i\sin(x)\sin(y)$$

$$\cos(z) = \frac{e^{iz} + e^{-iz}}{2}$$

$$\cosh(z) = \frac{e^{z} + e^{-z}}{2}$$

See Also

acos, acosh

cot, coth

Purpose

Cotangent and hyperbolic cotangent

Syntax

```
Y = cot(X)
Y = coth(X)
```

Description

The `cot` and `coth` functions operate element-wise on arrays. The functions' domains and ranges include complex values. All angles are in radians.

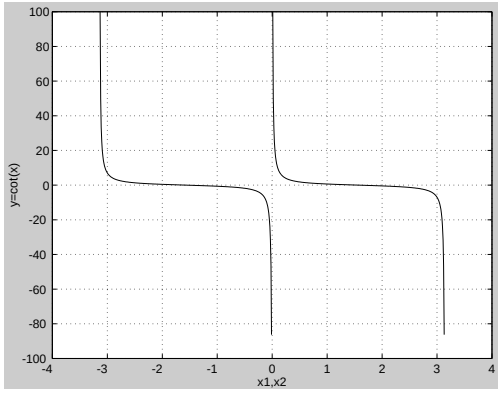
`Y = cot(X)` returns the cotangent for each element of `X`.

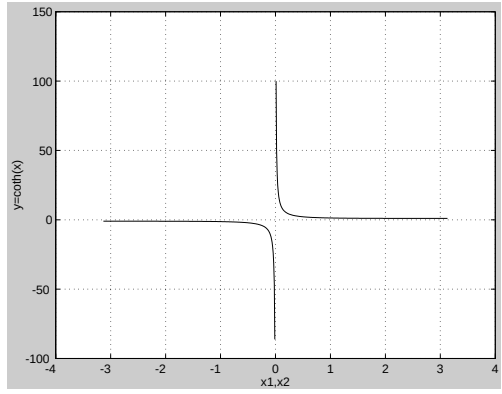
`Y = coth(X)` returns the hyperbolic cotangent for each element of `X`.

Examples

Graph the cotangent and hyperbolic cotangent over the domains $-\pi < x < 0$ and $0 < x < \pi$.

```
x1 = -pi+0.01:0.01:-0.01; x2 = 0.01:0.01:pi-0.01;
plot(x1,cot(x1),x2,cot(x2))
plot(x1,coth(x1),x2,coth(x2))
```





Algorithm

$$\cot(z) = \frac{1}{\tan(z)}$$

$$\coth(z) = \frac{1}{\tanh(z)}$$

See Also

`acot`, `acoth`

Purpose

Covariance matrix

Syntax

```
C = cov(X)
C = cov(x,y)
```

Description

`C = cov(x)` where `x` is a vector returns the variance of the vector elements. For matrices where each row is an observation and each column a variable, `cov(x)` is the covariance matrix. `diag(cov(x))` is a vector of variances for each column, and `sqrt(diag(cov(x)))` is a vector of standard deviations.

`C = cov(x,y)`, where `x` and `y` are column vectors of equal length, is equivalent to `cov([x y])`.

Remarks

cov removes the mean from each column before calculating the result.

The *covariance* function is defined as

$$\mathrm{cov}(x_1,x_2) = E[(x_1-\mu_1)(x_2-\mu_2)]$$

where E is the mathematical expectation and $\mu_i = Ex_i$.

Examples

Consider `A = [-1 1 2 ; -2 3 1 ; 4 0 3]`. To obtain a vector of variances for each column of `A`:

```
v = diag(cov(A))'
v =
   10.3333    2.3333    1.0000
```

Compare vector `v` with covariance matrix `C`:

```
C =
   10.3333   -4.1667    3.0000
   -4.1667    2.3333   -1.5000
    3.0000   -1.5000    1.0000
```

The diagonal elements `C(i,i)` represent the variances for the columns of `A`. The off-diagonal elements `C(i,j)` represent the covariances of columns `i` and `j`.

See Also

xcorr, xcov in the Signal Processing Toolbox, and:

corrcoef, mean, std

cplxpair

Purpose

Sort complex numbers into complex conjugate pairs

Syntax

```
B = cplxpair(A)
B = cplxpair(A,tol)
B = cplxpair(A,[],dim)
B = cplxpair(A,tol,dim)
```

Description

`B = cplxpair(A)` sorts the elements along different dimensions of a complex array, grouping together complex conjugate pairs.

The conjugate pairs are ordered by increasing real part. Within a pair, the element with negative imaginary part comes first. The purely real values are returned following all the complex pairs. The complex conjugate pairs are forced to be exact complex conjugates. A default tolerance of `100*eps` relative to `abs(A(i))` determines which numbers are real and which elements are paired complex conjugates.

If `A` is a vector, `cplxpair(A)` returns `A` with complex conjugate pairs grouped together.

If `A` is a matrix, `cplxpair(A)` returns `A` with its columns sorted and complex conjugates paired.

If `A` is a multidimensional array, `cplxpair(A)` treats the values along the first non-singleton dimension as vectors, returning an array of sorted elements.

`B = cplxpair(A,tol)` overrides the default tolerance.

`B = cplxpair(A,[],dim)` sorts `A` along the dimension specified by scalar dim.

`B = cplxpair(A,tol,dim)` sorts `A` along the specified dimension and overrides the default tolerance.

Diagnostics

If there are an odd number of complex numbers, or if the complex numbers cannot be grouped into complex conjugate pairs within the tolerance, `cplxpair` generates the error message:

```
Complex numbers can't be paired.
```

Purpose

Elapsed CPU time

Syntax

```
cputime
```

Description

`cputime` returns the total CPU time (in seconds) used by MATLAB from the time it was started. This number can overflow the internal representation and wrap around.

Examples

For example

```
t = cputime; surf(peaks(40)); e = cputime-t

e =

     0.4667
```

returns the CPU time used to run `surf(peaks(40))`.

See Also

`clock`, `etime`, `tic`, `toc`

cross

Purpose

Vector cross product

Syntax

```
W = cross(U,V)
W = cross(U,V,dim)
```

Description

`W = cross(U,V)` returns the cross product of the vectors `U` and `V`. That is, `W = U x V`. `U` and `V` are usually 3-element vectors. If `U` and `V` are multidimensional arrays, `cross` returns the cross product of `U` and `V` along the first dimension of length 3.

If `U` and `V` are arrays, `cross(U,V)` treats the first size 3 dimension of `U` and `V` as vectors, returning pages whose columns are cross products.

`W = cross(U,V,dim)` where `U` and `V` are multidimensional arrays, returns the cross product of `U` and `V` in dimension `dim`. `U` and `V` must have the same size, and both `size(U,dim)` and `size(V,dim)` must be 3.

Remarks

To perform a dot (scalar) product of two vectors of the same size, use:

`c = sum(a.*b)` or, if `a` and `b` are row vectors, `c = a.'*b`.

Examples

The cross and dot products of two vectors are calculated as shown:

```
a = [1 2 3]; b = [4 5 6];
c = cross(a,b)

c =

    -3     6    -3

d = sum(a.*b)

d =

    32
```

Purpose

Cosecant and hyperbolic cosecant

Syntax

```
Y = csc(x)
Y = csch(x)
```

Description

The csc and csch functions operate element-wise on arrays. The functions' domains and ranges include complex values. All angles are in radians.

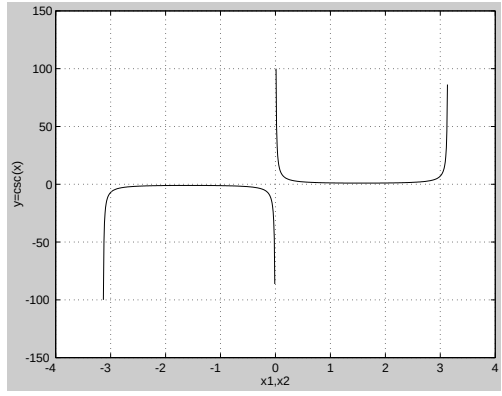
`Y = csc(x)` returns the cosecant for each element of x.

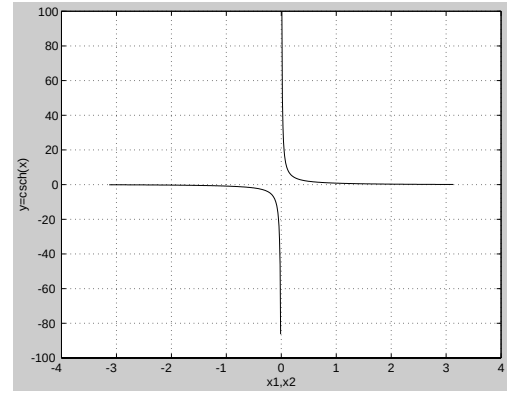
`Y = csch(x)` returns the hyperbolic cosecant for each element of x.

Examples

Graph the cosecant and hyperbolic cosecant over the domains $-\pi < x < 0$ and $0 < x < \pi$.

```
x1 = -pi+0.01:0.01:-0.01; x2 = 0.01:0.01:pi-0.01;
plot(x1,csc(x1),x2,csc(x2))
plot(x1,csch(x1),x2,csch(x2))
```





Algorithm

$$\csc(z) = \frac{1}{\sin(z)}$$

$$\operatorname{csch}(z) = \frac{1}{\sinh(z)}$$

See Also

acsc, acsch

cumprod

Purpose

Cumulative product

Syntax

```
B = cumprod(A)
B = cumprod(A,dim)
```

Description

`B = cumprod(A)` returns the cumulative product along different dimensions of an array.

If `A` is a vector, `cumprod(A)` returns a vector containing the cumulative product of the elements of `A`.

If `A` is a matrix, `cumprod(A)` returns a matrix the same size as `A` containing the cumulative products for each column of `A`.

If `A` is a multidimensional array, `cumprod(A)` works on the first nonsingleton dimension.

`B = cumprod(A,dim)` returns the cumulative product of the elements along the dimension of `A` specified by scalar `dim`. For example, `cumprod(A,1)` increments the first (row) index, thus working along the rows of `A`.

Examples

```
cumprod(1:5)  =  [1  2  6  24  120]

A = [1 2 3; 4 5 6];

disp(cumprod(A))
     1     2     3
     4    10    18

disp(cumprod(A,2))
     1     2     6
     4    20   120
```

See Also

`cumsum`, `prod`, `sum`

Purpose

Cumulative sum

Syntax

```
B = cumsum(A)
B = cumsum(A,dim)
```

Description

`B = cumsum(A)` returns the cumulative sum along different dimensions of an array.

If `A` is a vector, `cumsum(A)` returns a vector containing the cumulative sum of the elements of `A`.

If `A` is a matrix, `cumsum(A)` returns a matrix the same size as `A` containing the cumulative sums for each column of `A`.

If `A` is a multidimensional array, `cumsum(A)` works on the first nonsingleton dimension.

`B = cumsum(A,dim)` returns the cumulative sum of the elements along the dimension of `A` specified by scalar `dim`. For example, `cumsum(A,1)` works across the first dimension (the rows).

Examples

```
cumsum(1:5)  =  [1  3  6  10  15]

A = [1 2 3; 4 5 6];

disp(cumsum(A))
     1     2     3
     5     7     9

disp(cumsum(A,2))
     1     3     6
     4     9    15
```

See Also

`cumprod`, `prod`, `sum`

cumtrapz

Purpose

Cumulative trapezoidal numerical integration

Syntax

```
Z = cumtrapz(Y)
Z = cumtrapz(X,Y)
Z = cumtrapz(... dim)
```

Description

`Z = cumtrapz(Y)` computes an approximation of the cumulative integral of `Y` via the trapezoidal method with unit spacing. (This is similar to `cumsum(Y)`, except that trapezoidal approximation is used.) To compute the integral with other than unit spacing, multiply `Z` by the spacing increment.

For vectors, `cumtrapz(Y)` is the cumulative integral of `Y`.

For matrices, `cumtrapz(Y)` is a row vector with the cumulative integral over each column.

For multidimensional arrays, `cumtrapz(Y)` works across the first nonsingleton dimension.

`Z = cumtrapz(X,Y)` computes the cumulative integral of `Y` with respect to `X` using trapezoidal integration. `X` and `Y` must be vectors of the same length, or `X` must be a column vector and `Y` an array.

If `X` is a column vector and `Y` an array whose first nonsingleton dimension is `length(X)`, `cumtrapz(X,Y)` operates across this dimension.

`Z = cumtrapz(... dim)` integrates across the dimension of `Y` specified by scalar `dim`. The length of `X` must be the same as `size(Y,dim)`.

Example

Example: If `Y = [0 1 2; 3 4 5]`

```
cumtrapz(Y,1)
ans =
         0    1.0000    2.0000
    1.5000    2.5000    3.5000
```

and

```
cumtrapz(Y,2)
ans =
         0    0.5000    2.0000
    3.0000    3.5000    8.0000
```

See Also `cumsum`, `trapz`

date

Purpose Current date string

Syntax `str = date`

Description `str = date` returns a string containing the date in `dd-mmm-yyyy` format.

See Also `clock`, `datenum`, `now`

Purpose

Serial date number

Syntax

```
N = datenum(str)
N = datenum(str,P)
N = datenum(Y,M,D)
N = datenum(Y,M,D,H,MI,S)
```

Description

The `datenum` function converts date strings and date vectors into serial date numbers. Date numbers are serial days elapsed from some reference date. By default, the serial day 1 corresponds to 1-Jan-0000.

`N = datenum(str)` converts the date string *str* into a serial date number. Date strings with two-character years, e.g., `12-june-12`, are assumed to lie within the 100-year period centered about the current year.

NOTE The string *str* must be in one of the date formats `0`, `1`, `2`, `6`, `13`, `14`, `15`, or `16` as defined by `datestr`.

`N = datenum(str,P)` assumes that two-character years lie within the 100-yearperiod beginning with the pivot year p. The default pivot year is the current year minus 50 years.

`N = datenum(Y,M,D)` returns the serial date number for corresponding elements of the `Y`, `M`, and `D` (year, month, day) arrays. `Y`, `M`, and `D` must be arrays of the same size (or any can be a scalar). Values outside the normal range of each array are automatically “carried” to the next unit.

`N = datenum(Y,M,D,H,MI,S)` returns the serial date number for corresponding elements of the `Y`, `M`, `D`, `H`, `MI`, and `S` (year, month, hour, minute, and second) array values. `Y`, `M`, `D`, `H`, `MI`, and `S` must be arrays of the same size (or any can be a scalar).

Examples

Convert a date string to a serial date number.

```
n = datenum('19-May-1995')

n =

      728798
```

Specifying year, month, and day, convert a date to a serial date number.

```
n = datenum(1994,12,19)

n =

      728647
```

Convert a date string to a serial date number using the default pivot year

```
n = datenum('12-june-12')

n =

      735032
```

Convert the same date string to a serial date number using 1900 as the pivot year.

```
n = datenum('12-june-12', 1900)

n =

      698507
```

See Also

`datestr`, `datevec`, `now`

Purpose

Date string format

Syntax

```
str = datestr(D,dateform)
str = datestr(D,dateform,P)
```

Description

`str = datestr(D,dateform)` converts each element of the array of serial date numbers (`D`) to a string. Date strings with two-character years, e.g., `12-june-12`, are assumed to lie within the 100-year period centered about the current year.

`str = datestr(D,dateform,P)` assumes that two-character years lie within the 100-yearperiod beginning with the pivot year p. The default pivot year is the current year minus 50 years.

The optional argument `dateform` specifies the date format of the result. *dateform* can be either a number or a string:

dateform **(number)**	*dateform* **(string)**	**Example**
0	'dd-mmm-yyyy HH:MM:SS'	01-Mar-1995 03:45
1	'dd-mmm-yyyy'	01-Mar-1995
2	'mm/dd/yy'	03/01/95
3	'mmm'	Mar
4	'm'	M
5	'mm'	3
6	'mm/dd'	03/01
7	'dd'	1
8	'ddd'	Wed
9	'd'	W
10	'yyyy'	1995
11	'yy'	95

dateform (number)	*dateform* (string)	Example
12	'mmmyy'	Mar95
13	'HH:MM:SS'	15:45:17
14	'HH:MM:SS PM'	03:45:17 PM
15	'HH:MM'	15:45
16	'HH:MM PM'	03:45 PM
17	'QQ-YY'	Q1-96
18	'QQ'	Q1

NOTE *dateform* numbers 0, 1, 2, 6, 13, 14, 15, and 16 produce a string suitable for input to datenum or datevec. Other date string formats will not work with these functions.

Time formats like 'h:m:s', 'h:m:s.s', 'h:m pm', ... may also be part of the input array D. If you do not specify *dateform*, the date string format defaults to

- 1, if D contains date information only (01-Mar-1995)
- 16, if D contains time information only (03:45 PM)
- 0, if D contains both date and time information (01-Mar-1995 03:45)

See Also date, datenum, datevec

Purpose

Date components

```
C = datevec(A)
C = datevec(A,P)
[Y,M,D,H,MI,S] = datevec(A)
```

Description

`C = datevec(A)` splits its input into an n-by-6 array with each row containing the vector `[Y,M,D,H,MI,S]`. The first five date vector elements are integers. Input `A` can either consist of strings of the sort produced by the `datestr` function, or scalars of the sort produced by the `datenum` and `now` functions. Date strings with two-character years, e.g., `12-june-12`, are assumed to lie within the 100-year period centered about the current year.

`C = datevec(A,P)` assumes that two-character years lie within the 100-yearperiod beginning with the pivot year p. The default pivot year is the current year minus 50 years..

`[Y,M,D,H,MI,S] = datevec(A)` returns the components of the date vector as individual variables.

When creating your own date vector, you need not make the components integers. Any components that lie outside their conventional ranges affect the next higher component (so that, for instance, the anomalous June 31 becomes July 1). A zeroth month, with zero days, is allowed.

Examples

```
datevec('12/24/1984')

ans =

       1984         12         24          0          0          0


t = '725000.00',
```

Then `datevec(d)` and `datevec(t)` generate `[1984 12 24 0 0 0]`.

See Also

`clock`, `datenum`, `datestr`

dbclear

Purpose

Clear breakpoints

Syntax

```
dbclear all
dbclear all in mfile
dbclear in mfile
dbclear in mfile at lineno
dbclear in mfile at subfun
dbclear if error
dbclear if warning
dbclear if naninf
dbclear if infnan
```

Description

`dbclear all` removes all breakpoints in all M-files, as well as pauses set for error, warning, and naninf/infnan using `dbstop`.

`dbclear all in mfile` removes breakpoints in `mfile`.

`dbclear in mfile` removes the breakpoint set at the first executable line in `mfile`.

`dbclear in mfile at lineno` removes the breakpoint set at the line number `lineno` in `mfile`.

`dbclear in mfile at subfun` removes the breakpoint set at the subfunction `subfun` in `mfile`.

`dbclear if error` removes the pause set using `dbstop if error`.

`dbclear if warning` removes the pause set using `dbstop if warning`.

`dbclear if naninf` removes the pause set using `dbstop if naninf`.

`dbclear if infnan` removes the pause set using `dbstop if infnan`.

Remarks

The `at`, `in`, and `if` keywords, familiar to users of the UNIX debugger dbx, are optional.

See Also

`dbcont`, `dbdown`, `dbquit`, `dbstack`, `dbstatus`, `dbstep`, `dbstop`, `dbtype`, `dbup`, `partialpath`

Purpose

Resume execution

Syntax

```
dbcont
```

Description

`dbcont` resumes execution of an M-file from a breakpoint. Execution continues until either another breakpoint is encountered, an error occurs, or MATLAB returns to the base workspace prompt.

See Also

`dbclear`, `dbdown`, `dbquit`, `dbstack`, `dbstatus`, `dbstep`, `dbstop`, `dbtype`, `dbup`

dbdown

Purpose

Change local workspace context

Syntax

```
dbdown
```

Description

`dbdown` changes the current workspace context to the workspace of the called M-file when a breakpoint is encountered. You must have issued the `dbup` command at least once before you issue this command. `dbdown` is the opposite of `dbup`.

Multiple `dbdown` commands change the workspace context to each successively executed M-file on the stack until the current workspace context is the current breakpoint. It is not necessary, however, to move back to the current breakpoint to continue execution or to step to the next line.

See Also

`dbclear`, `dbcont`, `dbquit`, `dbstack`, `dbstatus`, `dbstep`, `dbstop`, `dbtype`, `dbup`

Purpose

Enable MEX-file debugging

Syntax

```
dbmex on
dbmex off
dbmex stop
dbmex print
```

Description

`dbmex on` enables MEX-file debugging for UNIX platforms. To use this option, first start MATLAB from within a debugger by typing: `matlab -Ddebugger`, where `debugger` is the name of the debugger.

`dbmex off` disables MEX-file debugging.

`dbmex stop` returns to the debugger prompt.

`dbmex print` displays MEX-file debugging information.

See Also

`dbclear`, `dbcont`, `dbdown`, `dbquit`, `dbstack`, `dbstatus`, `dbstep`, `dbstop`, `dbtype`, `dbup`

dbquit

Purpose

Quit debug mode

Syntax

```
dbquit
```

Description

`dbquit` immediately terminates the debugger and returns control to the base workspace prompt. The M-file being processed is *not* completed and no results are returned.

All breakpoints remain in effect.

See Also

`dbclear`, `dbcont`, `dbdown`, `dbstack`, `dbstatus`, `dbstep`, `dbstop`, `dbtype`, `dbup`

Purpose

Display function call stack

Syntax

```
dbstack
[ST,I] = dbstack
```

Description

`dbstack` displays the line numbers and M-file names of the function calls that led to the current breakpoint, listed in the order in which they were executed. In other words, the line number of the most recently executed function call (at which the current breakpoint occurred) is listed first, followed by its calling function, which is followed by its calling function, and so on, until the topmost M-file function is reached.

`[ST,I] = dbstack` returns the stack trace information in an `m`-by-`1` structure `ST` with the fields:

`name`	Function name
`line`	Function line number

The current workspace index is returned in `I`.

Examples

```
dbstack

In /usr/local/matlab/toolbox/matlab/cond.m at line 13
  In test1.m at line 2
  In test.m at line 3
```

See Also

`dbclear`, `dbcont`, `dbdown`, `dbquit`, `dbstatus`, `dbstep`, `dbstop`, `dbtype`, `dbup`

dbstatus

Purpose

List all breakpoints

Syntax

```
dbstatus
dbstatus function
s = dbstatus(...)
```

Description

`dbstatus` lists all breakpoints in effect including `error`, `warning`, and `naninf`.

`dbstatus function` displays a list of the line numbers for which breakpoints are set in the specified M-file.

`s = dbstatus(...)` returns the breakpoint information in an `m`-by-`1` structure with the fields:

`name`	Function name
`line`	Function line number
`cond`	Condition string (`error`, `warning`, or `naninf`)

Use `dbstatus class/function` or `dbstatus private/function` or `dbstatus class/private/function` to determine the status for methods, private functions, or private methods (for a class named `class`). In all of these forms you can further qualify the function name with a subfunction name as in `dbstatus function/subfunction`.

See Also

`dbclear`, `dbcont`, `dbdown`, `dbquit`, `dbstack`, `dbstep`, `dbstop`, `dbtype`, `dbup`

Purpose

Execute one or more lines from a breakpoint

Syntax

```
dbstep
dbstep nlines
dbstep in
```

Description

This command allows you to debug an M-file by following its execution from the current breakpoint. At a breakpoint, the `dbstep` command steps through execution of the current M-file one line at a time or at the rate specified by `nlines`.

`dbstep`, by itself, executes the next executable line of the current M-file. `dbstep` steps over the current line, skipping any breakpoints set in functions called by that line.

`dbstep nlines` executes the specified number of executable lines.

`dbstep in` steps to the next executable line. If that line contains a call to another M-file, execution resumes with the first executable line of the called file. If there is no call to an M-file on that line, `dbstep in` is the same as `dbstep`.

See Also

`dbclear`, `dbcont`, `dbdown`, `dbquit`, `dbstack`, `dbstatus`, `dbstop`, `dbtype`, `dbup`

dbstop

Purpose

Set breakpoints in an M-file function

Syntax

```
dbstop in mfile
dbstop in mfile at lineno
dbstop in mfile at subfun
dbstop if error
dbstop if warning
dbstop if naninf
dbstop if infnan
```

Description

`dbstop in mfile` temporarily stops execution of `mfile` when you run it, at the first executable line, putting MATLAB in debug mode. If you have graphical debugging enabled, the MATLAB Debugger opens with a breakpoint at the first executable line of `mfile`. You can then use the debugging utilities, review the workspace, or issue any valid MATLAB command. Use `dbcont` or `dbstep` to resume execution of `mfile`. Use `dbquit` to exit from the Debugger.

`dbstop in mfile at lineno` temporarily stops execution of `mfile` when you run it, just prior to execution of the line whose number is `lineno`, putting MATLAB in debug mode. If you have graphical debugging enabled, the MATLAB Debugger opens `mfile` with a breakpoint at line `lineno`. If that line is not executable, execution stops and the breakpoint is set at the next executable line following `lineno`. When execution stops, you can use the debugging utilities, review the workspace, or issue any valid MATLAB command. Use `dbcont` or `dbstep` to resume execution of `mfile`. Use `dbquit` to exit from the Debugger.

`dbstop in mfile at subfun` temporarily stops execution of `mfile` when you run it, just prior to execution of the subfunction `subfun`, putting MATLAB in debug mode. If you have graphical debugging enabled, the MATLAB Debugger opens `mfile` with a breakpoint at the subfunction specified by `subfun`. You can then use the debugging utilities, review the workspace, or issue any valid MATLAB command. Use `dbcont` or `dbstep` to resume execution of `mfile`. Use `dbquit` to exit from the Debugger.

`dbstop if error` stops execution when any M-file you subsequently run produces a run-time error, putting MATLAB in debug mode, paused at the line

that generated the error. You cannot resume execution after an error. Use `dbquit` to exit from the Debugger.

`dbstop if warning` stops execution when any M-file you subsequently run produces a run-time warning, putting MATLAB in debug mode, paused at the line that generated the warning. Use `dbcont` or `dbstep` to resume execution.

`dbstop if naninf` stops execution when any M-file you subsequently run encounters an infinite value (`Inf`), putting MATLAB in debug mode, paused at the line where `Inf` was encountered. Use `dbcont` or `dbstep` to resume execution. Use `dbquit` to exit from the Debugger.

`dbstop if infnan` stops execution when any M-file you subsequently run encounters a value that is not a number (`NaN`), putting MATLAB in debug mode, paused at the line where `NaN` was encountered. Use `dbcont` or `dbstep` to resume execution. Use `dbquit` to exit from the Debugger.

Remarks

The `at`, `in`, and `if` keywords, familiar to users of the UNIX debugger dbx, are optional.

Examples

The file buggy, used in these examples, consists of three lines.

```
function z = buggy(x)
n = length(x);
z = (1:n)./x;
```

Example 1 – Stop at First Executable Line

The statements

```
dbstop in buggy
buggy(2:5)
```

stop execution at the first executable line in buggy

```
n = length(x);
```

The command

```
dbstep
```

advances to the next line, at which point, you can examine the value of `n`.

Example 2 – Stop if Error

Because buggy only works on vectors, it produces an error if the input x is a full matrix. The statements

```
dbstop if error
buggy(magic(3))
```

produce

```
??? Error using ==> ./
Matrix dimensions must agree.
Error in ==> c:\buggy.m
On line 3 ==> z = (1:n)./x;
K»
```

and put MATLAB in debug mode.

Example 3 – Stop if Inf

In buggy, if any of the elements of the input x are zero, a division by zero occurs. The statements

```
dbstop if naninf
buggy(0:2)
```

produce

```
Warning: Divide by zero.
> In c:\buggy.m at line 3
K»
```

and put MATLAB in debug mode.

See Also

`dbclear`, `dbcont`, `dbdown`, `dbquit`, `dbstack`, `dbstatus`, `dbstep`, `dbtype`, `dbup`, `partialpath`

Purpose

List M-file with line numbers

Syntax

```
dbtype function
dbtype function start:end
```

Description

`dbtype function` displays the contents of the specified M-file function with line numbers preceding each line. `function` must be the name of an M-file function or a `MATLABPATH` relative partial pathname.

`dbtype function start:end` displays the portion of the file specified by a range of line numbers.

See Also

`dbclear`, `dbcont`, `dbdown`, `dbquit`, `dbstack`, `dbstatus`, `dbstep`, `dbstop`, `dbup`, `partialpath`

dbup

Purpose

Change local workspace context

Syntax

```
dbup
```

Description

This command allows you to examine the calling M-file by using any other MATLAB command. In this way, you determine what led to the arguments being passed to the called function.

`dbup` changes the current workspace context (at a breakpoint) to the workspace of the calling M-file.

Multiple `dbup` commands change the workspace context to each previous calling M-file on the stack until the base workspace context is reached. (It is not necessary, however, to move back to the current breakpoint to continue execution or to step to the next line.)

See Also

`dbclear`, `dbcont`, `dbdown`, `dbquit`, `dbstack`, `dbstatus`, `dbstep`, `dbstop`, `dbtype`

Purpose

Numerical double integration

Syntax

```
result = dblquad('fun',inmin,inmax,outmin,outmax)
result = dblquad('fun',inmin,inmax,outmin,outmax,tol,trace)
result = dblquad('fun',inmin,inmax,outmin,outmax,tol,trace,order)
```

Description

`result = dblquad('fun',inmin,inmax,outmin,outmax)` evaluates the double integral *fun*(inner,outer) using the quad quadrature function. `inner` is the inner variable, ranging from `inmin` to `inmax`, and `outer` is the outer variable, ranging from `outmin` to `outmax`. The first argument '*fun*' is a string representing the integrand function. This function must be a function of two variables of the form `fout = fun(inner,outer)`. The function must take a vector `inner` and a scalar `outer` and return a vector `fout` that is the function evaluated at `outer` and each value of `inner`.

`result = dblquad('fun',inmin,inmax,outmin,outmax,tol,trace)` passes `tol` and `trace` to the quad function. See the help entry for quad for a description of the `tol` and `trace` parameters.

`result = dblquad('fun',inmin,inmax,outmin,outmax,tol,trace,order)` passes `tol` and `trace` to the quad or quad8 function depending on the value of the string `order`. Valid values for `order` are `'quad'` and `'quad8'` or the name of any user-defined quadrature method with the same calling and return arguments as quad and quad8.

Example

`result = dblquad('integrnd',pi,2*pi,0,pi)` integrates the function `y*sin(x)+x*cos(y)`, where `x` ranges from π to 2π, and `y` ranges from 0 to π, assuming:

- `x` is the inner variable in the integration.
- `y` is the outer variable.
- the M-file `integrnd.m` is defined as:

```
function out = integrnd(x, y)
out = y*sin(x)+x*cos(y);
```

Note that `integrnd.m` is valid when `x` is a vector and `y` is a scalar. Also, `x` must be the first argument to `integrnd.m` since it is the inner variable.

See Also quad, quad8

Purpose

Set up advisory link

Syntax

```
rc = ddeadv(channel,'item','callback')
rc = ddeadv(channel,'item','callback','upmtx')
rc = ddeadv(channel,'item','callback','upmtx',format)
rc = ddeadv(channel,'item','callback','upmtx',format,timeout)
```

Description

ddeadv sets up an advisory link between MATLAB and a server application. When the data identified by the `item` argument changes, the string specified by the `callback` argument is passed to the `eval` function and evaluated. If the advisory link is a hot link, DDE modifies `upmtx`, the update matrix, to reflect the data in `item`.

If you omit optional arguments that are not at the end of the argument list, you must substitute the empty matrix for the missing argument(s).

Arguments

`rc`	Return code: `0` indicates failure, `1` indicates success.
`channel`	Conversation channel from `ddeinit`.
item	String specifying the DDE item name for the advisory link. Changing the data identified by `item` at the server triggers the advisory link.
callback	String specifying the callback that is evaluated on update notification. Changing the data identified by `item` at the server causes `callback` to get passed to the `eval` function to be evaluated.
upmtx (*optional*)	String specifying the name of a matrix that holds data sent with an update notification. If `upmtx` is included, changing `item` at the server causes `upmtx` to be updated with the revised data. Specifying `upmtx` creates a hot link. Omitting `upmtx` or specifying it as an empty string creates a warm link. If `upmtx` exists in the workspace, its contents are overwritten. If `upmtx` does not exist, it is created.

`format` (*optional*) — Two-element array specifying the format of the data to be sent on update. The first element specifies the Windows clipboard format to use for the data. The only currently supported format is `cf_text`, which corresponds to a value of 1. The second element specifies the type of the resultant matrix. Valid types are `numeric` (the default, which corresponds to a value of `0`) and `string` (which corresponds to a value of `1`). The default format array is `[1 0]`.

`timeout` (*optional*) — Scalar specifying the time-out limit for this operation. `timeout` is specified in milliseconds. (1000 milliseconds = 1 second). If advisory link is not established within `timeout` milliseconds, the function fails. The default value of `timeout` is three seconds.

Examples

Set up a hot link between a range of cells in Excel (Row 1, Column 1 through Row 5, Column 5) and the matrix `x`. If successful, display the matrix:

```
rc = ddeadv(channel, 'r1c1:r5c5', 'disp(x)', 'x');
```

Communication with Excel must have been established previously with a `ddeinit` command.

See Also

`ddeexec`, `ddeinit`, `ddepoke`, `ddereq`, `ddeterm`, `ddeunadv`

Purpose

Send string for execution

Syntax

```
rc = ddeexec(channel,'command')
rc = ddeexec(channel,'command','item')
rc = ddeexec(channel,'command','item',timeout)
```

Description

ddeexec sends a string for execution to another application via an established DDE conversation. Specify the string as the command argument.

If you omit optional arguments that are not at the end of the argument list, you must substitute the empty matrix for the missing argument(s).

Arguments

rc	Return code: 0 indicates failure, 1 indicates success.
channel	Conversation channel from ddeinit.
command	String specifying the command to be executed.
item (*optional*)	String specifying the DDE item name for execution. This argument is not used for many applications. If your application requires this argument, it provides additional information for command. Consult your server documentation for more information.
timeout (*optional*)	Scalar specifying the time-out limit for this operation. timeout is specified in milliseconds. (1000 milliseconds = 1 second). The default value of timeout is three seconds.

Examples

Given the channel assigned to a conversation, send a command to Excel:

```
rc = ddeexec(channel,'[formula.goto("r1c1")]')
```

Communication with Excel must have been established previously with a ddeinit command.

See Also

ddeadv, ddeinit, ddepoke, ddereq, ddeterm, ddeunadv

ddeinit

Purpose

Initiate DDE conversation

Syntax

```
channel = ddeinit('service','topic')
```

Description

`channel = ddeinit('service','topic')` returns a channel handle assigned to the conversation, which is used with other MATLAB DDE functions. '*service*' is a string specifying the service or application name for the conversation. '*topic*' is a string specifying the topic for the conversation.

Examples

To initiate a conversation with Excel for the spreadsheet `'stocks.xls'`:

```
channel = ddeinit('excel','stocks.xls')

channel =
         0.00
```

See Also

`ddeadv`, `ddeexec`, `ddepoke`, `ddereq`, `ddeterm`, `ddeunadv`

Purpose

Send data to application

Syntax

```
rc = ddepoke(channel,'item',data)
rc = ddepoke(channel,'item',data,format)
rc = ddepoke(channel,'item',data,format,timeout)
```

Description

`ddepoke` sends data to an application via an established DDE conversation. `ddepoke` formats the data matrix as follows before sending it to the server application:

- String matrices are converted, element by element, to characters and the resulting character buffer is sent.
- Numeric matrices are sent as tab-delimited columns and carriage-return, line-feed delimited rows of numbers. Only the real part of nonsparse matrices are sent.

If you omit optional arguments that are not at the end of the argument list, you must substitute the empty matrix for the missing argument(s).

Arguments

`rc`	Return code: `0` indicates failure, `1` indicates success.
`channel`	Conversation channel from `ddeinit`.
item	String specifying the DDE item for the data sent. Item is the server data entity that is to contain the data sent in the `data` argument.
`data`	Matrix containing the data to send.
`format` (*optional*)	Scalar specifying the format of the data requested. The value indicates the Windows clipboard format to use for the data transfer. The only format currently supported is `cf_text`, which corresponds to a value of `1`.
`timeout` (*optional*)	Scalar specifying the time-out limit for this operation. `timeout` is specified in milliseconds. (1000 milliseconds = 1 second). The default value of `timeout` is three seconds.

Examples

Assume that a conversation channel with Excel has previously been established with `ddeinit`. To send a 5-by-5 identity matrix to Excel, placing the data in Row 1, Column 1 through Row 5, Column 5:

```
rc = ddepoke(channel, 'r1c1:r5c5', eye(5));
```

See Also

`ddeadv`, `ddeexec`, `ddeinit`, `ddereq`, `ddeterm`, `ddeunadv`

Purpose

Request data from application

Syntax

```
data = ddereq(channel,'item')
data = ddereq(channel,'item',format)
data = ddereq(channel,'item',format,timeout)
```

Description

`ddereq` requests data from a server application via an established DDE conversation. `ddereq` returns a matrix containing the requested data or an empty matrix if the function is unsuccessful.

If you omit optional arguments that are not at the end of the argument list, you must substitute the empty matrix for the missing argument(s).

Arguments

`data`	Matrix containing requested data, empty if function fails.
`channel`	Conversation channel from `ddeinit`.
item	String specifying the server application's DDE item name for the data requested.
`format` (*optional*)	Two-element array specifying the format of the data requested. The first element specifies the Windows clipboard format to use. The only currently supported format is `cf_text`, which corresponds to a value of 1. The second element specifies the type of the resultant matrix. Valid types are `numeric` (the default, which corresponds to `0`) and `string` (which corresponds to a value of `1`). The default format array is `[1 0]`.
`timeout` (*optional*)	Scalar specifying the time-out limit for this operation. `timeout` is specified in milliseconds. (1000 milliseconds = 1 second). The default value of `timeout` is three seconds.

Examples

Assume that we have an Excel spreadsheet `stocks.xls`. This spreadsheet contains the prices of three stocks in row 3 (columns 1 through 3) and the number of shares of these stocks in rows 6 through 8 (column 2). Initiate conversation with Excel with the command:

```
channel = ddeinit('excel','stocks.xls')
```

DDE functions require the r*x*c*y* reference style for Excel worksheets. In Excel terminology the prices are in `r3c1:r3c3` and the shares in `r6c2:r8c2`.

To request the prices from Excel:

```
prices = ddereq(channel,'r3c1:r3c3')

prices =
          42.50       15.00       78.88
```

To request the number of shares of each stock:

```
shares = ddereq(channel, 'r6c2:r8c2')

shares =
         100.00
         500.00
         300.00
```

See Also

ddeadv, ddeexec, ddeinit, ddepoke, ddeterm, ddeunadv

Purpose

Terminate DDE conversation

Syntax

```
rc = ddeterm(channel)
```

Description

`rc = ddeterm(channel)` accepts a channel handle returned by a previous call to `ddeinit` that established the DDE conversation. `ddeterm` terminates this conversation. `rc` is a return code where `0` indicates failure and `1` indicates success.

Examples

To close a conversation channel previously opened with `ddeinit`:

```
rc = ddeterm(channel)

rc =

     1.00
```

See Also

`ddeadv`, `ddeexec`, `ddeinit`, `ddepoke`, `ddereq`, `ddeunadv`

ddeunadv

Purpose

Release advisory link

Syntax

```
rc = ddeunadv(channel,'item')
rc = ddeunadv(channel,'item',format)
rc = ddeunadv(channel,'item',format,timeout)
```

Description

ddeunadv releases the advisory link between MATLAB and the server application established by an earlier ddeadv call. The channel, *item*, and format must be the same as those specified in the call to ddeadv that initiated the link. If you include the timeout argument but accept the default format, you must specify format as an empty matrix.

Arguments

rc	Return code: 0 indicates failure, 1 indicates success.
channel	Conversation channel from ddeinit.
item	String specifying the DDE item name for the advisory link. Changing the data identified by item at the server triggers the advisory link.
format (*optional*)	Two-element array. This must be the same as the format argument for the corresponding ddeadv call.
timeout (*optional*)	Scalar specifying the time-out limit for this operation. timeout is specified in milliseconds. (1000 milliseconds = 1 second). The default value of timeout is three seconds.

Example

To release an advisory link established previously with ddeadv:

```
rc = ddeunadv(channel, 'r1c1:r5c5')
rc =

    1.00
```

See Also

ddeadv, ddeexec, ddeinit, ddepoke, ddereq, ddeterm

Purpose

Deal inputs to outputs

Syntax

```
[Y1,Y2,Y3,...] = deal(X)
[Y1,Y2,Y3,...] = deal(X1,X2,X3,...)
```

Description

`[Y1,Y2,Y3,...] = deal(X)` copies the single input to all the requested outputs. It is the same as `Y1 = X`, `Y2 = X`, `Y3 = X`, ...

`[Y1,Y2,Y3,...] = deal(X1,X2,X3,...)` is the same as `Y1 = X1`; `Y2 = X2`; `Y3 = X3`; ...

Remarks

`deal` is most useful when used with cell arrays and structures via comma separated list expansion. Here are some useful constructions:

`[S.field] = deal(X)` sets all the fields with the name `field` in the structure array `S` to the value `X`. If `S` doesn't exist, use `[S(1:m).field] = deal(X)`.

`[X{:}] = deal(A.field)` copies the values of the field with name `field` to the cell array `X`. If `X` doesn't exist, use `[X{1:m}] = deal(A.field)`.

`[Y1,Y2,Y3,...] = deal(X{:})` copies the contents of the cell array `X` to the separate variables `Y1,Y2,Y3,...`

`[Y1,Y2,Y3,...] = deal(S.field)` copies the contents of the fields with the name `field` to separate variables `Y1,Y2,Y3,...`

Examples

Use deal to copy the contents of a 4-element cell array into four separate output variables.

```
C = {rand(3) ones(3,1) eye(3) zeros(3,1)};
[a,b,c,d] = deal(C{:})

a =

    0.9501   0.4860   0.4565
    0.2311   0.8913   0.0185
    0.6068   0.7621   0.8214

b =

    1
    1
    1

c =

    1   0   0
    0   1   0
    0   0   1

d =

    0
    0
    0
```

Use deal to obtain the contents of all the name fields in a structure array:

```
A.name = 'Pat'; A.number = 176554;
A(2).name = 'Tony'; A(2).number = 901325;
[name1,name2] = deal(A(:).name)

name1 =

Pat

name2 =

Tony
```

deblank

Purpose

Strip trailing blanks from the end of a string

Syntax

```
str = deblank(str)
c = deblank(c)
```

Description

The `deblank` function is useful for cleaning up the rows of a character array.

`str = deblank(str)` removes the trailing blanks from the end of a character string *str*.

`c = deblank(c)`, when `c` is a cell array of strings, applies `deblank` to each element of `c`.

Examples

```
A{1,1} = 'MATLAB    ';
A{1,2} = 'SIMULINK    ';
A{2,1} = 'Toolboxes    ';
A{2,2} = 'The MathWorks    ';

A =

    'MATLAB    '       'SIMULINK    '
    'Toolboxes    '    'The MathWorks    '

deblank(A)

ans =

    'MATLAB'        'SIMULINK'
    'Toolboxes'     'The MathWorks'
```

Purpose

Decimal number to base conversion

Syntax

```
str = dec2base(d,base)
str = dec2base(d,base,n)
```

Description

`str = dec2base(d,base)` converts the nonnegative integer `d` to the specified base.`d` must be a nonnegative integer smaller than 2^52, and `base` must be an integer between 2 and 36. The returned argument `str` is a string.

`str = dec2base(d,base,n)` produces a representation with at least `n` digits.

Examples

The expression `dec2base(23,2)` converts 23_{10} to base 2, returning the string `'10111'`.

See Also

`base2dec`

dec2bin

Purpose

Decimal to binary number conversion

Syntax

```
str = dec2bin(d)
str = dec2bin(d,n)
```

Description

`str = dec2bin(d)` returns the binary representation of `d` as a string. `d` must be a nonnegative integer smaller than 2^{52}.

`str = dec2bin(d,n)` produces a binary representation with at least `n` bits.

Examples

`dec2bin(23)` returns `'10111'`.

See Also

`bin2dec`, `dec2hex`

Purpose

Decimal to hexadecimal number conversion

Syntax

```
str = dec2hex(d)
str = dec2hex(d,n)
```

Description

`str = dec2hex(d)` converts the decimal integer `d` to its hexadecimal representation stored in a MATLAB string. `d` must be a nonnegative integer smaller than 2^{52}.

`str = dec2hex(d,n)` produces a hexadecimal representation with at least `n` digits.

Examples

`dec2hex(1023)` is the string `'3ff'`.

See Also

`dec2bin`, `format`, `hex2dec`, `hex2num`

deconv

Purpose

Deconvolution and polynomial division

Syntax

```
[q,r] = deconv(v,u)
```

Description

`[q,r] = deconv(v,u)` deconvolves vector `u` out of vector `v`, using long division. The quotient is returned in vector `q` and the remainder in vector `r` such that `v = conv(u,q)+r`.

If `u` and `v` are vectors of polynomial coefficients, convolving them is equivalent to multiplying the two polynomials, and deconvolution is polynomial division. The result of dividing `v` by `u` is quotient `q` and remainder `r`.

Examples

If

```
u = [1   2   3   4]
v = [10   20   30]
```

the convolution is

```
c = conv(u,v)
c =
    10     40     100     160     170     120
```

Use deconvolution to recover `u`:

```
[q,r] = deconv(c,u)
q =
    10    20    30
r =
    0      0      0      0      0      0
```

This gives a quotient equal to `v` and a zero remainder.

Algorithm

`deconv` uses the `filter` primitive.

See Also

`convmtx`, `conv2`, and `filter` in the Signal Processing Toolbox, and:

`conv`, `residue`

Purpose

Discrete Laplacian

Syntax

```
L = del2(U)
L = del2(U,h)
L = del2(U,hx,hy)
L = del2(U,hx,hy,hz,...)
```

Definition

If the matrix `U` is regarded as a function $u(x,y)$ evaluated at the point on a square grid, then `4*del2(U)` is a finite difference approximation of Laplace's differential operator applied to u, that is:

$$l = \frac{\nabla^2 u}{4} = \frac{1}{4}\left(\frac{d^2u}{dx^2} + \frac{d^2u}{dy^2}\right)$$

where:

$$l_{ij} = \frac{1}{4}(u_{i+1,\,j} + u_{i-1,\,j} + u_{i,\,j+1} + u_{i,\,j-1}) - u_{i,\,j}$$

in the interior. On the edges, the same formula is applied to a cubic extrapolation.

For functions of more variables $u(x,y,z,...)$, `del2(U)` is an approximation,

$$l = \frac{\nabla^2 u}{2N} = \frac{1}{2N}\left(\frac{d^2u}{dx^2} + \frac{d^2u}{dy^2} + \frac{d^2u}{dz^2} + \cdots\right)$$

where N is the number of variables in u.

del2

Description

`L = del2(U)` where `U` is a rectangular array is a discrete approximation of

$$l = \frac{\nabla^2 u}{4} = \frac{1}{4}\left(\frac{d^2 u}{dx^2} + \frac{d^2 u}{dy^2}\right)$$

The matrix `L` is the same size as `U` with each element equal to the difference between an element of `U` and the average of its four neighbors.

`L = del2(U)` when `U` is an multidimensional array, returns an approximation of

$$\frac{\nabla^2 u}{2N}$$

where N is `ndims(u)`.

`L = del2(U,h)` where `H` is a scalar uses `H` as the spacing between points in each direction (`h=1` by default).

`L = del2(U,hx,hy)` when `U` is a rectangular array, uses the spacing specified by `hx` and `hy`. If `hx` is a scalar, it gives the spacing between points in the x-direction. If `hx` is a vector, it must be of length `size(u,2)` and specifies the x-coordinates of the points. Similarly, if `hy` is a scalar, it gives the spacing between points in the y-direction. If `hy` is a vector, it must be of length `size(u,1)` and specifies the y-coordinates of the points.

`L = del2(U,hx,hy,hz,...)` where `U` is multidimensional uses the spacing given by `hx`, `hy`, `hz`, ...

Examples

The function

$$u(x, y) = x^2 + y^2$$

has

$$\nabla^2 u = 4$$

For this function, `4*del2(U)` is also 4.

```
[x,y] = meshgrid(-4:4,-3:3);
U = x.*x+y.*y
U =
    25    18    13    10     9    10    13    18    25
    20    13     8     5     4     5     8    13    20
    17    10     5     2     1     2     5    10    17
    16     9     4     1     0     1     4     9    16
    17    10     5     2     1     2     5    10    17
    20    13     8     5     4     5     8    13    20
    25    18    13    10     9    10    13    18    25


V = 4*del2(U)
V =
     4     4     4     4     4     4     4     4     4
     4     4     4     4     4     4     4     4     4
     4     4     4     4     4     4     4     4     4
     4     4     4     4     4     4     4     4     4
     4     4     4     4     4     4     4     4     4
     4     4     4     4     4     4     4     4     4
     4     4     4     4     4     4     4     4     4
```

See Also

`diff`, `gradient`

delaunay

Purpose

Delaunay triangulation

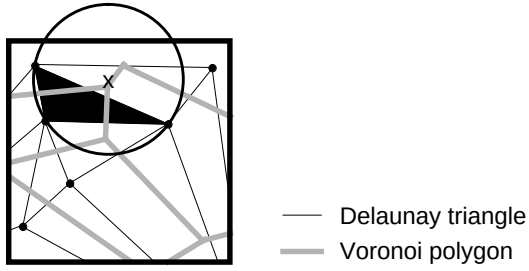
Syntax

```
TRI = delaunay(x,y)

TRI = delaunay(x,y,'sorted')
```

Definition

Given a set of data points, the *Delaunay triangulation* is a set of lines connecting each point to its natural neighbors. The Delaunay triangulation is related to the Voronoi diagram— the circle circumscribed about a Delaunay triangle has its center at the vertex of a Voronoi polygon.



Description

`TRI = delaunay(x,y)` returns a set of triangles such that no data points are contained in any triangle's circumscribed circle. Each row of the `m`-by-3 matrix `TRI` defines one such triangle and contains indices into the vectors `x` and `y`.

To avoid the degeneracy of collinear data, `delaunay` adds some random fuzz to the data. The default fuzz standard deviation `4*sqrt(eps)` has been chosen to maintain about seven digits of accuracy in the data.

`tri = delaunay(x,y,fuzz)` uses the specified value for the fuzz standard deviation. It is possible that no value of `fuzz` produces a correct triangulation. In this unlikely situation, you need to preprocess your data to avoid collinear or nearly collinear data.

`TRI = delaunay(x,y,'sorted')` assumes that the points `x` and `y` are sorted first by `y` and then by `x` and that duplicate points have already been eliminated.

Remarks

The Delaunay triangulation is used with: `griddata` (to interpolate scattered data), `convhull`, `voronoi` (to compute the `voronoi` diagram), and is useful by itself to create a triangular grid for scattered data points.

The functions dsearch and tsearch search the triangulation to find nearest neighbor points or enclosing triangles, respectively.

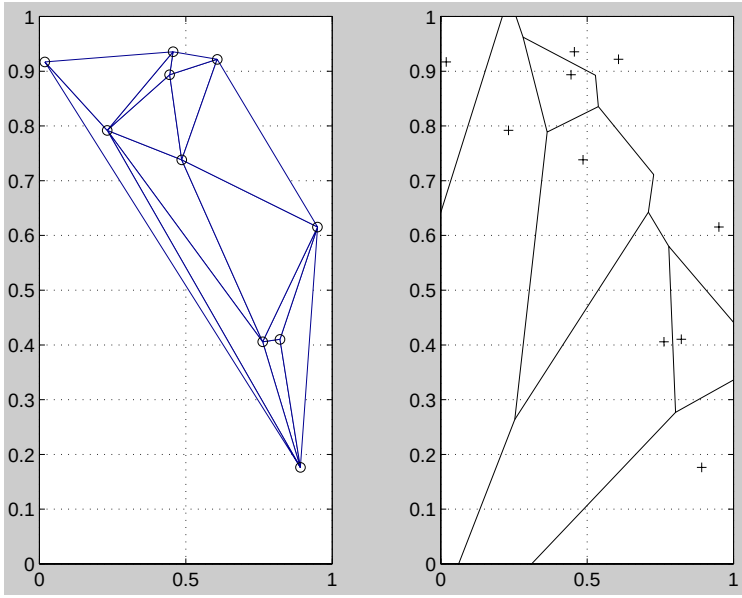
Examples

This code plots the Delaunay triangulation for 10 randomly generated points.

```
rand('state',0);
x = rand(1,10);
y = rand(1,10);
TRI = delaunay(x,y);
subplot(1,2,1),...
trimesh(TRI,x,y,zeros(size(x))); view(2),...
axis([0 1 0 1]); hold on;
plot(x,y,'o');
set(gca,'box','on');
```

Compare the Voronoi diagram of the same points:

```
[vx, vy] = voronoi(x,y,TRI);
subplot(1,2,2),...
plot(x,y,'r+',vx,vy,'b-'),...
axis([0 1 0 1])
```



See Also `convhull`, `dsearch`, `griddata`, `tsearch`, `voronoi`

Purpose

Delete files and graphics objects

Syntax

```
delete filename
delete(h)
```

Description

`delete filename` deletes the named file. Wildcards may be used.

`delete(h)` deletes the graphics object with handle `h`. The function deletes the object without requesting verification even if the object is a window.

Use the functional form of `delete`, such as `delete('filename')`, when the filename is stored in a string.

See Also

`dir`, `type`

det

Purpose

Matrix determinant

Syntax

```
d = det(X)
```

Description

`d = det(X)` returns the determinant of the square matrix `X`. If `X` contains only integer entries, the result `d` is also an integer.

Remarks

Using `det(X) == 0` as a test for matrix singularity is appropriate only for matrices of modest order with small integer entries. Testing singularity using `abs(det(X)) <= tolerance` is not recommended as it is difficult to choose the correct tolerance. The function `cond(X)` can check for singular and nearly singular matrices.

Algorithm

The determinant is computed from the triangular factors obtained by Gaussian elimination

```
[L,U] = lu(A)
s =  det(L)        % This is always +1 or –1
det(A) = s*prod(diag(U))
```

Examples

The statement `A = [1  2  3;  4  5  6;  7  8  9]`

produces

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

This happens to be a singular matrix, so `d = det(A)` produces `d = 0`. Changing `A(3,3)` with `A(3,3) = 0` turns `A` into a nonsingular matrix. Now `d = det(A)` produces `d = 27`.

See Also

`cond`, `condest`, `inv`, `lu`, `rref`

The arithmetic operators `\`, `/`

Purpose

Remove linear trends.

Syntax

```
y = detrend(x)
y = detrend(x,'constant')
y = detrend(x,'linear',bp)
```

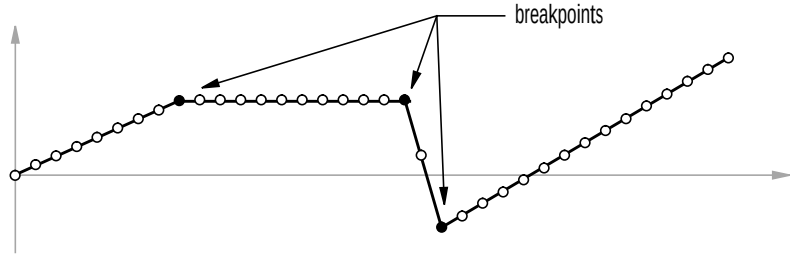
Description

`detrend` removes the mean value or linear trend from a vector or matrix, usually for FFT processing.

`y = detrend(x)` removes the best straight-line fit from vector `x` and returns it in `y`. If `x` is a matrix, `detrend` removes the trend from each column.

`y = detrend(x,'constant')` removes the mean value from vector `x` or, if `x` is a matrix, from each column of the matrix.

`y = detrend(x,'linear',bp)` removes a continuous, piecewise linear trend from vector `x` or, if `x` is a matrix, from each column of the matrix. Vector `bp` contains the indices of the breakpoints between adjacent linear segments. The breakpoint between two segments is defined as the data point that the two segments share.



`detrend(x,'linear')`, with no breakpoint vector specified, is the same as `detrend(x)`.

Example

```
sig = [0 1 -2 1 0 1 -2 1 0];      % signal with no linear trend
trend = [0 1 2 3 4 3 2 1 0];      % two-segment linear trend
x = sig+trend;                    % signal with added trend
y = detrend(x,'linear',5)         % breakpoint at 5th element

y =

   -0.0000
    1.0000
   -2.0000
    1.0000
    0.0000
    1.0000
   -2.0000
    1.0000
   -0.0000
```

Note that the breakpoint is specified to be the fifth element, which is the data point shared by the two segments.

Algorithm

`detrend` computes the least-squares fit of a straight line (or composite line for piecewise linear trends) to the data and subtracts the resulting function from the data. To obtain the equation of the straight-line fit, use `polyfit`.

See Also

`polyfit`

Purpose

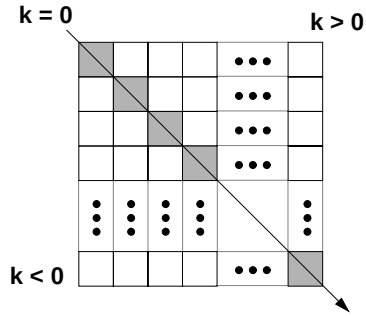
Diagonal matrices and diagonals of a matrix

Syntax

```
X = diag(v,k)
X = diag(v)
v = diag(X,k)
v = diag(X)
```

Description

`X = diag(v,k)` when `v` is a vector of `n` components, returns a square matrix `X` of order `n+abs(k)`, with the elements of `v` on the `k`th diagonal. `k = 0` represents the main diagonal, `k > 0` above the main diagonal, and `k < 0` below the main diagonal.



`X = diag(v)` puts `v` on the main diagonal, same as above with `k = 0`.

`v = diag(X,k)` for matrix `X`, returns a column vector `v` formed from the elements of the `k`th diagonal of `X`.

`v = diag(X)` returns the main diagonal of `X`, same as above with `k = 0`.

Examples

`diag(diag(X))` is a diagonal matrix.

`sum(diag(X))` is the trace of `X`.

The statement

```
diag(-m:m)+diag(ones(2*m,1),1)+diag(ones(2*m,1),-1)
```

produces a tridiagonal matrix of order `2*m+1`.

See Also

`spdiags`, `tril`, `triu`

diary

Purpose

Save session in a disk file

Syntax

```
diary
diary filename
diary off
diary on
```

Description

The `diary` command creates a log of keyboard input and system responses. The output of `diary` is an ASCII file, suitable for printing or for inclusion in reports and other documents.

`diary` toggles `diary` mode on and off.

`diary filename` writes a copy of all subsequent keyboard input and most of the resulting output (but not graphs) to the named file. If the file already exists, output is appended to the end of the file.

`diary off` suspends the diary.

`diary on` resumes diary mode using the current filename, or the default filename `diary` if none has yet been specified.

Remarks

The function form of the syntax, `diary('filename')`, is also permitted.

Limitations

You cannot put a diary into the files named `off` and `on`.

Purpose

Differences and approximate derivatives

Syntax

```
Y = diff(X)
Y = diff(X,n)
Y = diff(X,n,dim)
```

Description

`Y = diff(X)` calculates differences between adjacent elements of `X`.

If `X` is a vector, then `diff(X)` returns a vector, one element shorter than `X`, of differences between adjacent elements:

```
[X(2)-X(1) X(3)-X(2) ... X(n)-X(n-1)]
```

If `X` is a matrix, then `diff(X)` returns a matrix of column differences:

```
[X(2:m,:)-X(1:m-1,:)]
```

In general, `diff(X)` returns the differences calculated along the first non-singleton (`size(X,dim) > 1`) dimension of `X`.

`Y = diff(X,n)` applies `diff` recursively *n* times, resulting in the nth difference. Thus, `diff(X,2)` is the same as `diff(diff(X))`.

`Y = diff(X,n,dim)` is the nth difference function calculated along the dimension specified by scalar `dim`. If order *n* equals or exceeds the length of dimension `dim`, `diff` returns an empty array.

Remarks

Since each iteration of `diff` reduces the length of `X` along dimension `dim`, it is possible to specify an order *n* sufficiently high to reduce `dim` to a singleton (`size(X,dim) = 1`) dimension. When this happens, `diff` continues calculating along the next nonsingleton dimension.

Examples

The quantity `diff(y)./diff(x)` is an approximate derivative.

```
x = [1 2 3 4 5];
y = diff(x)
y =
     1     1     1     1

z = diff(x,2)
z =
     0     0     0
```

Given,

```
A = rand(1,3,2,4);
```

`diff(A)` is the first-order difference along dimension 2.

`diff(A,3,4)` is the third-order difference along dimension 4.

See Also

`gradient`, `prod`, `sum`

Purpose

Directory listing

Syntax

```
dir
dir dirname
names = dir
names = dir('dirname')
```

Description

`dir` lists the files in the current directory.

`dir dirname` lists the files in the specified directory. You can use pathnames and wildcards.

`names = dir('dirname')` returns the list of files in the specified directory (or the current directory if `dirname` is not specified) to an `m`-by-`1` structure with the fields:

`name`	Filename
`date`	Modification date
`bytes`	Number of bytes allocated to the file
`isdir`	`1` if name is a directory; `0` if not

Examples

```
cd /Matlab/Toolbox/Local; dir

Contents.m matlabrc.m siteid.m userpath.m

names = dir

names =

4x1 struct array with fields:
    name
    date
    bytes
    isdir
```

See Also

`cd`, `delete`, `ls`, `type`, `what`

disp

Purpose

Display text or array

Syntax

```
disp(X)
```

Description

`disp(X)` displays an array, without printing the array name. If `X` contains a text string, the string is displayed.

Another way to display an array on the screen is to type its name, but this prints a leading "`X =`," which is not always desirable.

Examples

One use of `disp` in an M-file is to display a matrix with column labels:

```
disp('         Corn          Oats          Hay')
disp(rand(5,3))
```

which results in

```
    Corn         Oats         Hay
  0.2113       0.8474       0.2749
  0.0820       0.4524       0.8807
  0.7599       0.8075       0.6538
  0.0087       0.4832       0.4899
  0.8096       0.6135       0.7741
```

See Also

`format`, `int2str`, `num2str`, `rats`, `sprintf`

Purpose

Read an ASCII delimited file into a matrix

Syntax

```
M = dlmread(filename,delimiter)
M = dlmread(filename,delimiter,r,c)
M = dlmread(filename,delimiter,range)
```

Description

`M = dlmread(filename,delimiter)` reads data from the ASCII delimited format `filename`, using the delimiter `delimiter`. A comma (,) is the default delimiter. Use `'\t'` to specify a tab delimiter.

`M = dlmread(filename,delimiter,r,c)` reads data from the ASCII delimited format `filename`, using the delimiter `delimiter`, starting at file offset `r` and `c`, where `r` is the row offset and `c` is the column offset. `r` and `c` are zero based so that `r=0`, `c=0` specifies the first value in the file, which is the upper left corner. A comma (,) is the default delimiter. Use `'\t'` to specify a tab delimiter.

`M = dlmread(filename,delimiter,range)` imports an indexed or named range of ASCII-delimited data, using the delimiter `delimiter`. A comma (,) is the default delimiter. Use `'\t'` to specify a tab delimiter. Specify `range` by

```
range = [UpperLeftRow UpperLeftColumn LowerRightRow
LowerRightColumn]
```

or using spreadsheet notation, for example,

```
range = 'a1..b7'
```

Remarks

`dlmread` fills empty delimited fields with zero. Data files having lines that end with a non-space delimiter produce a result that has an additional last column of zeros.

See Also

`dlmwrite`, `textread`, `wk1read`, `wk1write`

dlmwrite

Purpose

Write a matrix to an ASCII delimited file

Syntax

```
dlmwrite(filename,A,delimiter)
dlmwrite(filename,A,delimiter,r,c)
```

Description

The `dlmwrite` command a MATLAB matrix.

`dlmwrite(filename,A,delimiter)` converts matrix `A` into an ASCII-format file, readable by spreadsheet programs. The data is written to the upper left-most cell of the spreadsheet `filename`, using `delimiter` to separate matrix elements. A comma (,) is the default delimiter. Use `'\t'` to produce tab-delimited files.

`dlmwrite(filename,A,delimiter,r,c)` converts matrix `A` into an ASCII-format file, readable by spreadsheet programs, using `delimiter` to separate matrix elements. The data is written to the spreadsheet `filename`, starting at spreadsheet cell `r` and `c`, where `r` is the row offset and `c` is the column offset.`r` and `c` are zero based so that `r=0`, `c=0` specifies the first value in the file, which is the upper left corner. A comma (,) is the default delimiter. Use `'\t'` to specify a tab delimiter.

Remarks

Any elements whose value is 0 will be omitted. For example, the array `[1 0 2]` will appear in a file as `'1,,2'` when the delimiter is a comma.

See Also

`dlmread`, `wk1read`, `wk1write`

Purpose

Dulmage-Mendelsohn decomposition

Syntax

```
p = dmperm(A)
[p,q,r] = dmperm(A)
[p,q,r,s] = dmperm(A)
```

Description

If A is a reducible matrix, the linear system $Ax = b$ can be solved by permuting A to a block upper triangular form, with irreducible diagonal blocks, and then performing block backsubstitution. Only the diagonal blocks of the permuted matrix need to be factored, saving fill and arithmetic in the blocks above the diagonal.

`p = dmperm(A)` returns a row permutation `p` so that if `A` has full column rank, `A(p,:)` is square with nonzero diagonal. This is also called a *maximum matching*.

`[p,q,r] = dmperm(A)` where `A` is a square matrix, finds a row permutation `p` and a column permutation `q` so that `A(p,q)` is in block upper triangular form. The third output argument `r` is an integer vector describing the boundaries of the blocks: The kth block of `A(p,q)` has indices `r(k):r(k+1)-1`.

`[p,q,r,s] = dmperm(A)`, where `A` is not square, finds permutations `p` and `q` and index vectors `r` and `s` so that `A(p,q)` is block upper triangular. The blocks have indices `(r(i):r(i+1)-1, s(i):s(i+1)-1)`.

In graph theoretic terms, the diagonal blocks correspond to strong Hall components of the adjacency graph of `A`.

doc

Purpose

Display HTML documentation in a Web browser

Syntax

```
doc
doc function
doc toolbox/function
```

Description

`doc` launches the Help Desk.

`doc function` displays the HTML documentation for the MATLAB function `function`. If `function` is overloaded, `doc` lists the overloaded functions in the MATLAB command window.

`doc toolbox/function` displays the HTML documentation for the specified toolbox function.

See Also

`help`, `helpdesk`, `helpwin`, `lookfor`, `type`

Purpose

Display location of help file directory for UNIX platforms

Syntax

```
docopt
[doccmd,options,docpath]=docopt
```

Description

`docopt` displays the location of the online help file directory. It is used for UNIX platforms only. (For the PC, select **Preferences** from the **File** menu to view or change the online help file directory location.) You specify where the online help information will be located when you install MATLAB. It can be on a disk or CD-ROM in your local system. If you relocate your online help file directory, edit the `docopt.m` file, changing the location in it.

`[doccmd,options,docpath]=docopt` displays three strings: `doccmd`, `options`, and `docpath`.

`doccmd`	The command that `doc` uses to display MATLAB documentation. The default is `netscape`.
`options`	Additional configuration options for use with `doccmd`.
`docpath`	The path to the MATLAB online help files. If `docpath` is empty, the DOC command assumes the help files are in the default location.

Remarks

To globally replace the online help file directory location, update `$MATLAB/toolbox/local/docopt.m`.

To override the global setting, copy `$MATLAB/toolbox/local/docopt.m` to `$HOME/matlab/docopt.m` and make changes there. For the changes to take effect in the current MATLAB session, `$HOME/matlab` must be on your MATLAB path.

See Also

`doc`, `help`, `helpdesk`, `helpwin`, `lookfor`, `type`

double

Purpose

Convert to double precision

Syntax

```
double(X)
```

Description

`double(x)` returns the double precision value for `X`. If `X` is already a double precision array, `double` has no effect.

Remarks

`double` is called for the expressions in `for`, `if`, and `while` loops if the expression isn't already double precision. `double` should be overloaded for any object when it makes sense to convert it to a double precision value.

Purpose

Search for nearest point

Syntax

```
K = dsearch(x,y,TRI,xi,yi)
K = dsearch(x,y,TRI,xi,yi,S)
```

Description

`K = dsearch(x,y,TRI,xi,yi)` returns the index of the nearest (x,y) point to the point (xi,yi). `dsearch` requires a triangulation `TRI` of the points `x,y` obtained from `delaunay`.

`K = dsearch(x,y,TRI,xi,yi,S)` uses the sparse matrix `S` instead of computing it each time:

```
S = sparse(TRI(:,[1 1 2 2 3 3]),TRI(:,[2 3 1 3 1 2]),1,nxy,nxy)
```

where `nxy = prod(size(x))`.

See Also

`delaunay`, `tsearch`, `voronoi`

echo

Purpose

Echo M-files during execution

Syntax

```
echo on
echo off
echo
echo fcnname on
echo fcnname off
echo fcnname
echo on all
echo off all
```

Description

The echo command controls the echoing of M-files during execution. Normally, the commands in M-files do not display on the screen during execution. Command echoing is useful for debugging or for demonstrations, allowing the commands to be viewed as they execute.

The echo command behaves in a slightly different manner for script files and function files. For script files, the use of echo is simple; echoing can be either on or off, in which case any script used is affected:

`echo on`	Turns on the echoing of commands in all script files.
`echo off`	Turns off the echoing of commands in all script files.
`echo`	Toggles the echo state.

With function files, the use of echo is more complicated. If echo is enabled on a function file, the file is interpreted, rather than compiled. Each input line is then displayed as it is executed. Since this results in inefficient execution, use echo only for debugging.

`echo` *fcnname* `on`	Turns on echoing of the named function file.
`echo` *fcnname* `off`	Turns off echoing of the named function file.
`echo` *fcnname*	Toggles the echo state of the named function file.
`echo on all`	Set echoing on for all function files.
`echo off all`	Set echoing off for all function files.

See Also

`function`

Purpose

Edit an M-file

Syntax

```
edit
edit fun
edit file.ext
edit class/fun
edit private/fun
edit class/private/fun
```

Description

`edit` opens a new editor window.

`edit fun` opens the M-file `fun.m` in the default editor.

`edit file.ext` opens the specified text file.

`edit class/fun`, `edit private/fun`, or `edit class/private/fun` can be used to edit a method, private function, or private method (for the class named `class`).

Remarks

PC Users

You also can start MATLAB's Editor/Debugger by selecting **New** or **Open** from the **File** menu, or by clicking the new (page icon) button or the open (folder icon) button on the toolbar.

Specify the default editor for MATLAB in the Command Window. Select **Preferences** from the **File** menu. On the **General** page, select MATLAB's Editor/Debugger or specify another.

UNIX Users

At the time when MATLAB is installed, you specify the default editor. To change the setting, edit your `~home/.Xdefaults` file. If the MATLAB Editor is the default, turn it off in the `.Xdefaults` file.

```
matlab*builtInEditor: Off
matlab*graphicalDebugger: Off
```

Then before starting MATLAB, run

```
xrdb –merge ~home/.Xdefaults
```

If you set the Editor `Off`, use the option

```
matlab*externalEditorCommand: $EDITOR $FILE &
```

to control what the `edit` command does. MATLAB substitutes `$EDITOR` with the name of your default editor and `$FILE` with the filename. This option can be modified to any sort of command line you want.

For information about saving Editor options and turning off the Editor during a MATLAB session, see the "UNIX Handbook" section in Chapter 2 of *Using MATLAB*.

Purpose

Find eigenvalues and eigenvectors

Syntax

```
d = eig(A)
[V,D] = eig(A)
[V,D] = eig(A,'nobalance')
d = eig(A,B)
[V,D] = eig(A,B)
```

Description

`d = eig(A)` returns a vector of the eigenvalues of matrix `A`.

`[V,D] = eig(A)` produces matrices of eigenvalues (`D`) and eigenvectors (`V`) of matrix `A`, so that `A*V = V*D`. Matrix `D` is the *canonical form* of `A`—a diagonal matrix with `A`'s eigenvalues on the main diagonal. Matrix `V` is the *modal matrix*—its columns are the eigenvectors of `A`.

The eigenvectors are scaled so that the norm of each is 1.0. Use `[W,D] = eig(A'); W = W'` to compute the *left eigenvectors*, which satisfy `W*A = D*W`.

`[V,D] = eig(A,'nobalance')` finds eigenvalues and eigenvectors without a preliminary balancing step. Ordinarily, balancing improves the conditioning of the input matrix, enabling more accurate computation of the eigenvectors and eigenvalues. However, if a matrix contains small elements that are really due to roundoff error, balancing may scale them up to make them as significant as the other elements of the original matrix, leading to incorrect eigenvectors. Use the `nobalance` option in this event. See the `balance` function for more details.

`d = eig(A,B)` returns a vector containing the generalized eigenvalues, if `A` and `B` are square matrices.

`[V,D] = eig(A,B)` produces a diagonal matrix `D` of generalized eigenvalues and a full matrix `V` whose columns are the corresponding eigenvectors so that `A*V = B*V*D`. The eigenvectors are scaled so that the norm of each is 1.0.

Remarks

The eigenvalue problem is to determine the nontrivial solutions of the equation:

$$Ax = \lambda x$$

where A is an n-by-n matrix, x is a length n column vector, and λ is a scalar. The n values of λ that satisfy the equation are the *eigenvalues*, and the corresponding values of x are the *right eigenvectors*. In MATLAB, the function eig solves for the eigenvalues λ, and optionally the eigenvectors x.

The *generalized* eigenvalue problem is to determine the nontrivial solutions of the equation

$$Ax = \lambda Bx$$

where both A and B are n-by-n matrices and λ is a scalar. The values of λ that satisfy the equation are the *generalized eigenvalues* and the corresponding values of x are the *generalized right eigenvectors*.

If B is nonsingular, the problem could be solved by reducing it to a standard eigenvalue problem

$$B^{-1}Ax = \lambda x$$

Because B can be singular, an alternative algorithm, called the QZ method, is necessary.

When a matrix has no repeated eigenvalues, the eigenvectors are always independent and the eigenvector matrix V *diagonalizes* the original matrix A if applied as a similarity transformation. However, if a matrix has repeated eigenvalues, it is not similar to a diagonal matrix unless it has a full (independent) set of eigenvectors. If the eigenvectors are not independent then the original matrix is said to be *defective*. Even if a matrix is defective, the solution from eig satisfies A*X = X*D.

Examples

The matrix

```
B = [3 -2 -.9 2*eps;-2 4 -1 -eps;-eps/4 eps/2 -1 0;-.5  -.5 .1 1];
```

has elements on the order of roundoff error. It is an example for which the nobalance option is necessary to compute the eigenvectors correctly. Try the statements

```
[VB,DB] = eig(B)
B*VB - VB*DB
[VN,DN] = eig(B,'nobalance')
B*VN - VN*DN
```

Algorithm

For real matrices, `eig(X)` uses the EISPACK routines `BALANC`, `BALBAK`, `ORTHES`, `ORTRAN`, and `HQR2`. `BALANC` and `BALBAK` balance the input matrix. `ORTHES` converts a real general matrix to Hessenberg form using orthogonal similarity transformations. `ORTRAN` accumulates the transformations used by `ORTHES`. `HQR2` finds the eigenvalues and eigenvectors of a real upper Hessenberg matrix by the QR method. The EISPACK subroutine `HQR2` is modified to make computation of eigenvectors optional.

When `eig` is used with two input arguments, the EISPACK routines `QZHES`, `QZIT`, `QZVAL`, and `QZVEC` solve for the generalized eigenvalues via the QZ algorithm. Modifications handle the complex case.

When `eig` is used with one complex argument, the solution is computed using the QZ algorithm as `eig(X,eye(X))`. Modifications to the QZ routines handle the special case $B = I$.

For detailed descriptions of these algorithms, see the *EISPACK Guide*.

Diagnostics

If the limit of 30n iterations is exhausted while seeking an eigenvalue:

```
Solution will not converge.
```

See Also

`balance`, `condeig`, `hess`, `qz`, `schur`

References

[1] Smith, B. T., J. M. Boyle, J. J. Dongarra, B. S. Garbow, Y. Ikebe, V. C. Klema, and C. B. Moler, *Matrix Eigensystem Routines – EISPACK Guide*, Lecture Notes in Computer Science, Vol. 6, second edition, Springer-Verlag, 1976.

[2] Garbow, B. S., J. M. Boyle, J. J. Dongarra, and C. B. Moler, *Matrix Eigensystem Routines – EISPACK Guide Extension*, Lecture Notes in Computer Science, Vol. 51, Springer-Verlag, 1977.

[3] Moler, C. B. and G.W. Stewart, "An Algorithm for Generalized Matrix Eigenvalue Problems", *SIAM J. Numer. Anal.*, Vol. 10, No. 2, April 1973.

eigs

Purpose

Find a few eigenvalues and eigenvectors

Syntax

```
d = eigs(A)
d = eigs('Afun',n)
d = eigs(A,B,k,sigma,options)
d = eigs('Afun',n,B,k,sigma,options)
[V,D] = eigs(A,...)
[V,D] = eigs('Afun',n,...)
[V,D,flag] = eigs(A,...)
[V,D,flag] = eigs('Afun',n,...)
```

Description

`eigs` solves the eigenvalue problem `A*v = lambda*v` or the generalized eigenvalue problem `A*v = lambda*B*v`, where `B` is symmetric positive definite. Only a few selected eigenvalues, or eigenvalues and eigenvectors, are computed, in contrast to `eig`, which computes all eigenvalues and eigenvectors.

`eigs(A)` or `eigs('Afun',n)` solves the eigenvalue problem where the first input argument is either a square matrix (which can be full or sparse, symmetric or nonsymmetric, real or complex), or a string containing the name of an M-file which applies a linear operator to the columns of a given matrix. In the latter case, the second input argument must be `n`, the order of the problem. For example, `eigs('fft', ...)` is much faster than `eigs(F, ...)`, where `F` is the explicit FFT matrix.

With one output argument, `d` is a vector containing `k` eigenvalues.With two output arguments, `V` is a matrix with `k` columns and `D` is a `k`-by-`k` diagonal matrix so that `A*V = V*D` or `A*V = B*V*D`. With three output arguments, `flag` indicates whether or not the eigenvalues were computed to the desired tolerance. `flag = 0` indicates convergence; `flag = 1` indicates no convergence.

The remaining input arguments are optional and can be given in practically any order:

Argument	Value
B	A matrix the same size as A. If B is not specified, B = eye(size(A)) is used. B must be a symmetric positive definite matrix.
k	An integer, the number of eigenvalues desired. If k is not specified, k = min(n,6) eigenvalues are computed.
sigma	A scalar shift or a two letter string. If sigma is not specified, the k eigenvalues largest in magnitude are computed. If sigma is 0, the k eigenvalues smallest in magnitude are computed. If sigma is a real or complex scalar, the *shift*, the k eigenvalues nearest sigma, are computed. If sigma is one of the following strings, it specifies the desired eigenvalues: 'lm' Largest Magnitude (the default) 'sm' Smallest Magnitude (same as sigma = 0) 'lr' Largest Real part 'sr' Smallest Real part 'be' Both Ends. Computes k/2 eigenvalues from each end of the spectrum (one more from the high end if k is odd.)

Note 1. If sigma is a scalar with no fractional part, k must be specified first. For example, eigs(A,2.0) finds the two largest magnitude eigenvalues, not the six eigenvalues closest to 2.0, as you may have wanted.
Note 2. If sigma is exactly an eigenvalue of A, eigs will encounter problems when it performs divisions of the form 1/(lambda – sigma), where lambda is an approximation of an eigenvalue of A. Restart with eigs(A,sigma2), where sigma2 is close to, but not equal to, sigma.

The options structure specifies certain parameters in the algorithm.

Parameter	Description	Default Value
options.tol	Convergence tolerance norm(A*V–V*D) <= tol*norm(A)	1e–10 (symmetric) 1e–6 (nonsymmetric)
options.p	Dimension of the Arnoldi basis	2*k
options.maxit	Maximum number of iterations	300
options.disp	Number of eigenvalues displayed at each iteration. Set to 0 for no intermediate output.	20
options.issym	Positive if Afun is symmetric	0
options.cheb	Positive if A is a string, sigma is 'lr','sr', or a shift, and polynomial acceleration should be applied.	0
options.v0	Starting vector for the Arnoldi factorization	rand(n,1)–.5

Remarks

`d = eigs(A,k)` is not a substitute for

```
d = eig(full(A))
d = sort(d)
d = d(end–k+1:end)
```

but is most appropriate for large sparse matrices. If the problem fits into memory, it may be quicker to use `eig(full(A))`.

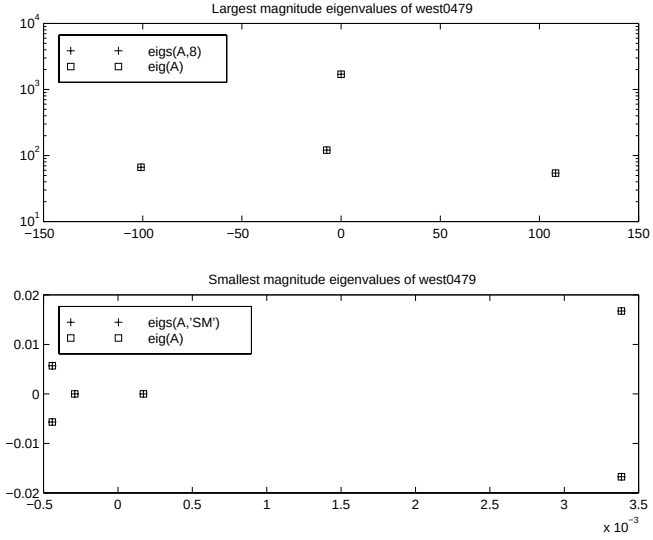
Examples

Example 1:

`west0479` is a real 479-by-479 sparse matrix with both real and pairs of complex conjugate eigenvalues. `eig` computes all 479 eigenvalues. `eigs` easily picks out the smallest and largest magnitude eigenvalues.

```
load west0479
d = eig(full(west0479))
dlm = eigs(west0479,8)
dsm = eigs(west0479,'sm')
```

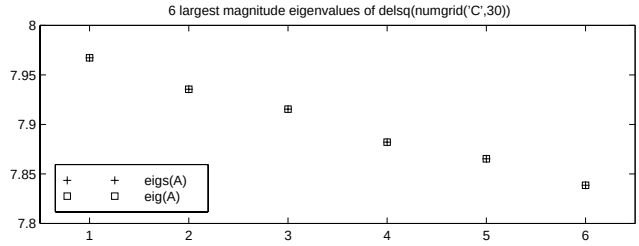
These plots show the eigenvalues of `west0479` as computed by `eig` and `eigs`. The first plot shows the four largest magnitude eigenvalues in the top half of the complex plane (but not their complex conjugates in the bottom half). The second subplot shows the six smallest magnitude eigenvalues.

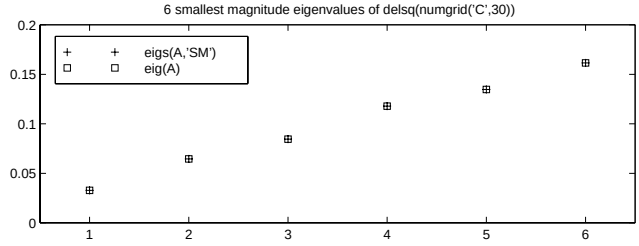


Example 2:

`A = delsq(numgrid('C',30))` is a symmetric positive definite matrix of size 632 with eigenvalues reasonably well-distributed in the interval (0 8), but with 18 eigenvalues repeated at 4. `eig` computes all 632 eigenvalues. `eigs` computes the six largest and smallest magnitude eigenvalues of `A` successfully with:

```
d = eig(full(A))
dlm = eigs(A)
dsm = eigs(A,'sm')
```

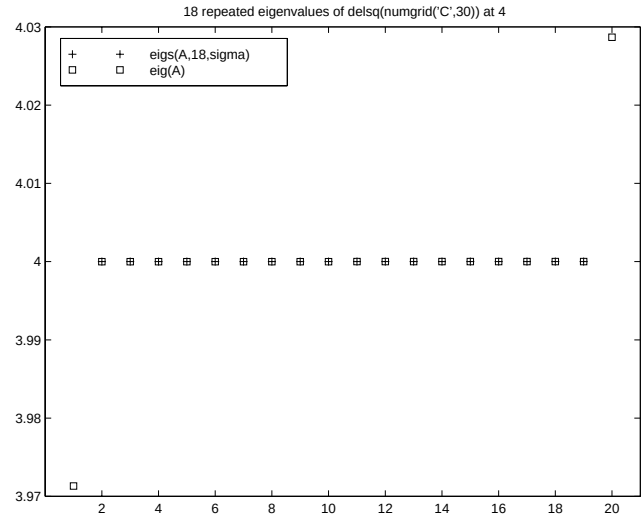




However, the repeated eigenvalue at 4 must be handled more carefully. The call `eigs(A,18,4.0)` to compute 18 eigenvalues near 4.0 tries to find eigenvalues of `A - 4.0*I`. This involves divisions of the form `1/(lambda - 4.0)`, where `lambda` is an estimate of an eigenvalue of `A`. As `lambda` gets closer to 4.0, `eigs` fails. We must use `sigma` near but not equal to 4 to find those 18 eigenvalues.

```
sigma = 4 - 1e-6
[V,D] = eigs(A,18,sigma)
```

The plot shows the 20 eigenvalues closest to 4 that were computed by `eig`.



See Also

`eig`, `svds`

References

[1] R. Radke, “A MATLAB Implementation of the Implicitly Restarted Arnoldi Method for Solving Large-Scale Eigenvalue Problems,” Dept. of Computational and Applied Math, Rice University, Houston, Texas.

[2] D. C. Sorensen, “Implicit Application of Polynomial Filters in a k-step Arnoldi Method,” *SIAM Journal on Matrix Analysis and Applications*, volume 13, number 1, 1992, pp 357-385.

[3] R. B. Lehoucq and D. C. Sorensen, “Deflation Techniques within an Implicitly Restarted Iteration,” *SIAM Journal on Matrix Analysis and Applications*,
volume 17, 1996, pp 789-821.

ellipj

Purpose

Jacobi elliptic functions

Syntax

```
[SN,CN,DN] = ellipj(U,M)
[SN,CN,DN] = ellipj(U,M,tol)
```

Definition

The Jacobi elliptic functions are defined in terms of the integral:

$$u = \int_0^{\phi} \frac{d\theta}{(1 - m\sin^2\theta)^{\frac{1}{2}}}$$

Then

$$sn(u) = \sin\phi,\ cn(u) = \cos\phi,\ dn(u) = (1 - \sin^2\phi)^{\frac{1}{2}},\ am(u) = \phi$$

Some definitions of the elliptic functions use the modulus k instead of the parameter m. They are related by:

$$k^2 = m = \sin^2\alpha$$

The Jacobi elliptic functions obey many mathematical identities; for a good sample, see [1].

Description

`[SN,CN,DN] = ellipj(U,M)` returns the Jacobi elliptic functions `SN`, `CN`, and `DN`, evaluated for corresponding elements of argument `U` and parameter `M`. Inputs `U` and `M` must be the same size (or either can be scalar).

`[SN,CN,DN] = ellipj(U,M,tol)` computes the Jacobi elliptic functions to accuracy `tol`. The default is `eps`; increase this for a less accurate but more quickly computed answer.

Algorithm

`ellipj` computes the Jacobi elliptic functions using the method of the arithmetic-geometric mean [1]. It starts with the triplet of numbers:

$$a_0 = 1, b_0 = (1-m)^{\frac{1}{2}}, c_0 = (m)^{\frac{1}{2}}$$

`ellipj` computes successive iterates with:

$$a_i = \frac{1}{2}(a_{i-1} + b_{i-1})$$
$$b_i = (a_{i-1} b_{i-1})^{\frac{1}{2}}$$
$$c_i = \frac{1}{2}(a_{i-1} - b_{i-1})$$

Next, it calculates the amplitudes in radians using:

$$\sin(2\phi_{n-1} - \phi_n) = \frac{c_n}{a_n}\sin(\phi_n)$$

being careful to unwrap the phases correctly. The Jacobian elliptic functions are then simply:

$$sn(u) = \sin\phi_0$$
$$cn(u) = \cos\phi_0$$
$$dn(u) = (1 - m \cdot sn(u)^2)^{\frac{1}{2}}$$

Limitations

The `ellipj` function is limited to the input domain $0 \le m \le 1$. Map other values of `M` into this range using the transformations described in [1], equations 16.10 and 16.11. `U` is limited to real values.

See Also

`ellipke`

References

[1] Abramowitz, M. and I.A. Stegun, *Handbook of Mathematical Functions*, Dover Publications, 1965, 17.6.

ellipke

Purpose

Complete elliptic integrals of the first and second kind

Syntax

```
K = ellipke(M)
[K,E] = ellipke(M)
[K,E] = ellipke(M,tol)
```

Definition

The *complete* elliptic integral of the first kind [1] is:

$$K(m) = F(\pi/2 | m),$$

where F, the elliptic integral of the first kind, is:

$$K(m) = \int_0^1 [(1-t^2)(1-mt^2)]^{\frac{-1}{2}}\, dt = \int_0^{\frac{\pi}{2}} (1-m\sin^2\theta)^{\frac{-1}{2}}\, d\theta$$

The complete elliptic integral of the second kind,

$$E(m) = E(K(m)) = E\langle \pi/2 | m \rangle,$$

is:

$$E(m) = \int_0^1 (1-t^2)^{\frac{-1}{2}}(1-mt^2)^{\frac{1}{2}}\, dt = \int_0^{\frac{\pi}{2}} (1-m\sin^2\theta)^{\frac{1}{2}} d\theta$$

Some definitions of `K` and `E` use the modulus k instead of the parameter m. They are related by:

$$k^2 = m = \sin^2\alpha$$

Description

`K = ellipke(M)` returns the complete elliptic integral of the first kind for the elements of `M`.

`[K,E] = ellipke(M)` returns the complete elliptic integral of the first and second kinds.

`[K,E] = ellipke(M,tol)` computes the Jacobian elliptic functions to accuracy `tol`. The default is `eps`; increase this for a less accurate but more quickly computed answer.

Algorithm

`ellipke` computes the complete elliptic integral using the method of the arithmetic-geometric mean described in [1], section 17.6. It starts with the triplet of numbers:

$$a_0 = 1,\ b_0 = (1-m)^{\frac{1}{2}},\ c_0 = (m)^{\frac{1}{2}}$$

`ellipke` computes successive iterations of a_i, b_i, and c_i with:

$$a_i = \frac{1}{2}(a_{i-1} + b_{i-1})$$
$$b_i = (a_{i-1}b_{i-1})^{\frac{1}{2}}$$
$$c_i = \frac{1}{2}(a_{i-1} - b_{i-1})$$

stopping at iteration n when $cn \approx 0$, within the tolerance specified by `eps`. The complete elliptic integral of the first kind is then:

$$K(m) = \frac{\pi}{2a_n}$$

Limitations

`ellipke` is limited to the input domain $0 \le m \le 1$.

See Also

`ellipj`

References

[1] Abramowitz, M. and I.A. Stegun, *Handbook of Mathematical Functions*, Dover Publications, 1965, 17.6.

else

Purpose

Conditionally execute statements

Syntax

```
if expression
     statements
else
     statements
end
```

Description

The `else` command is used to delineate an alternate block of statements.

```
if expression
     statements
else
     statements
end
```

The second set of *statements* is executed if the *expression* has any zero elements. The expression is usually the result of

```
expression rop expression
```

where *rop* is ==, <, >, <=, >=, or ~=.

See Also

`break`, `elseif`, `end`, `for`, `if`, `return`, `switch`, `while`

Purpose

Conditionally execute statements

Syntax

```
if expression
      statements
elseif expression
      statements
end
```

Description

The `elseif` command conditionally executes statements.

```
if expression
      statements
elseif expression
      statements
end
```

The second block of *statements* executes if the first *expression* has any zero elements and the second *expression* has all nonzero elements. The expression is usually the result of

```
expression rop expression
```

where *rop* is ==, <, >, <=, >=, or ~=.

`else if`, with a space between the `else` and the `if`, differs from `elseif`, with no space. The former introduces a new, nested, `if`, which must have a matching `end`. The latter is used in a linear sequence of conditional statements with only one terminating `end`.

The two segments

```
if A                        if A
   x = a                        x = a
else                        elseif B
   if B                         x = b
      x = b                 elseif C
   else                         x = c
       if C                 else
          x = c                 x = d
       else                 end
           x = d
       end
   end
end
```

produce identical results. Exactly one of the four assignments to `x` is executed, depending upon the values of the three logical expressions, `A`, `B`, and `C`.

See Also

`break`, `else`, `end`, `for`, `if`, `return`, `switch`, `while`

Purpose

Terminate for, while, switch, try, and if statements or indicate last index

Syntax

```
while expression% (or if, for, or try)
   statements
end

B = A(index:end,index)
```

Description

end is used to terminate for, while, switch, try, and if statements. Without an end statement, for, while, switch, try, and if wait for further input. Each end is paired with the closest previous unpaired for, while, switch, try, or if and serves to delimit its scope.

The end command also serves as the last index in an indexing expression. In that context, `end = (size(x,k))` when used as part of the kth index. Examples of this use are `X(3:end)` and `X(1,1:2:end-1)`. When using end to grow an array, as in `X(end+1)=5`, make sure X exists first.

You can overload the end statement for a user object by defining an end method for the object. The end method should have the calling sequence `end(obj,k,n)`, where obj is the user object, k is the index in the expression where the end syntax is used, and n is the total number of indices in the expression. For example, consider the expression

```
A(end-1,:)
```

MATLAB will call the end method defined for A using the syntax

```
end(A,1,2)
```

Examples

This example shows end used with the for and if statements.

```
for i = 1:n
   if a(i) == 0
       a(i) = a(i) + 2;
    end
end
```

In this example, end is used in an indexing expression.

```
A = magic(5)

A =

    17    24     1     8    15
    23     5     7    14    16
     4     6    13    20    22
    10    12    19    21     3
    11    18    25     2     9

B = A(end,2:end)

B =

    18    25     2     9
```

See Also

break, for, if, return, switch, try, while

Purpose

End of month

Syntax

```
E = eomday(Y,M)
```

Description

`E = eomday(Y,M)` returns the last day of the year and month given by corresponding elements of arrays `Y` and `M`.

Examples

Because 1996 is a leap year, the statement `eomday(1996,2)` returns `29`.

To show all the leap years in this century, try:

```
y = 1900:1999;
E = eomday(y,2*ones(length(y),1)');
y(find(E==29))'

ans =
  Columns 1 through 6
       1904       1908       1912       1916       1920       1924

  Columns 7 through 12
       1928       1932       1936       1940       1944       1948

  Columns 13 through 18
       1952       1956       1960       1964       1968       1972

  Columns 19 through 24
       1976       1980       1984       1988       1992       1996
```

See Also

`datenum`, `datevec`, `weekday`

eps

Purpose

Floating-point relative accuracy

Syntax

```
eps
```

Description

`eps` returns the distance from 1.0 to the next largest floating-point number.

The value `eps` is a default tolerance for `pinv` and `rank`, as well as several other MATLAB functions. On machines with IEEE floating-point arithmetic, `eps = 2^(-52)`, which is roughly `2.22e-16`.

See Also

`realmax`, `realmin`

Purpose

Error functions

Syntax

`Y = erf(X)`	Error function
`Y = erfc(X)`	Complementary error function
`Y = erfcx(X)`	Scaled complementary error function
`X = erfinv(Y)`	Inverse of the error function

Definition

The error function `erf(X)` is twice the integral of the Gaussian distribution with 0 mean and variance of $1/2$:

$$erf(x) = \frac{2}{\sqrt{\pi}} \int_0^x e^{-t^2} dt$$

The complementary error function `erfc(X)` is defined as:

$$erfc(x) = \frac{2}{\sqrt{\pi}} \int_x^\infty e^{-t^2} dt = 1 - erf(x)$$

The scaled complementary error function `erfcx(X)` is defined as:

$$erfcx(x) = e^{x^2} erfc(x)$$

For large `X`, `erfcx(X)` is approximately $\left(\frac{1}{\sqrt{\pi}}\right)\frac{1}{x}$.

Description

`Y = erf(X)` returns the value of the error function for each element of real array `X`.

`Y = erfc(X)` computes the value of the complementary error function.

`Y = erfcx(X)` computes the value of the scaled complementary error function.

`X = erfinv(Y)` returns the value of the inverse error function for each element of `Y`. The elements of `Y` must fall within the domain $-1 < Y < 1$.

Examples

`erfinv(1)` is `Inf`

`erfinv(-1)` is `-Inf`.

For `abs(Y) > 1`, `erfinv(Y)` is `NaN`.

Remarks

The relationship between the error function and the standard normal probability distribution is:

```
x = –5:0.1:5;
standard_normal_cdf = (1 + (erf(x/sqrt(2)))./2;
```

Algorithms

For the error functions, the MATLAB code is a translation of a Fortran program by W. J. Cody, Argonne National Laboratory, NETLIB/SPECFUN, March 19, 1990. The main computation evaluates near-minimax rational approximations from [1].

For the inverse of the error function, rational approximations accurate to approximately six significant digits are used to generate an initial approximation, which is then improved to full accuracy by two steps of Newton's method. The M-file is easily modified to eliminate the Newton improvement. The resulting code is about three times faster in execution, but is considerably less accurate.

References

[1] Cody, W. J., "Rational Chebyshev Approximations for the Error Function," *Math. Comp.*, pgs. 631-638, 1969

Purpose

Display error messages

Syntax

```
error('error_message')
```

Description

`error('error_message')` displays an error message and returns control to the keyboard. The error message contains the input string *error_message*.

The `error` command has no effect if *error_message* is a null string.

Examples

The `error` command provides an error return from M-files.

```
function foo(x,y)
if nargin ~= 2
     error('Wrong number of input arguments')
end
```

The returned error message looks like:

```
» foo(pi)
??? Error using ==> foo
Wrong number of input arguments
```

See Also

`dbstop`, `disp`, `lasterr`, `warning`

errortrap

Purpose Continue execution after errors during testing

Syntax

```
errortrap on
errortrap off
```

Description `errortrap on` continues execution after errors when they occur. Execution continues with the next statement in a top level script.

`errortrap off` (the default) stops execution when an error occurs.

Purpose

Elapsed time

Syntax

```
e = etime(t2,t1)
```

Description

`e = etime(t2,t1)` returns the time in seconds between vectors `t1` and `t2`. The two vectors must be six elements long, in the format returned by `clock`:

```
T = [Year Month Day Hour Minute Second]
```

Examples

Calculate how long a 2048-point real FFT takes.

```
x = rand(2048,1);
t = clock; fft(x); etime(clock,t)
ans =
      0.4167
```

Limitations

As currently implemented, the `etime` function fails across month and year boundaries. Since `etime` is an M-file, you can modify the code to work across these boundaries if needed.

See Also

`clock`, `cputime`, `tic`, `toc`

eval

Purpose

Execute a string containing a MATLAB expression

Syntax

```
eval(expression)
[a1,a2,a3,...] = eval(expression)
eval(expression,catch_expr)
```

Description

`eval(`*`expression`*`)` executes *`expression`*, a string containing any valid MATLAB expression. You can construct *`expression`* by concatenating substrings and variables inside square brackets:

```
expression = [string1,int2str(var),string2,...]
```

`[a1,a2,a3,...] = eval(`*`expression`*`)` executes *`expression`* and returns the results in the specified output variables. Using the `eval` output argument list is recommended over including the output arguments in the expression string:

```
eval('[a1,a2,a3,...] = function(var)')
```

The above syntax avoids strict checking by the MATLAB parser and can produce untrapped errors and other unexpected behavior.

`eval(`*`expression`*`,`*`catch_expr`*`)` executes *`expression`* and, if an error is detected, executes the *`catch_expr`* string. If *`expression`* produces an error, the error string can be obtained with the `lasterr` function. This syntax is useful when *`expression`* is a string that must be constructed from substrings. If this is not the case, use the `try...catch` control flow statement in your code.

Examples

This example executes a simple MATLAB expression:

```
A = '1+4';

aval = eval(A)

aval =

     5
```

This for loop generates a sequence of 12 matrices named M1 through M12:

```
for n = 1:12

      magic_str = ['M',int2str(n),' = magic(n)'];
      eval(magic_str)

end
```

See Also

assignin, catch, evalin, feval, lasterr, try

evalc

Purpose

Evaluate MATLAB expression with capture

Syntax

```
T = evalc(S)
T = evalc(s1,s2)
[T,X,Y,Z,...] = evalc(S)
```

Description

`T = evalc(S)` is the same as `eval(S)` except that anything that would normally be written to the command window is captured and returned in the character array `T` (lines in `T` are separated by `\n` characters).

`T = evalc(s1,s2)` is the same as `eval(s1,s2)` except that any output is captured into `T`.

`[T,X,Y,Z,...] = evalc(S)` is the same as `[X,Y,Z,...] = eval(S)` except that any output is captured into `T`.

Remark

When you are using `evalc`, `diary`, `more`, and `input` are disabled.

See Also

`diary`, `eval`, `evalin`, `input`, `more`

Purpose

Execute a string containing a MATLAB expression in a workspace

Syntax

```
evalin(ws,expression)
[a1,a2,a3,...] = evalin(ws,expression)
evalin(ws,expression,catch_expr)
```

Description

`evalin(ws,expression)` executes *expression*, a string containing any valid MATLAB expression, in the context of the workspace `ws`. `ws` can have a value of `'base'` or `'caller'` to denote the MATLAB base workspace or the workspace of the caller function. You can construct *expression* by concatenating substrings and variables inside square brackets:

```
expression = [string1,int2str(var),string2,...]
```

`[a1,a2,a3,...] = evalin(ws,expression)` executes *expression* and returns the results in the specified output variables. Using the `evalin` output argument list is recommended over including the output arguments in the expression string:

```
evalin(ws,'[a1,a2,a3,...] = function(var)')
```

The above syntax avoids strict checking by the MATLAB parser and can produce untrapped errors and other unexpected behavior.

`evalin(ws,expression,catch_expr)` executes *expression* and, if an error is detected, executes the *catch_expr* string. If *expression* produces an error, the error string can be obtained with the `lasterr` function. This syntax is useful when *expression* is a string that must be constructed from substrings. If this is not the case, use the `try...catch` control flow statement in your code.

Remarks

The MATLAB base workspace is the workspace that is seen from the MATLAB command line (when not in the debugger). The caller workspace is the workspace of the function that called the M-file. Note, the base and caller workspaces are equivalent in the context of an M-file that is invoked from the MATLAB command line.

Examples

This example extracts the value of the variable `var` in the MATLAB base workspace and captures the value in the local variable `v`:

```
v = evalin('base','var');
```

Limitation

`evalin` cannot be used recursively to evaluate an expression. For example, a sequence of the form `evalin('caller','evalin(''caller'',''x'')')` doesn't work.

See Also

`assignin`, `catch`, `eval`, `feval`, `lasterr`, `try`

Purpose

Check if a variable or file exists

Syntax

```
a = exist('item')
ident = exist('item','kind')
```

Description

`a = exist('item')` returns the status of the variable or file `item`:

`0`	If `item` does not exist.
`1`	If the variable `item` exists in the workspace.
`2`	If `item` is an M-file or a file of unknown type.
`3`	If `item` is a MEX-file.
`4`	If `item` is a MDL-file.
`5`	If `item` is a built-in MATLAB function.
`6`	If `item` is a P-file.
`7`	If `item` is a directory.

`exist('item')` returns `2` if `item` is on the MATLAB search path. `item` may be a `MATLABPATH` relative partial pathname. `item` may be `item.ext`, but the filename extension (`ext`) cannot be `mdl`, `p`, or `mex`.

`ident = exist('item','kind')` returns logical true (`1`) if an item of the specified `kind` is found, and returns `0` otherwise. `kind` may be:

`var`	Checks only for variables.
`builtin`	Checks only for built-in functions.
`file`	Checks only for files.
`dir`	Checks only for directories.

Examples

`exist` can check whether a MATLAB function is built-in or a file:

```
ident = exist('plot')
ident =
     5
```

`plot` is a built-in function.

See Also dir, help, lookfor, partialpath, what, which, who

Purpose

Exponential

Syntax

```
Y = exp(X)
```

Description

The exp function is an elementary function that operates element-wise on arrays. Its domain includes complex numbers.

`Y = exp(X)` returns the exponential for each element of `X`. For complex $z = x + i*y$, it returns the complex exponential: $e^z = e^x(\cos(y) + i\sin(y))$

Remark

Use `expm` for matrix exponentials.

See Also

`expm`, `log`, `log10`, `expint`

expint

Purpose

Exponential integral

Syntax

```
Y = expint(X)
```

Definitions

The exponential integral is defined as:

$$\int_x^\infty \frac{e^{-t}}{t}\,dt$$

Another common definition of the exponential integral function is the Cauchy principal value integral:

$$E_i(x) = \int_{-\infty}^{x} e^{-t}dt$$

which, for real positive `x`, is related to `expint` as follows:

```
expint(-x+i*0) = -Ei(x) - i*pi
Ei(x) = real(-expint(-x))
```

Description

`Y = expint(X)` evaluates the exponential integral for each element of `X`.

Algorithm

For elements of `X` in the domain [–38, 2], `expint` uses a series expansion representation (equation 5.1.11 in [1]):

$$E_i(x) = -\gamma - \ln x - \sum_{n=1}^{\infty} \frac{(-1)^n x^n}{n\ n!}$$

For all other elements of `X`, `expint` uses a continued fraction representation (equation 5.1.22 in [1]):

$$E_n(z) = e^{-z}\left(\frac{1}{z+}\frac{n}{1+}\frac{1}{z+}\frac{n+1}{1+}\frac{2}{z+}\ldots\right), \quad |angle(z)| < \pi$$

References

[1] Abramowitz, M. and I. A. Stegun. *Handbook of Mathematical Functions.* Chapter 5, New York: Dover Publications, 1965.

expm

Purpose

Matrix exponential

Syntax

```
Y = expm(X)
```

Description

`Y = expm(X)` raises the constant *e* to the matrix power `X`. Complex results are produced if `X` has nonpositive eigenvalues.

Use `exp` for the element-by-element exponential.

Algorithm

The `expm` function is built-in, but it uses the Padé approximation with scaling and squaring algorithm expressed in the file `expm1.m`.

A second method of calculating the matrix exponential uses a Taylor series approximation. This method is demonstrated in the file `expm2.m`. The Taylor series approximation is not recommended as a general-purpose method. It is often slow and inaccurate.

A third way of calculating the matrix exponential, found in the file `expm3.m`, is to diagonalize the matrix, apply the function to the individual eigenvalues, and then transform back. This method fails if the input matrix does not have a full set of linearly independent eigenvectors.

References [1] and [2] describe and compare many algorithms for computing `expm(X)`. The built-in method, `expm1`, is essentially method 3 of [2].

Examples

Suppose `A` is the 3-by-3 matrix

```
1        1        0
0        0        2
0        0       -1
```

then `expm(A)` is

```
2.7183   1.7183        1.0862
0        1.0000        1.2642
0             0        0.3679
```

while `exp(A)` is

```
2.7183        2.7183        1.0000
1.0000        1.0000        7.3891
1.0000        1.0000        0.3679
```

Notice that the diagonal elements of the two results are equal; this would be true for any triangular matrix. But the off-diagonal elements, including those below the diagonal, are different.

See Also

`exp`, `funm`, `logm`, `sqrtm`

References

[1] Golub, G. H. and C. F. Van Loan, *Matrix Computation*, p. 384, Johns Hopkins University Press, 1983.

[2] Moler, C. B. and C. F. Van Loan, "Nineteen Dubious Ways to Compute the Exponential of a Matrix," *SIAM Review 20*, 1979, pp. 801-836.

eye

Purpose

Identity matrix

Syntax

```
Y = eye(n)
Y = eye(m,n)
Y = eye(size(A))
```

Description

`Y = eye(n)` returns the `n`-by-`n` identity matrix.

`Y = eye(m,n)` or `eye([m n])` returns an `m`-by-`n` matrix with `1`'s on the diagonal and `0`'s elsewhere.

`Y = eye(size(A))` returns an identity matrix the same size as `A`.

Limitations

The identity matrix is not defined for higher-dimensional arrays. The assignment `y = eye([2,3,4])` results in an error.

See Also

`ones`, `rand`, `randn`, `zeros`

Purpose

Prime factors

Syntax

```
f = factor(n)
f = factor(symb)
```

Description

`f = factor(n)` returns a row vector containing the prime factors of `n`.

Examples

```
f = factor(123)
f =
     3    41
```

See Also

`isprime`, `primes`

factorial

Purpose Factorial function

Syntax `factorial(n)`

Description `factorial(n)` is the product of all the integers from `1` to `n`, i.e. `prod(1:n)`. Since double pricision numbers only have about 15 digits, the answer is only accurate for `n <= 21`. For larger `n`, the answer will have the right magnitute, and is accurate for the first 15 digits.

See Also `prod`

Purpose

Close one or more open files

Syntax

```
status = fclose(fid)
status = fclose('all')
```

Description

`status = fclose(fid)` closes the specified file, if it is open, returning `0` if successful and `-1` if unsuccessful. Argument `fid` is a file identifier associated with an open file (See `fopen` for a complete description).

`status = fclose('all')` closes all open files, (except standard input, output, and error), returning `0` if successful and `-1` if unsuccessful.

See Also

`ferror`, `fopen`, `fprintf`, `fread`, `fscanf`, `fseek`, `ftell`, `fwrite`

feof

Purpose

Test for end-of-file

Syntax

```
eofstat = feof(fid)
```

Description

`eofstat = feof(fid)` tests whether the end-of-file indicator is set for the file with identifier `fid`. It returns `1` if the end-of-file indicator is set, or `0` if it is not. (See `fopen` for a complete description of `fid`.)

The end-of-file indicator is set when there is no more input from the file.

See Also

`fopen`

Purpose

Query MATLAB about errors in file input or output

Syntax

```
message = ferror(fid)
message = ferror(fid,'clear')
[message,errnum] = ferror(...)
```

Description

`message = ferror(fid)` returns the error message `message`. Argument `fid` is a file identifier associated with an open file (See `fopen` for a complete description of `fid`).

`message = ferror(fid,'clear')` clears the error indicator for the specified file.

`[message,errnum] = ferror(...)` returns the error status number `errnum` of the most recent file I/O operation associated with the specified file.

If the most recent I/O operation performed on the specified file was successful, the value of `message` is empty and `ferror` returns an `errnum` value of `0`.

A nonzero `errnum` indicates that an error occurred in the most recent file I/O operation. The value of `message` is a string that may contain information about the nature of the error. If the message is not helpful, consult the C run-time library manual for your host operating system for further details.

See Also

`fclose`, `fopen`, `fprintf`, `fread`, `fscanf`, `fseek`, `ftell`, `fwrite`

feval

Purpose

Function evaluation

Syntax

```
[y1,y2, ...] = feval(function,x1,...,xn)
```

Description

`[y1,y2...] = feval(`*function*`,x1, ...,xn)` If *function* is a string containing the name of a function (usually defined by an M-file), then `feval(`*function*`,x1,...,xn)` evaluates that function at the given arguments.

Examples

The statements:

```
[V,D] = feval('eig',A)
[V,D] = eig(A)
```

are equivalent. `feval` is useful in functions that accept string arguments specifying function names. For example, the function:

```
function plotf(fun,x)
y = feval(fun,x);
plot(x,y)
```

can be used to graph other functions.

See Also

`assignin`, `builtin`, `eval`, `evalin`

Purpose

One-dimensional fast Fourier transform

Syntax

```
Y = fft(X)
Y = fft(X,n)
Y = fft(X,[],dim)
Y = fft(X,n,dim)
```

Definition

The functions `X = fft(x)` and `x = ifft(X)` implement the transform and inverse transform pair given for vectors of length `N` by:

$$X(k) = \sum_{j=1}^{N} x(j)\omega_N^{(j-1)(k-1)}$$

$$x(j) = (1/N)\sum_{k=1}^{N} X(k)\omega_N^{-(j-1)(k-1)}$$

where

$$\omega_N = e^{(-2\pi i)/N}$$

is an nth root of unity.

Description

`Y = fft(X)` returns the discrete Fourier transform of vector `X`, computed with a fast Fourier transform (FFT) algorithm.

If `X` is a matrix, `fft` returns the Fourier transform of each column of the matrix.

If `X` is a multidimensional array, `fft` operates on the first nonsingleton dimension.

`Y = fft(X,n)` returns the `n`-point FFT. If the length of `X` is less than `n`, `X` is padded with trailing zeros to length `n`. If the length of `X` is greater than `n`, the sequence `X` is truncated. When `X` is a matrix, the length of the columns are adjusted in the same manner.

`Y = fft(X,[],dim)` and `Y = fft(X,n,dim)` apply the FFT operation across the dimension `dim`.

Remarks

The `fft` function employs a radix-2 fast Fourier transform algorithm if the length of the sequence is a power of two, and a slower mixed-radix algorithm if it is not. See “Algorithm.”

Examples

A common use of Fourier transforms is to find the frequency components of a signal buried in a noisy time domain signal. Consider data sampled at 1000 Hz. Form a signal containing 50 Hz and 120 Hz and corrupt it with some zero-mean random noise:

```
t = 0:0.001:0.6;
x = sin(2*pi*50*t)+sin(2*pi*120*t);
y = x + 2*randn(size(t));
plot(y(1:50))
```

It is difficult to identify the frequency components by looking at the original signal. Converting to the frequency domain, the discrete Fourier transform of the noisy signal y is found by taking the 512-point fast Fourier transform (FFT):

```
Y = fft(y,512);
```

The power spectral density, a measurement of the energy at various frequencies, is

```
Pyy = Y.* conj(Y) / 512;
```

Graph the first 257 points (the other 255 points are redundant) on a meaningful frequency axis.

```
f = 1000*(0:256)/512;
plot(f,Pyy(1:257))
```

This represents the frequency content of y in the range from DC up to and including the Nyquist frequency. (The signal produces the strong peaks.)

Algorithm

When the sequence length is a power of two, a high-speed radix-2 fast Fourier transform algorithm is employed. The radix-2 FFT routine is optimized to perform a real FFT if the input sequence is purely real, otherwise it computes the complex FFT. This causes a real power-of-two FFT to be about 40% faster than a complex FFT of the same length.

When the sequence length is not an exact power of two, an alternate algorithm finds the prime factors of the sequence length and computes the mixed-radix discrete Fourier transforms of the shorter sequences.

The time it takes to compute an FFT varies greatly depending upon the sequence length. The FFT of sequences whose lengths have many prime factors is computed quickly; the FFT of those that have few is not. Sequences whose lengths are prime numbers are reduced to the raw (and slow) discrete Fourier transform (DFT) algorithm. For this reason it is generally better to stay with power-of-two FFTs unless other circumstances dictate that this cannot be done. For example, on one machine a 4096-point real FFT takes 2.1 seconds and a complex FFT of the same length takes 3.7 seconds. The FFTs of neighboring sequences of length 4095 and 4097, however, take 7 seconds and 58 seconds, respectively.

See Also

`dftmtx`, `filter`, and `freqz` in the Signal Processing Toolbox, and:

`fft2`, `fftshift`, `ifft`

fft2

Purpose

Two-dimensional fast Fourier transform

Syntax

```
Y = fft2(X)
Y = fft2(X,m,n)
```

Description

`Y = fft2(X)` performs the two-dimensional FFT. The result `Y` is the same size as `X`.

`Y = fft2(X,m,n)` truncates `X`, or pads `X` with zeros to create an `m`-by-`n` array before doing the transform. The result is `m`-by-`n`.

Algorithm

`fft2(X)` can be simply computed as

```
fft(fft(X).').'
```

This computes the one-dimensional FFT of each column `X`, then of each row of the result. The time required to compute `fft2(X)` depends strongly on the number of prime factors in `[m,n] = size(X)`. It is fastest when `m` and `n` are powers of 2.

See Also

`fft`, `fftshift`, `ifft2`

Purpose

Multidimensional fast Fourier transform

Syntax

```
Y = fftn(X)
Y = fftn(X,siz)
```

Description

`Y = fftn(X)` performs the N-dimensional fast Fourier transform. The result `Y` is the same size as `X`.

`Y = fftn(X,siz)` pads `X` with zeros, or truncates `X`, to create a multidimensional array of size `siz` before performing the transform. The size of the result `Y` is `siz`.

Algorithm

`fftn(X)` is equivalent to

```
Y = X;
for p = 1:length(size(X))
    Y = fft(Y,[],p);
end
```

This computes in-place the one-dimensional fast Fourier transform along each dimension of `X`. The time required to compute `fftn(X)` depends strongly on the number of prime factors of the dimensions of `X`. It is fastest when all of the dimensions are powers of 2.

See Also

`fft`, `fft2`, `ifftn`

fftshift

Purpose

Shift DC component of fast Fourier transform to center of spectrum

Syntax

```
Y = fftshift(X)
```

Description

`Y = fftshift(X)` rearranges the outputs of `fft`, `fft2`, and `fftn` by moving the zero frequency component to the center of the array.

For vectors, `fftshift(X)` swaps the left and right halves of `X`. For matrices, `fftshift(X)` swaps quadrants one and three of `X` with quadrants two and four. For higher-dimensional arrays, `fftshift(X)` swaps "half-spaces" of `X` along each dimension.

Examples

For any matrix `X`

```
Y = fft2(X)
```

has `Y(1,1) = sum(sum(X))`; the DC component of the signal is in the upper-left corner of the two-dimensional FFT. For

```
Z = fftshift(Y)
```

this DC component is near the center of the matrix.

See Also

`fft`, `fft2`, `fftn`, `ifftshift`

Purpose

Return the next line of a file as a string without line terminators

Syntax

```
line = fgetl(fid)
```

Description

`line = fgetl(fid)` returns the next line of the file with identifier `fid`. If `fgetl` encounters the end of a file, it returns `-1`. (See `fopen` for a complete description of `fid`.)

The returned string `line` does not include the line terminator(s) with the text line. To obtain the line terminators, use `fgets`.

See Also

`fgets`

fgets

Purpose

Return the next line of a file as a string with line terminators

Syntax

```
line = fgets(fid)
line = fgets(fid,nchar)
```

Description

`line = fgets(fid)` returns the next line for the file with identifier `fid`. If `fgets` encounters the end of a file, it returns `-1`. (See `fopen` for a complete description of `fid`.)

The returned string `line` includes the line terminators associated with the text line. To obtain the string without the line terminators, use `fgetl`.

`line = fgets(fid,nchar)` returns at most `nchar` characters of the next line. No additional characters are read after the line terminators or an end-of-file.

See Also

`fgetl`

Purpose

Field names of a structure

Syntax

```
names = fieldnames(s)
```

Description

`names = fieldnames(s)` returns a cell array of strings containing the structure field names associated with the structure `s`.

Examples

Given the structure:

```
mystr(1,1).name = 'alice';
mystr(1,1).ID = 0;
mystr(2,1).name = 'gertrude';
mystr(2,1).ID = 1
```

Then the command `n = fieldnames(mystr)` yields

```
n =

    'name'
    'ID'
```

See Also

`getfield`, `setfield`

fileparts

Purpose

Return filename parts

Syntax

```
[path,name,ext,ver] = fileparts(file)
```

Description

`[path,name,ext,ver] = fileparts(file)` returns the path, filename, extension, and version for the specified file. `ver` will be nonempty only on VMS systems. `fileparts` is platform dependent.

You can reconstruct the file from the parts using

```
fullfile(path,[name ext ver])
```

See Also

`fullfile`

Purpose

Filter data with an infinite impulse response (IIR) or finite impulse response (FIR) filter

Syntax

```
y = filter(b,a,X)
[y,zf] = filter(b,a,X)
[y,zf] = filter(b,a,X,zi)
y = filter(b,a,X,zi,dim)
[...] = filter(b,a,X,[],dim)
```

Description

The `filter` function filters a data sequence using a digital filter which works for both real and complex inputs. The filter is a *direct form II transposed* implementation of the standard difference equation (see "Algorithm").

`y = filter(b,a,X)` filters the data in vector `X` with the filter described by numerator coefficient vector `b` and denominator coefficient vector `a`. If `a(1)` is not equal to `1`, `filter` normalizes the filter coefficients by `a(1)`. If `a(1)` equals `0`, `filter` returns an error.

If `X` is a matrix, `filter` operates on the columns of `X`. If `X` is a multidimensional array, `filter` operates on the first nonsingleton dimension.

`[y,zf] = filter(b,a,X)` returns the final conditions, `zf`, of the filter delays. Output `zf` is a vector of `max(size(a),size(b))` or an array of such vectors, one for each column of `X`.

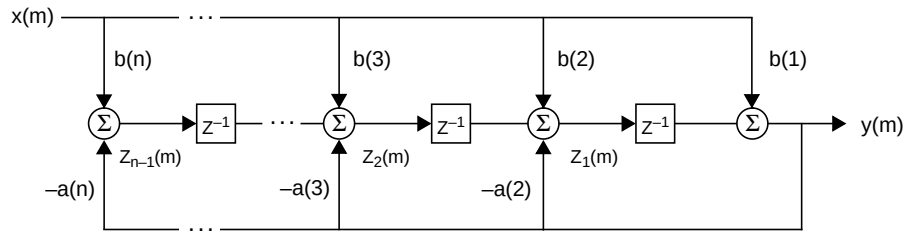
`[y,zf] = filter(b,a,X,zi)` accepts initial conditions and returns the final conditions, `zi` and `zf` respectively, of the filter delays. Input `zi` is a vector (or an array of vectors) of length `max(length(a),length(b))-1`.

`y = filter(b,a,X,zi,dim)` and

`[...] = filter(b,a,X,[],dim)` operate across the dimension `dim`.

Algorithm

The `filter` function is implemented as a direct form II transposed structure,



or

```
y(n) = b(1)*x(n) + b(2)*x(n-1) + ... + b(nb+1)*x(n-nb)
                 - a(2)*y(n-1) - ... - a(na+1)*y(n-na)
```

where `n-1` is the filter order, and which handles both FIR and IIR filters [1].

The operation of `filter` at sample m is given by the time domain difference equations

$$
\begin{aligned}
y(m) &= b(1)x(m) + z_1(m-1) \\
z_1(m) &= b(2)x(m) + z_2(m-1) - a(2)y(m) \\
&\vdots \quad = \quad \vdots \qquad\qquad \vdots \\
z_{n-2}(m) &= b(n-1)x(m) + z_{n-1}(m-1) - a(n-1)y(m) \\
z_{n-1}(m) &= b(n)x(m) - a(n)y(m)
\end{aligned}
$$

The input-output description of this filtering operation in the z-transform domain is a rational transfer function,

$$Y(z) = \frac{b(1) + b(2)z^{-1} + \ldots + b(nb+1)z^{-nb}}{1 + a(2)z^{-1} + \ldots + a(na+1)z^{-na}} X(z)$$

See Also

`filtfilt` in the Signal Processing Toolbox, and:

`filter2`

References

[1] Oppenheim, A. V. and R.W. Schafer. *Discrete-Time Signal Processing*, Englewood Cliffs, NJ: Prentice-Hall, 1989, pp. 311–312.

filter2

Purpose

Two-dimensional digital filtering

Syntax

```
Y = filter2(h,X)
Y = filter2(h,X,shape)
```

Description

`Y = filter2(h,X)` filters the data in `X` with the two-dimensional FIR filter in the matrix `h`. It computes the result, `Y`, using two-dimensional correlation, and returns the central part of the correlation that is the same size as `X`.

`Y = filter2(h,X,shape)` returns the part of `Y` specified by the `shape` parameter. `shape` is a string with one of these values:

- `'full'` returns the full two-dimensional correlation. In this case, `Y` is larger than `X`.
- `'same'` (the default) returns the central part of the correlation. In this case, `Y` is the same size as `X`.
- `'valid'` returns only those parts of the correlation that are computed without zero-padded edges. In this case, `Y` is smaller than `X`.

Remarks

Two-dimensional correlation is equivalent to two-dimensional convolution with the filter matrix rotated 180 degrees. See the Algorithm section for more information about how `filter2` performs linear filtering.

Algorithm

Given a matrix `X` and a two-dimensional FIR filter `h`, `filter2` rotates your filter matrix 180 degrees to create a convolution kernel. It then calls `conv2`, the two-dimensional convolution function, to implement the filtering operation.

`filter2` uses `conv2` to compute the full two-dimensional convolution of the FIR filter with the input matrix. By default, `filter2` then extracts the central part of the convolution that is the same size as the input matrix, and returns this as the result. If the `shape` parameter specifies an alternate part of the convolution for the result, `filter2` returns the appropriate part.

See Also

`conv2`, `filter`

Purpose

Find indices and values of nonzero elements

Syntax

```
k = find(x)
[i,j] = find(X)
[i,j,v] = find(X)
```

Description

`k = find(X)` returns the indices of the array `x` that point to nonzero elements. If none is found, `find` returns an empty matrix.

`[i,j] = find(X)` returns the row and column indices of the nonzero entries in the matrix `X`. This is often used with sparse matrices.

`[i,j,v] = find(X)` returns a column vector `v` of the nonzero entries in `X`, as well as row and column indices.

In general, `find(X)` regards `X` as `X(:)`, which is the long column vector formed by concatenating the columns of `X`.

Examples

`[i,j,v] = find(X~=0)` produces a vector `v` with all `1`s, and returns the row and column indices.

Some operations on a vector

```
x = [11  0  33  0  55]';
find(x)

ans =

     1
     3
     5

find(x == 0)

ans =

     2
     4
```

```
find(0 < x & x < 10*pi)

ans =

     1
```

And on a matrix

```
M = magic(3)

M =

     8     1     6
     3     5     7
     4     9     2

[i,j,v] = find(M > 6)

i =            j =            v =

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

See Also

nonzeros, sparse

The logical operators &, |, ~

The relational operators <, <=, >, >=, ==, ~=

The colon operator :

Purpose

Find one string within another

Syntax

```
k = findstr(str1,str2)
```

Description

`k = findstr(`*`str1`*`,`*`str2`*`)` finds the starting indices of any occurrences of the shorter string within the longer.

Examples

```
str1 = 'Find the starting indices of the shorter string.';
str2 = 'the';
findstr(str1,str2)

ans =
     6    30
```

See Also

`strcmp`, `strmatch`, `strncmp`

fix

Purpose

Round towards zero

Syntax

```
B = fix(A)
```

Description

`B = fix(A)` rounds the elements of `A` toward zero, resulting in an array of integers. For complex `A`, the imaginary and real parts are rounded independently.

Examples

```
a =

  Columns 1 through 4

 -1.9000         -0.2000          3.4000          5.6000

  Columns 5 through 6

   7.0000             2.4000 + 3.6000i

fix(a)

ans =

  Columns 1 through 4

 -1.0000              0          3.0000          5.0000

  Columns 5 through 6

   7.0000             2.0000 + 3.0000i
```

See Also

`ceil`, `floor`, `round`

Purpose

Flip array along a specified dimension

Syntax

```
B = flipdim(A,dim)
```

Description

`B = flipdim(A,dim)` returns `A` with dimension `dim` flipped.

When the value of `dim` is `1`, the array is flipped row-wise down. When `dim` is `2`, the array is flipped columnwise left to right. `flipdim(A,1)` is the same as `flipud(A)`, and `flipdim(A,2)` is the same as `fliplr(A)`.

Examples

`flipdim(A,1)` where

```
  A =

       1     4
       2     5
       3     6
```

produces

```
       3     6
       2     5
       1     4
```

See Also

`fliplr`, `flipud`, `permute`, `rot90`

fliplr

Purpose

Flip matrices left-right

Syntax

```
B = fliplr(A)
```

Description

`B = fliplr(A)` returns `A` with columns flipped in the left-right direction, that is, about a vertical axis.

Examples

```
A =
     1     4
     2     5
     3     6
```

produces

```
     4     1
     5     2
     6     3
```

Limitations

Array `A` must be two dimensional.

See Also

`flipdim`, `flipud`, `rot90`

Purpose

Flip matrices up-down

Syntax

```
B = flipud(A)
```

Description

`B = flipud(A)` returns `A` with rows flipped in the up-down direction, that is, about a horizontal axis.

Examples

```
A =
     1     4
     2     5
     3     6
```

produces

```
     3     6
     2     5
     1     4
```

Limitations

Array `A` must be two dimensional.

See Also

`flipdim`, `fliplr`, `rot90`

floor

Purpose

Round towards minus infinity

Syntax

```
B = floor(A)
```

Description

`B = floor(A)` rounds the elements of `A` to the nearest integers less than or equal to `A`. For complex `A`, the imaginary and real parts are rounded independently.

Examples

```
a =

  Columns 1 through 4

 -1.9000         -0.2000          3.4000          5.6000

  Columns 5 through 6

   7.0000             2.4000 + 3.6000i

floor(a)

ans =

  Columns 1 through 4

 -2.0000         -1.0000          3.0000          5.0000

  Columns 5 through 6

   7.0000             2.0000 + 3.0000i
```

See Also

`ceil`, `fix`, `round`

Purpose

Count floating-point operations

Syntax

```
f = flops
flops(0)
```

Description

`f = flops` returns the cumulative number of floating-point operations.

`flops(0)` resets the count to zero.

Examples

If `A` and `B` are real `n`-by-`n` matrices, some typical flop counts for different operations are:

Operation	Flop Count
`A+B`	`n^2`
`A*B`	`2*n^3`
`A^100`	`99*(2*n^3)`
`lu(A)`	`(2/3)*n^3`

MATLAB's version of the LINPACK benchmark is:

```
n = 100;
A = rand(n,n);
b = rand(n,1);
flops(0)
tic;
x = A\b;
t = toc
megaflops = flops/t/1.e6
```

Algorithm

It is not feasible to count all the floating-point operations, but most of the important ones are counted. Additions and subtractions are each one flop if real and two if complex. Multiplications and divisions count one flop each if the result is real and six flops if it is complex. Elementary functions count one if real and more if complex.

fmin

Purpose

Minimize a function of one variable

NOTE The name of this function has been changed to `fminbnd` in Release 11 (MATLAB 5.3). While `fmin` is supported in Release 11, it will be removed in a future release so please begin using `fminbnd`.

Syntax

```
x = fmin('fun',x1,x2)
x = fmin('fun',x1,x2,options)
x = fmin('fun',x1,x2,options,P1,P2, ...)
[x,options] = fmin(...)
```

Description

`x = fmin('fun',x1,x2)` returns a value of `x` which is a local minimizer of `fun(x)` in the interval $x_1 < x < x_2$.

`x = fmin('fun',x1,x2,options)` does the same as the above, but uses `options` control parameters.

`x = fmin('fun',x1,x2,options,P1,P2,...)` does the same as the above, but passes arguments to the objective function, `fun(x,P1,P2,...)`. Pass an empty matrix for `options` to use the default value.

`[x,options] = fmin(...)` returns, in `options(10)`, a count of the number of steps taken.

Arguments

`x1,x2`	Interval over which *function* is minimized.
`P1,P2...`	Arguments to be passed to *function*.

fun A string containing the name of the function to be minimized.

options A vector of control parameters. Only three of the 18 components of options are referenced by fmin; Optimization Toolbox functions use the others. The three control options used by fmin are:

- options(1) — If this is nonzero, intermediate steps in the solution are displayed. The default value of options(1) is 0.
- options(2) — This is the termination tolerance. The default value is 1.e-4.
- options(14) — This is the maximum number of steps. The default value is 500.

Examples

`fmin('cos',3,4)` computes π to a few decimal places.

`fmin('cos',3,4,[1,1.e-12])` displays the steps taken to compute π to 12 decimal places.

To find the minimum of the function $f(x) = x^3 - 2x - 5$ on the interval $(0, 2)$, write an M-file called `f.m`.

```
function y = f(x)
y = x.^3-2*x-5;
```

Then invoke `fmin` with

```
x = fmin('f', 0, 2)
```

The result is

```
x =
    0.8165
```

The value of the function at the minimum is

```
y = f(x)

y =
    -6.0887
```

Algorithm

The algorithm is based on golden section search and parabolic interpolation. A Fortran program implementing the same algorithms is given in [1].

See Also

`fmins` Minimize a function of several variables
`fzero` Zero of a function of one variable
`foptions` in the Optimization Toolbox (or type `help foptions`).

References

[1] Forsythe, G. E., M. A. Malcolm, and C. B. Moler, *Computer Methods for Mathematical Computations*, Prentice-Hall, 1976.

Purpose

Minimize a function of one variable

Syntax

```
x = fminbnd(fun,x1,x2)
x = fminbnd(fun,x1,x2,options)
x = fminbnd(fun,x1,x2,options,P1,P2,...)
[x,fval] = fminbnd(...)
[x,fval,exitflag] = fminbnd(...)
[x,fval,exitflag,output] = fminbnd(...)
```

Description

`fminbnd` finds the minimum of a function of one variable within a fixed interval.

`x = fminbnd(fun,x1,x2)` returns a value `x` that is a local minimizer of the function that is described in `fun` (usually an M-file, built-in function, or inline object) in the interval `x1 < x < x2`. The function `fun` should return a scalar function value `f` when called with `feval`: `f=feval(fun,x)`.

`x = fminbnd(fun,x1,x2,options)` minimizes with the optimization parameters specified in the structure `options`. You can define these parameters using the `optimset` function. `fminbnd` uses these `options` structure fields:

- `Display` – Level of display. `off` displays no output; `iter` displays output at each iteration; `final` displays just the final output.
- `MaxFunEvals` – Maximum number of function evaluations allowed.
- `MaxIter` – Maximum number of iterations allowed.
- `TolX` – Termination tolerance on `x`.

`x = fminbnd(fun,x1,x2,options,P1,P2,...)` provides for additional arguments, `P1`, `P2`, etc., which are passed to the objective function, `fun(x,P1,P2,...)`. Use `options=[]` as a placeholder if no options are set.

`[x,fval] = fminbnd(...)` returns the value of the objective function computed in `fun` at `x`.

`[x,fval,exitflag] = fminbnd(...)` returns a value `exitflag` that describes the exit condition of `fminbnd`:

- `> 0` indicates that the function converged to a solution `x`.
- `0` indicates that the maximum number of function evaluations was reached.

`[x,fval,exitflag,output] = fminbnd(...)` returns a structure `output` that contains information about the optimization:

- `output.algorithm` – The algorithm used.
- `output.funcCount` – The number of function evaluations.
- `output.iterations` – The number of iterations taken.

Arguments

`fun` is a string containing the name of the function that computes the objective function to be minimized at the point `x`. The function returns one argument, a scalar valued function `f` to be minimized. For example, if `fun='fun'`, the first line of the M-file `fun.m` is

```
f = fun(x)
```

`fun` can also be the name of a built-in function such as `fun='sin'`.

Alternatively, you can specify an inline object. For example,

```
fun = inline('sin(x*x)');
```

Other arguments are described in the syntax descriptions above.

Examples

`x = fminbnd('cos',3,4)` computes π to a few decimal places and gives a message on termination.

```
[x,fval,exitflag] =
   fminbnd('cos',3,4,optimset('TolX',1e-12,'Display','off'))
```

computes π to about 12 decimal places, suppresses output, returns the function value at `x`, and returns an `exitflag` of 1.

The argument `fun` can also be an inline function. To find the minimum of the function $f(x) = x^3 - 2x - 5$ on the interval `(0,2)`, create an inline object `f`

```
f = inline('x.^3-2*x-5');
```

Then invoke `fminbnd` with

```
x = fminbnd(f, 0, 2)
```

The result is

```
x =
    0.8165
```

The value of the function at the minimum is

```
y = f(x)

y =
   -6.0887
```

Algorithm

The algorithm is based on golden section search and parabolic interpolation. A Fortran program implementing the same algorithm is given in [1].

Limitations

The function to be minimized must be continuous. `fminbnd` may only give local solutions.

`fminbnd` often exhibits slow convergence when the solution is on a boundary of the interval.

`fminbnd` only handles real variables.

See Also

`fminsearch`, `fzero`, `optimset`, `inline`

References

[1] Forsythe, G. E., M. A. Malcolm, and C. B. Moler, *Computer Methods for Mathematical Computations*, Prentice-Hall, 1976.

fmins

Purpose

Minimize a function of several variables

NOTE The name of this function has been changed to `fminsearch` in Release 11 (MATLAB 5.3). While `fmins` is supported in Release 11, it will be removed in a future release so please begin using `fminsearch`.

Syntax

```
x = fmins('fun',x0)
x = fmins('fun',x0,options)
x = fmins('fun',x0,options,[],P1,P2, ...)
[x,options] = fmins(...)
```

Description

`x = fmins('fun',x0)` returns a vector `x` which is a local minimizer of `fun(x)` near x_0.

`x = fmins('fun',x0,options)` does the same as the above, but uses `options` control parameters.

`x = fmins('fun',x0,options,[],P1,P2,...)` does the same as above, but passes arguments to the objective function, `fun(x,P1,P2, ...)`. Pass an empty matrix for `options` to use the default value.

`[x,options] = fmins(...)` returns, in `options(10)`, a count of the number of steps taken.

Arguments

`x0`	Starting vector.
`P1,P2...`	Arguments to be passed to *fun*.
`[]`	Argument needed to provide compatibility with `fminu` in the Optimization Toolbox.

fun	A string containing the name of the objective function to be minimized. `fun(x)` is a scalar valued function of a vector variable.
`options`	A vector of control parameters. Only four of the 18 components of `options` are referenced by `fmins`; Optimization Toolbox functions use the others. The four control `options` used by `fmins` are: • `options(1)` — If this is nonzero, intermediate steps in the solution are displayed. The default value of `options(1)` is 0. • `options(2)` and `options(3)` — These are the termination tolerances for `x` and `function(x)`, respectively. The default values are `1.e-4`. • `options(14)` — This is the maximum number of steps. The default value is `500`.

Examples

A classic test example for multidimensional minimization is the Rosenbrock banana function:

$$f(x) = 100(x_2 - x_1^2)^2 + (1 - x_1)^2$$

The minimum is at `(1,1)` and has the value `0`. The traditional starting point is `(-1.2,1)`. The M-file `banana.m` defines the function.

```
function f = banana(x)
f = 100*(x(2)-x(1)^2)^2+(1-x(1))^2;
```

The statements

```
[x,out] = fmins('banana',[-1.2, 1]);
x
out(10)
```

produce

```
x =

    1.0000    1.0000

ans =

    165
```

This indicates that the minimizer was found to at least four decimal places in 165 steps.

Move the location of the minimum to the point `[a,a^2]` by adding a second parameter to `banana.m`.

```
function f = banana(x,a)
if nargin < 2, a = 1; end
f = 100*(x(2)-x(1)^2)^2+(a-x(1))^2;
```

Then the statement

```
[x,out] = fmins('banana', [-1.2, 1], [0, 1.e-8], [], sqrt(2));
```

sets the new parameter to `sqrt(2)` and seeks the minimum to an accuracy higher than the default.

Algorithm

The algorithm is the Nelder-Mead simplex search described in the two references. It is a direct search method that does not require gradients or other derivative information. If `n` is the length of `x`, a simplex in `n`-dimensional space is characterized by the `n+1` distinct vectors which are its vertices. In two-space, a simplex is a triangle; in three-space, it is a pyramid.

At each step of the search, a new point in or near the current simplex is generated. The function value at the new point is compared with the function's values at the vertices of the simplex and, usually, one of the vertices is replaced by the new point, giving a new simplex. This step is repeated until the diameter of the simplex is less than the specified tolerance.

See Also

`fmin` Minimize a function of one variable
`foptions` in the Optimization Toolbox (or type `help foptions`).

References

[1] Nelder, J. A. and R. Mead, “A Simplex Method for Function Minimization,” *Computer Journal*, Vol. 7, p. 308-313.

[2] Dennis, J. E. Jr. and D. J. Woods, “New Computing Environments: Micro-computers in Large-Scale Computing,” edited by A. Wouk, *SIAM*, 1987, pp. 116-122.

fminsearch

Purpose

Minimize a function of several variables

Syntax

```
x = fminsearch(fun,x0)
x = fminsearch(fun,x0,options)
x = fminsearch(fun,x0,options,P1,P2,...)
[x,fval] = fminsearch(...)
[x,fval,exitflag] = fminsearch(...)
[x,fval,exitflag,output] = fminsearch(...)
```

Description

`fminsearch` finds the minimum of a scalar function of several variables, starting at an initial estimate. This is generally referred to as *unconstrained nonlinear optimization*.

`x = fminsearch(fun,x0)` returns a vector `x` that is a local minimizer of the function described in `fun` (usually an M-file, built-in function or an inline object) near the starting vector `x0`. `fun` should return a scalar function value `f` evaluated at `x` when called with `feval`: `f=feval(fun,x)`.

`x = fminsearch(fun,x0,options)` minimizes with the optimization parameters specified in the structure `options`. You can define these parameters using the `optimset` function. `fminsearch` uses these `options` structure fields:

- `Display` – Level of display. `off` displays no output; `iter` displays output at each iteration; `final` displays just the final output.
- `MaxFunEvals` – Maximum number of function evaluations allowed.
- `MaxIter` – Maximum number of iterations allowed.
- `TolFun` – Termination tolerance on the function value.
- `TolX` – Termination tolerance on `x`.

`x = fminsearch(fun,x0,options,P1,P2,...)` passes the problem-dependent parameters `P1`, `P2`, etc., directly to the function `fun`: `feval(fun,x,P1,P2,...)`. Pass an empty matrix for `options` to use the default values.

`[x,fval] = fminsearch(...)` returns in `fval` the value of the objective function `fun` at the solution `x`.

`[x,fval,exitflag] = fminsearch(...)` returns a value `exitflag` that describes the exit condition of `fminsearch`:

- `> 0` indicates that the function converged to a solution `x`.
- `0` indicates that the maximum number of function evaluations was reached.
- `< 0` indicates that the function did not converge to a solution.

`[x,fval,exitflag,output] = fminsearch(...)` returns a structure `output` that contains information about the optimization:

- `output.algorithm` – The algorithm used.
- `output.funcCount` – The number of function evaluations.
- `output.iterations` – The number of iterations taken.

Arguments

`fun` is a string containing the name of the function that computes the objective function to be minimized at the point `x`. The function returns one argument, a scalar valued function `f` to be minimized, given a vector `x`. For example, if `fun='fun'`, the first line of the M-file `fun.m` is

```
f = fun(x)
```

`fun` can also be the name of a built-in function such as `fun='norm'`.(Note that `norm` takes a vector and returns a scalar.)

Alternatively, you can specify an inline object. For example,

```
fun = inline('sin(x''*x)');
```

Other arguments are described in the syntax descriptions above.

Examples

A classic test example for multidimensional minimization is the Rosenbrock banana function

$$f(x) = 100(x_2 - x_1^2)^2 + (1 - x_1)^2$$

The minimum is at `(1,1)` and has the value `0`. The traditional starting point is `(-1.2,1)`. The M-file `banana.m` defines the function.

```
function f = banana(x)
f = 100*(x(2)-x(1)^2)^2+(1-x(1))^2;
```

The statement

```
[x,fval] = fminsearch('banana',[-1.2, 1])
```

produces

```
x =

    1.0000    1.0000

fval =

    8.1777e-010
```

This indicates that the minimizer was found to at least four decimal places with a value near zero.

Move the location of the minimum to the point `[a,a^2]` by adding a second parameter to `banana.m`.

```
function f = banana(x,a)
if nargin < 2, a = 1; end
f = 100*(x(2)-x(1)^2)^2+(a-x(1))^2;
```

Then the statement

```
[x,fval] = fminsearch('banana', [-1.2, 1], ...
   optimset('TolX',1e-8), sqrt(2));
```

sets the new parameter to `sqrt(2)` and seeks the minimum to an accuracy higher than the default on `x`.

Algorithm

`fminsearch` uses the simplex search method of [1]. This is a direct search method that does not use numerical or analytic gradients.

If `n` is the length of `x`, a simplex in `n`-dimensional space is characterized by the `n+1` distinct vectors that are its vertices. In two-space, a simplex is a triangle; in three-space, it is a pyramid. At each step of the search, a new point in or near the current simplex is generated. The function value at the new point is compared with the function's values at the vertices of the simplex and, usually, one of the vertices is replaced by the new point, giving a new simplex. This step is repeated until the diameter of the simplex is less than the specified tolerance.

Limitations

`fminsearch` can often handle discontinuity, particularly if it does not occur near the solution. `fminsearch` may only give local solutions.

`fminsearch` only minimizes over the real numbers, that is, *x* must only consist of real numbers and *f(x)* must only return real numbers. When *x* has complex variables, they must be split into real and imaginary parts.

See Also

`fminbnd`, `optimset`, `inline`

References

[1] Lagarias, J.C., J. A. Reeds, M.H. Wright, and P.E. Wright, "Convergence Properties of the Nelder-Mead Simplex Algorithm in Low Dimensions," May 1, 1997. To appear in the *SIAM Journal of Optimization*.

fopen

Purpose

Open a file or obtain information about open files

Syntax

```
fid = fopen(filename,permission)
[fid,message] = fopen(filename,permission,format)
fids = fopen('all')
[filename,permission, format] = fopen(fid)
```

Description

If `fopen` successfully opens a file, it returns a file identifier `fid`, and the value of `message` is empty. The file identifier can be used as the first argument to other file input/output routines. If `fopen` does not successfully open the file, it returns a `-1` value for `fid`. In that case, the value of `message` is a string that helps you determine the type of error that occurred.

Two `fids` are predefined and cannot be explicitly opened or closed:

`1`	Standard output, which is always open for appending (`permission` set to `'a'`)
`2`	Standard error, which is always open for appending (`permission` set to `'a'`)

`fid = fopen(filename,permission)` opens the file `filename` in the mode specified by `permission` and returns `fid`, the file identifier. `filename` may a `MATLABPATH` relative partial pathname. If the file is opened for reading and it is not found in the current working directory, `fopen` searches down MATLAB's search path.

`permission` can be:

`'r'`	Open the file for reading (default).
`'r+'`	Open the file for reading and writing.
`'w'`	Delete the contents of an existing file or create a new file, and open it for writing.
`'w+'`	Delete the contents of an existing file or create new file, and open it for reading and writing.
`'W'`	Write without automatic flushing; used with tape drives

`'a'`	Create and open a new file or open an existing file for writing, appending to the end of the file.
`'a+'`	Create and open a new file or open an existing file for reading and writing, appending to the end of the file.
`'A'`	Append without automatic flushing; used with tape drives

Files can be opened in binary mode (the default) or in text mode and for some systems, you must make the distinction when you use fopen. On PC and VMS systems, you must distinguish between text and binary mode. On UNIX systems, you do not need to distinguish between binary and text mode. In text mode, line separators are deleted on input before they reach MATLAB and are added for output. In binary mode, line separators are not deleted or added. To open a file in text mode, add a `'t'` to the permission string, for example, `'rt'`, which forces the file to be opened in text mode. Similarly, use a `'b'` to force the file to be opened in binary mode (the default).

`[fid,message] = fopen(filename,permission,format)` opens a file as above, returning file identifier and message. In addition, you specify the numeric format with `format`, a string defining the numeric format of the file, allowing you to share files between machines of different formats. If you omit the `format` argument, the numeric format of the local machine is used. Individual calls to `fread` or `fwrite` can override the numeric format specified in a call to `fopen`.

`format` can be:

`'cray'` or `'c'`	Cray floating point with big-endian byte ordering
`'ieee-be'` or `'b'`	IEEE floating point with big-endian byte ordering
`'ieee-le'` or `'l'`	IEEE floating point with little-endian byte ordering
`'ieee-be.l64'` or `'s'`	IEEE floating point with big-endian byte ordering and 64-bit long data type
`'ieee-le.l64'` or `'a'`	IEEE floating point with little-endian byte ordering and 64-bit long data type

`'native'` or `'n'`	the numeric format of the machine you are currently running
`'vaxd'` or `'d'`	VAX D floating point and VAX ordering
`'vaxg'` or `'g'`	VAX G floating point and VAX ordering

`fids = fopen('all')` returns a row vector containing the file identifiers of all open files, not including `1` and `2` (standard output and standard error). The number of elements in the vector is equal to the number of open files.

`[filename,permission,format] = fopen(fid)` returns the full `filename` string, the `permission` string, and the `format` string associated with the specified file. An invalid `fid` returns empty strings for all output arguments. Both `permission` and `format` are optional.

See Also

`fclose`, `ferror`, `fprintf`, `fread`, `fscanf`, `fseek`, `ftell`, `fwrite`

Purpose

Repeat statements a specific number of times

Syntax

```
for variable = expression
    statements
end
```

Description

The general format is

```
for variable = expression
    statement
    ...
    statement
end
```

The columns of the *expression* are stored one at a time in the variable while the following statements, up to the `end`, are executed.

In practice, the *expression* is almost always of the form `scalar : scalar`, in which case its columns are simply scalars.

The scope of the `for` statement is always terminated with a matching `end`.

Examples

Assume `n` has already been assigned a value. Create the Hilbert matrix, using `zeros` to preallocate the matrix to conserve memory:

```
a = zeros(n,n)  % Preallocate matrix
for i = 1:n
    for j = 1:n
        a(i,j) = 1/(i+j -1);
    end
end
```

Step `s` with increments of `-0.1`

```
for s = 1.0: -0.1: 0.0,..., end
```

Successively set `e` to the unit `n`-vectors:

```
for e = eye(n),..., end
```

The line

```
for V = A,..., end
```

has the same effect as

```
for j = 1:n, V = A(:,j);..., end
```

except `j` is also set here.

See Also

`break`, `end`, `if`, `return`, `switch`, `while`

The colon operator `:`

Purpose

Control the output display format

Syntax

```
format
format type
```

Description

MATLAB performs all computations in double precision.The `format` command described below changes the display format.

Command	Result	Example
`format`	Default. Same as `short`.	
`format short`	5 digit scaled fixed point	`3.1416`
`format long`	15 digit scaled fixed point	`3.14159265358979`
`format short e`	5 digit floating point	`3.1416e+00`
`format long e`	15 digit floating point	`3.141592653589793e+00`
`format short g`	Best of 5 digit fixed or floating	`3.1416`
`format long g`	Best of 15 digit fixed or floating	`3.14159265358979`
`format hex`	Hexadecimal	`400921fb54442d18`
`format bank`	Fixed dollars and cents	`3.14`
`format rat`	Ratio of small integers	`355/113`
`format +`	+,–, blank	`+`
`format compact`	Suppresses excess line feeds	
`format loose`	Adds line feeds	

Algorithms

The command `format +` displays +, –, and blank characters for positive, negative, and zero elements. `format hex` displays the hexadecimal representation of a binary double-precision number. `format rat` uses a

continued fraction algorithm to approximate floating-point values by ratios of small integers. See `rat.m` for the complete code.

See Also

`fprintf`, `num2str`, `rat`, `sprintf`, `spy`

Purpose

Write formatted data to file

Syntax

```
count = fprintf(fid,format,A,...)
fprintf(format,A,...)
```

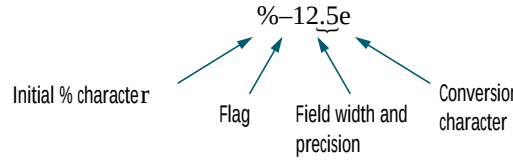
Description

`count = fprintf(fid,format,A,...)` formats the data in the real part of matrix `A` (and in any additional matrix arguments) under control of the specified `format` string, and writes it to the file associated with file identifier `fid`. `fprintf` returns a count of the number of bytes written.

Argument `fid` is an integer file identifier obtained from `fopen`. (It may also be `1` for standard output (the screen) or `2` for standard error. See `fopen` for more information.) Omitting `fid` from `fprintf`'s argument list causes output to appear on the screen, and is the same as writing to standard output (`fid = 1`).

`fprintf(format,A,...)` writes to standard output, the screen.

The `format` string specifies notation, alignment, significant digits, field width, and other aspects of output format. It can contain ordinary alphanumeric characters, along with escape characters, conversion specifiers, and other characters, organized as shown below.



Remarks

The `fprintf` function behaves like its ANSI C language `fprintf()` namesake with certain exceptions and extensions, including:

These non-standard subtype specifiers are supported for conversion specifiers %o, %u, %x, and %X.	b	The underlying C data type is a double rather than an unsigned integer. For example, to print a double-precision value in hexadecimal, use a format like '%bx'.
	t	The underlying C data type is a float rather than an unsigned integer.
When input matrix A is nonscalar, `fprintf` is *vectorized*.		The format string is cycled through the elements of A (columnwise) until all the elements are used up. It is then cycled in a similar manner, without reinitializing, through any additional matrix arguments.

The following tables describe the nonalphanumeric characters found in format specification strings.

Escape Characters

Character	Description
\b	Backspace
\f	Form feed
\n	New line
\r	Carriage return
\t	Horizontal tab
\\	Backslash
\'' or '' (two single quotes)	Single quotation mark
%%	Percent character

Conversion Specifiers

Conversion characters specify the notation of the output.

Specifier	Description
%c	Single character
%d	Decimal notation (signed)
%e	Exponential notation (using a lowercase e as in 3.1415e+00)
%E	Exponential notation (using an uppercase E as in 3.1415E+00)
%f	Fixed-point notation
%g	The more compact of %e or %f, as defined in [2]; insignificant zeros do not print

Specifier	Description
%G	Same as %g, but using an uppercase E
%o	Octal notation (unsigned)
%s	String of characters
%u	Decimal notation (unsigned)
%x	Hexadecimal notation (using lowercase letters a–f)
%X	Hexadecimal notation (using uppercase letters A–F)

Other Characters

Other characters can be inserted into the conversion specifier between the % and the conversion character.

Character	Description	Example
A minus sign (–)	Left-justifies the converted argument in its field.	%–5.2d
A plus sign (+)	Always prints a sign character (+ or –).	%+5.2d
Zero (0)	Pads with zeros rather than spaces.	%05.2d
Digits (field width)	A digit string that specifies the minimum number of digits to be printed.	%6f
Digits (precision)	A digit string including a period (.) that specifies the number of digits to be printed to the right of the decimal point.	%6.2f

For more information about format strings, refer to the printf() and fprintf() routines in the documents listed in “References”.

Examples

The statements

```
x = 0:.1:1;
y = [x; exp(x)];
fid = fopen('exp.txt','w');
fprintf(fid,'%6.2f %12.8f\n',y);
fclose(fid)
```

create a text file called `exp.txt` containing a short table of the exponential function:

```
0.00    1.00000000
0.10    1.10517092
...
1.00    2.71828183
```

The command

```
fprintf('A unit circle has circumference %g.\n',2*pi)
```

displays a line on the screen:

```
A unit circle has circumference 6.283186.
```

To insert a single quotation mark in a string, use two single quotation marks together. For example,

```
fprintf(1,'It''s Friday.\n')
```

displays on the screen:

```
It's Friday.
```

The commands

```
B = [8.8  7.7; 8800  7700]
fprintf(1,'X is %6.2f meters or %8.3f mm\n',9.9,9900,B)
```

display the lines:

```
X is 9.90 meters or 9900.000 mm
X is 8.80 meters or 8800.000 mm
X is 7.70 meters or 7700.000 mm
```

Explicitly convert MATLAB double-precision variables to integral values for use with an integral conversion specifier. For instance, to convert signed 32-bit data to hexadecimal format:

```
a = [6 10 14 44];
fprintf('%9X\n',a + (a<0)*2^32)
        6
        A
        E
       2C
```

See Also

`fclose`, `ferror`, `fopen`, `fread`, `fscanf`, `fseek`, `ftell`, `fwrite`

References

[1] Kernighan, B.W. and D.M. Ritchie, *The C Programming Language*, Second Edition, Prentice-Hall, Inc., 1988.

[2] ANSI specification X3.159-1989: “Programming Language C,” ANSI, 1430 Broadway, New York, NY 10018.

Purpose

Create and edit print frames for Simulink and Stateflow block diagrams

Syntax

```
frameedit
frameedit filename
```

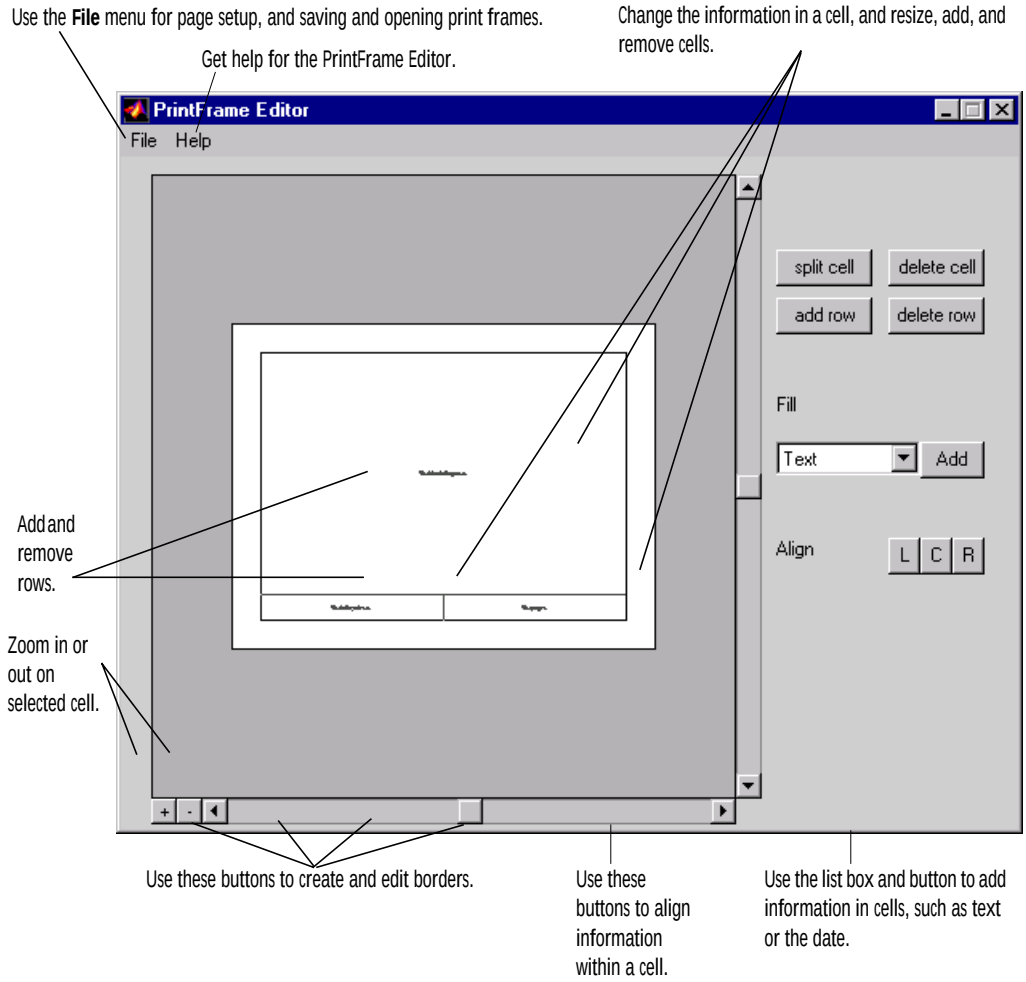
Description

`frameedit` starts the PrintFrame Editor, a graphical user interface you use to create borders for Simulink and Stateflow block diagrams. With no argument, `frameedit` opens the **PrintFrame Editor** window with a new file.

`frameedit filename` opens the **PrintFrame Editor** window with the specified filename, where `filename` is a figure file (`.fig`) previously created and saved using `frameedit`.

Remarks

This illustrates the main features of the PrintFrame Editor.



Closing the PrintFrame Editor

To close the **PrintFrame Editor** window, click the close box in the upper right corner, or select **Close** from the **File** menu.

Printing Simulink Block Diagrams with Print Frames

Select **Print** from the Simulink **File** menu. Check the **Frame** box and supply the filename for the print frame you want to use. Click **OK** in the **Print** dialog box.

Getting Help for the PrintFrame Editor

For further instructions on using the PrintFrame Editor, select **PrintFrame Editor Help** from the **Help** menu in the PrintFrame Editor.

fread

Purpose

Read binary data from file

Syntax

```
[A,count] = fread(fid,size,precision)
[A,count] = fread(fid,size,precision,skip)
```

Description

`[A,count] = fread(fid,size,precision)` reads binary data from the specified file and writes it into matrix `A`. Optional output argument `count` returns the number of elements successfully read. `fid` is an integer file identifier obtained from `fopen`.

`size` is an optional argument that determines how much data is read. If `size` is not specified, `fread` reads to the end of the file. Valid options are:

`n`	Reads `n` elements into a column vector.
`inf`	Reads to the end of the file, resulting in a column vector containing the same number of elements as are in the file.
`[m,n]`	Reads enough elements to fill an `m`-by-`n` matrix, filling in elements in column order, padding with zeros if the file is too small to fill the matrix.

If `fread` reaches the end of the file and the current input stream does not contain enough bits to write out a complete matrix element of the specified precision, `fread` pads the last byte or element with zero bits until the full value is obtained. If an error occurs, reading is done up to the last full value.

`precision` is a string representing the numeric precision of the values read, `precision` controls the number of bits read for each value and the interpretation of those bits as an integer, a floating-point value, or a character. The `precision` string may contain a positive integer repetition factor of the form `'n*'` which prepends one of the strings above, like `'40*uchar'`. If `precision` is not specified, the default `'uchar'` (8-bit unsigned character) is assumed. See “Remarks” for more information.

`[A,count] = fread(fid,size,precision,skip)` includes an optional `skip` argument that specifies the number of bytes to skip after each `precision` value is read. With the `skip` argument present, `fread` reads in one value and does a skip of input, reads in another value and does a skip of input, etc. for at most `size` times. This is useful for extracting data in noncontiguous fields from fixed

length records. If `precision` is a bit format like `'bitN'` or `'ubitN'`, `skip` is specified in bits.

Remarks

Numeric precisions can differ depending on how numbers are represented in your computer's architecture, as well as by the type of compiler used to produce executable code for your computer.

The tables below give C-compliant, platform-independent numeric precision string formats that you should use whenever you want your code to be portable.

For convenience, MATLAB accepts some C and Fortran data type equivalents for the MATLAB precisions listed. If you are a C or Fortran programmer, you may find it more convenient to use the names of the data types in the language with which you are most familiar.

MATLAB	C or Fortran	Interpretation
`'schar'`	`'signed char'`	Signed character; 8 bits
`'uchar'`	`'unsigned char'`	Unsigned character; 8 bits
`'int8'`	`'integer*1'`	Integer; 8 bits
`'int16'`	`'integer*2'`	Integer; 16 bits
`'int32'`	`'integer*4'`	Integer; 32 bits
`'int64'`	`'integer*8'`	Integer; 64 bits
`'uint8'`	`'integer*1'`	Unsigned integer; 8 bits
`'uint16'`	`'integer*2'`	Unsigned integer; 16 bits
`'uint32'`	`'integer*4'`	Unsigned integer; 32 bits
`'uint64'`	`'integer*8'`	Unsigned integer; 64 bits
`'float32'`	`'real*4'`	Floating-point; 32 bits
`'float64'`	`'real*8'`	Floating-point; 64 bits
`'double'`	`'real*8'`	Floating-point; 64 bits

If you always work on the same platform and do not care about portability, these platform-dependent numeric precision string formats are also available.

MATLAB	C or Fortran	Interpretation
`'char'`	`'char*1'`	Character; 8 bits
`'short'`	`'short'`	Integer; 16 bits
`'int'`	`'int'`	Integer; 32 bits
`'long'`	`'long'`	Integer; 32 or 64 bits
`'ushort'`	`'unsigned short'`	Unsigned integer; 16 bits
`'uint'`	`'unsigned int'`	Unsigned integer; 32 bits
`'ulong'`	`'unsigned long'`	Unsigned integer; 32 or 64 bits
`'float'`	`'float'`	Floating-point; 32 bits

Two formats map to an input stream of bits rather than bytes.

MATLAB	C or Fortran	Interpretation
`'bitN'`		Signed integer; `N` bits ($1 \le N \le 64$)
`'ubitN'`		Unsigned integer; `N` bits ($1 \le N \le 64$)

See Also

`fclose`, `ferror`, `fopen`, `fprintf`, `fread`, `fscanf`, `fseek`, `ftell`, `fwrite`

Purpose

Determine frequency spacing for frequency response

Syntax

```
[f1,f2] = freqspace(n)
[f1,f2] = freqspace([m n])
[x1,y1] = freqspace(...,'meshgrid')
f = freqspace(N)
f = freqspace(N,'whole')
```

Description

`freqspace` returns the implied frequency range for equally spaced frequency responses. `freqspace` is useful when creating desired frequency responses for various one- and two-dimensional applications.

`[f1,f2] = freqspace(n)` returns the two-dimensional frequency vectors `f1` and `f2` for an `n`-by-`n` matrix.

For `n` odd, both `f1` and `f2` are `[-n+1:2:n-1]/n`.

For `n` even, both `f1` and `f2` are `[-n:2:n-2]/n`.

`[f1,f2] = freqspace([m n])` returns the two-dimensional frequency vectors `f1` and `f2` for an `m`-by-`n` matrix.

`[x1,y1] = freqspace(...,'meshgrid')` is equivalent to

```
[f1,f2] = freqspace(...);
[x1,y1] = meshgrid(f1,f2);
```

`f = freqspace(N)` returns the one-dimensional frequency vector `f` assuming `N` evenly spaced points around the unit circle. For `N` even or odd, `f` is `(0:2/N:1)`. For `N` even, `freqspace` therefore returns `(N+2)/2` points. For `N` odd, it returns `(N+1)/2` points.

`f = freqspace(N,'whole')` returns `N` evenly spaced points around the whole unit circle. In this case, `f` is `0:2/N:2*(N-1)/N`.

See Also

`meshgrid`

frewind

Purpose Rewind an open file

Syntax `frewind(fid)`

Description `frewind(fid)` sets the file position indicator to the beginning of the file specified by `fid`, an integer file identifier obtained from `fopen`.

Remarks Rewinding a `fid` associated with a tape device may not work even though `frewind` does not generate an error message.

See Also `fclose`, `ferror`, `fopen`, `fprintf`, `fread`, `fscanf`, `fseek`, `ftell`, `fwrite`

Purpose

Read formatted data from file

Syntax

```
A = fscanf(fid,format)
[A,count] = fscanf(fid,format,size)
```

Description

`A = fscanf(fid,format)` reads all the data from the file specified by `fid`, converts it according to the specified `format` string, and returns it in matrix `A`. Argument `fid` is an integer file identifier obtained from `fopen`. `format` is a string specifying the format of the data to be read. See "Remarks" for details.

`[A,count] = fscanf(fid,format,size)` reads the amount of data specified by `size`, converts it according to the specified `format` string, and returns it along with a `count` of elements successfully read. `size` is an argument that determines how much data is read. Valid options are:

`n`	Read `n` elements into a column vector.
`inf`	Read to the end of the file, resulting in a column vector containing the same number of elements as are in the file.
`[m,n]`	Read enough elements to fill an `m`-by-`n` matrix, filling the matrix in column order. `n` can be `Inf`, but not `m`.

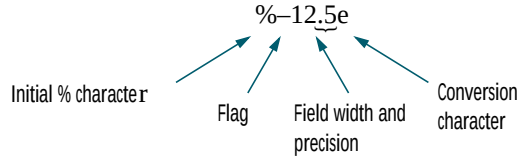
`fscanf` differs from its C language namesakes `scanf()` and `fscanf()` in an important respect — it is *vectorized* in order to return a matrix argument. The `format` string is cycled through the file until an end-of-file is reached or the amount of data specified by `size` is read in.

Remarks

When MATLAB reads a specified file, it attempts to match the data in the file to the format string. If a match occurs, the data is written into the matrix in column order. If a partial match occurs, only the matching data is written to the matrix, and the read operation stops.

The `format` string consists of ordinary characters and/or conversion specifications. Conversion specifications indicate the type of data to be

matched and involve the character %, optional width fields, and conversion characters, organized as shown below:



Add one or more of these characters between the % and the conversion character:

An asterisk (*)	Skip over the matched value, if the value is matched but not stored in the output matrix.
A digit string	Maximum field width.
A letter	The size of the receiving object; for example, `h` for short as in `%hd` for a short integer, or `l` for long as in `%ld` for a long integer or `%lg` for a double floating-point number.

Valid conversion characters are:

`%c`	Sequence of characters; number specified by field width
`%d`	Decimal numbers
`%e, %f, %g`	Floating-point numbers
`%i`	Signed integer
`%o`	Signed octal integer
`%s`	A series of non-white-space characters
`%u`	Signed decimal integer
`%x`	Signed hexadecimal integer
`[...]`	Sequence of characters (scanlist)

If `%s` is used, an element read may use several MATLAB matrix elements, each holding one character. Use `%c` to read space characters or `%s` to skip all white space.

Mixing character and numeric conversion specifications cause the resulting matrix to be numeric and any characters read to appear as their ASCII values, one character per MATLAB matrix element.

For more information about format strings, refer to the `scanf()` and `fscanf()` routines in a C language reference manual.

Examples

The example in `fprintf` generates an ASCII text file called `exp.txt` that looks like:

```
0.00    1.00000000
0.10    1.10517092
...
1.00    2.71828183
```

Read this ASCII file back into a two-column MATLAB matrix:

```
fid = fopen('exp.txt');
a = fscanf(fid,'%g %g',[2 inf]) % It has two rows now.
a = a';
fclose(fid)
```

See Also

`fgetl`, `fgets`, `fread`, `fprintf`, `fscanf`, `input`, `sscanf`, `textread`

fseek

Purpose

Set file position indicator

Syntax

```
status = fseek(fid,offset,origin)
```

Description

`status = fseek(fid,offset,origin)` repositions the file position indicator in the file with the given `fid` to the byte with the specified `offset` relative to `origin`.

Arguments

`fid` An integer file identifier obtained from `fopen`.

`offset` A value that is interpreted as follows:

- `offset > 0` Move position indicator `offset` bytes toward the end of the file.
- `offset = 0` Do not change position.
- `offset < 0` Move position indicator `offset` bytes toward the beginning of the file.

`origin` A string whose legal values are:

- `'bof'` `-1`: Beginning of file.
- `'cof'` `0`: Current position in file.
- `'eof'` `1`: End of file.

`status` A returned value that is `0` if the `fseek` operation is successful and `-1` if it fails. If an error occurs, use the function `ferror` to get more information.

See Also

`fopen`, `ftell`

Purpose

Get file position indicator

Syntax

```
position = ftell(fid)
```

Description

`position = ftell(fid)` returns the location of the file position indicator for the file specified by `fid`, an integer file identifier obtained from `fopen`. The `position` is a nonnegative integer specified in bytes from the beginning of the file. A returned value of `-1` for `position` indicates that the query was unsuccessful; use `ferror` to determine the nature of the error.

See Also

`fclose`, `ferror`, `fopen`, `fprintf`, `fread`, `fscanf`, `fseek`, `fwrite`

full

Purpose

Convert sparse matrix to full matrix

Syntax

```
A = full(S)
```

Description

`A = full(S)` converts a sparse matrix `S` to full storage organization. If `S` is a full matrix, it is left unchanged. If `A` is full, `issparse(A)` is `0`.

Remarks

Let `X` be an `m`-by-`n` matrix with `nz = nnz(X)` nonzero entries. Then `full(X)` requires space to store `m*n` real numbers while `sparse(X)` requires space to store `nz` real numbers and `(nz+n)` integers.

On most computers, a real number requires twice as much storage as an integer. On such computers, `sparse(X)` requires less storage than `full(X)` if the density, `nnz/prod(size(X))`, is less than one third. Operations on sparse matrices, however, require more execution time per element than those on full matrices, so density should be considerably less than two-thirds before sparse storage is used.

Examples

Here is an example of a sparse matrix with a density of about two-thirds. `sparse(S)` and `full(S)` require about the same number of bytes of storage.

```
S = sparse(rand(200,200) < 2/3);
A = full(S);
whos
Name     Size      Bytes   Class
  A    200X200   320000   double array (logical)
  S    200X200   318432   sparse array (logical)
```

See Also

`sparse`

Purpose

Build full filename from parts

Syntax

```
fullfile(dir1,dir2, ...,filename)
```

Description

`fullfile(dir1,dir2, ...,filename)` builds a full filename from the directories and filename specified. This is conceptually equivalent to

```
f = [dir1 dirsep dir2 dirsep ... dirsep filename]
```

except that care is taken to handle the cases when the directories begin or end with a directory separator. Specify the filename as `''` to build a pathname from parts. On VMS, care is taken to handle the cases involving `[or]`.

Examples

`fullfile(matlabroot,'toolbox/matlab/general/Contents.m')` and

`fullfile(matlabroot,'toolbox','matlab','general','Contents.m')`

produce the same result on UNIX, but only the second one works on all platforms.

function

Purpose

Function M-files

Description

You add new functions to MATLAB's vocabulary by expressing them in terms of existing functions. The existing commands and functions that compose the new function reside in a text file called an *M-file*.

M-files can be either *scripts* or *functions*. Scripts are simply files containing a sequence of MATLAB statements. Functions make use of their own local variables and accept input arguments.

The name of an M-file begins with an alphabetic character, and has a filename extension of `.m` . The M-file name, less its extension, is what MATLAB searches for when you try to use the script or function.

A line at the top of a function M-file contains the syntax definition. The name of a function, as defined in the first line of the M-file, should be the same as the name of the file without the `.m` extension. For example, the existence of a file on disk called `stat.m` with

```
function [mean,stdev] = stat(x)
n = length(x);
mean = sum(x)/n;
stdev = sqrt(sum((x–mean).^2/n));
```

defines a new function called `stat` that calculates the mean and standard deviation of a vector. The variables within the body of the function are all local variables.

A *subfunction*,visible only to the other functions in the same file, is created by defining a new function with the `function` keyword after the body of the preceding function or subfunction. For example, `avg` is a subfunction within the file `stat.m`:

```
function [mean,stdev] = stat(x)
n = length(x);
mean = avg(x,n);
stdev = sqrt(sum((x-avg(x,n)).^2)/n);

function mean = avg(x,n)
mean = sum(x)/n;
```

Subfunctions are not visible outside the file where they are defined. Functions normally return when the end of the function is reached. Use a `return` statement to force an early return.

When MATLAB does not recognize a function by name, it searches for a file of the same name on disk. If the function is found, MATLAB compiles it into memory for subsequent use. In general, if you input the name of something to MATLAB, the MATLAB interpreter:

1. Checks to see if the name is a variable.
2. Checks to see if the name is an internal function (`eig`, `sin`) that was not overloaded.
3. Checks to see if the name is a local function (local in sense of multifunction file).
4. Checks to see if the name is a function in a private directory.
5. Locates any and all occurrences of function in method directories and on the path. Order is of no importance.

At execution, MATLAB:

6. Checks to see if the name is wired to a specific function (2, 3, & 4 above)
7. Uses precedence rules to determine which instance from 5 above to call (we may default to an internal MATLAB function). Constructors have higher precedence than anything else.

When you call an M-file function from the command line or from within another M-file, MATLAB parses the function and stores it in memory. The parsed function remains in memory until cleared with the clear command or you `quit` MATLAB. The `pcode` command performs the parsing step and stores the result on the disk as a P-file to be loaded later.

See Also

`nargin`, `nargout`, `pcode`, `varargin`, `varargout`, `what`

funm

Purpose

Evaluate functions of a matrix

Syntax

```
Y = funm(X,'function')
[Y,esterr] = funm(X,'function')
```

Description

`Y = funm(X,'function')` evaluates *function* using Parlett's method [1]. `X` must be a square matrix, and *function* any element-wise function.

The commands `funm(X,'sqrt')` and `funm(X,'log')` are equivalent to the commands `sqrtm(X)` and `logm(X)`. The commands `funm(X,'exp')` and `expm(X)` compute the same function, but by different algorithms. `expm(X)` is preferred.

`[Y,esterr] = funm(X,'function')` does not print any message, but returns a very rough estimate of the relative error in the computer result. If `X` is symmetric or Hermitian, then its Schur form is diagonal, and `funm` is able to produce an accurate result.

Examples

The statements

```
S = funm(X,'sin');
C = funm(X,'cos');
```

produce the same results to within roundoff error as

```
E = expm(i*X);
C = real(E);
S = imag(E);
```

In either case, the results satisfy `S*S+C*C = I`, where `I = eye(size(X))`.

Algorithm

The matrix functions are evaluated using Parlett's algorithm, which is described in [1]. The algorithm uses the Schur factorization of the matrix and may give poor results or break down completely when the matrix has repeated eigenvalues. A warning message is printed when the results may be inaccurate.

See Also

`expm`, `logm`, `sqrtm`

References

[1] Golub, G. H. and C. F. Van Loan, *Matrix Computation*, Johns Hopkins University Press, 1983, p. 384.

[2] Moler, C. B. and C. F. Van Loan, "Nineteen Dubious Ways to Compute the Exponential of a Matrix," *SIAM Review 20*, 1979, pp. 801-836.

fwrite

Purpose

Write binary data to a file

Syntax

```
count = fwrite(fid,A,precision)
count = fwrite(fid,A,precision,skip)
```

Description

`count = fwrite(fid,A,precision)` writes the elements of matrix `A` to the specified file, translating MATLAB values to the specified numeric `precision`. (See "Remarks" for more information.)

The data is written to the file in column order, and a `count` is kept of the number of elements written successfully. Argument `fid` is an integer file identifier obtained from `fopen`.

`count = fwrite(fid,A,precision,skip)` includes an optional `skip` argument that specifies the number of bytes to skip before each `precision` value is written. With the `skip` argument present, `fwrite` skips and writes one value, skips and writes another value, etc. until all of `A` is written. This is useful for inserting data into noncontiguous fields in fixed-length records. If `precision` is a bit format like `'bitN'` or `'ubitN'`, `skip` is specified in bits.

Remarks

Numeric precisions can differ depending on how numbers are represented in your computer's architecture, as well as by the type of compiler used to produce executable code for your computer.

The tables below give C-compliant, platform-independent numeric precision string formats that you should use whenever you want your code to be portable.

For convenience, MATLAB accepts some C and Fortran data type equivalents for the MATLAB precisions listed. If you are a C or Fortran programmer, you may find it more convenient to use the names of the data types in the language with which you are most familiar.

MATLAB	C or Fortran	Interpretation
`'schar'`	`'signed char'`	Signed character; 8 bits
`'float32'`	`'real*4'`	Floating-point; 32 bits
`'float64'`	`'real*8'`	Floating-point; 64 bits

MATLAB	C or Fortran	Interpretation
'int8'	'integer*1'	Integer; 8 bits
'int16'	'integer*2'	Integer; 16 bits
'int32'	'integer*4'	Integer; 32 bits
'int64'	'integer*8'	Integer; 64 bits
'uchar'	'unsigned char'	Unsigned character; 8 bits
'uint8'	'integer*1'	Unsigned integer; 8 bits
'uint16'	'integer*2'	Unsigned integer; 16 bits
'uint32'	'integer*4'	Unsigned integer; 32 bits
'uint64'	'integer*8'	Unsigned integer; 64 bits
'double'	'double'	Floating-point; 64 bits

If you always work on the same platform and do not care about portability, these platform-dependent numeric precision string formats are also available.

MATLAB	C or Fortran	Interpretation
'char'	'char*1'	Character; 8 bits
'short'	'short'	Integer; 16 bits
'int'	'int'	Integer; 32 bits
'long'	'long'	Integer; 32 or 64 bits
'ushort'	'unsigned short'	Unsigned integer; 16 bits
'uint'	'unsigned int'	Unsigned integer; 32 bits
'ulong'	'unsigned long'	Unsigned integer; 32 or 64 bits
'float'	'float'	Floating-point; 32 bits

Two formats map to an input stream of bits rather than bytes:

MATLAB	C or Fortran	Interpretation
`'bitN'`		Signed integer; `N` bits (`1 ≤ N ≤ 64`)
`'ubitN'`		Unsigned integer; `N` bits (`1 ≤ N ≤ 64`)

Examples

```
fid = fopen('magic5.bin','wb');
fwrite(fid,magic(5),'integer*4')
```

creates a 100-byte binary file, containing the 25 elements of the 5-by-5 magic square, stored as 4-byte integers.

See Also

`fclose`, `ferror`, `fopen`, `fprintf`, `fread`, `fscanf`, `fseek`, `ftell`

Purpose

Zero of a function of one variable

Syntax

```
x = fzero(fun,x0)
x = fzero(fun,x0,options)
x = fzero(fun,x0,options,P1,P2,...)
[x,fval] = fzero(...)
[x,fval,exitflag] = fzero(...)
[x,fval,exitflag,output] = fzero(...)
```

Description

`x = fzero(fun,x0)` tries to find a zero of `fun` near `x0`. `fun` (usually an M-file, built-in function, or an inline object) should take a scalar real value and return a real scalar value when called with `feval`: `f=feval(fun,x)`. The value `x` returned by `fzero` is near a point where `fun` changes sign, or `NaN` if the search fails.

`x = fzero(fun,x0)` where `x0` is a vector of length two, assumes `x0` is an interval where the sign of `fun(x0(1))` differs from the sign of `fun(x0(2))`. An error occurs if this is not true. Calling `fzero` with such an interval guarantees `fzero` will return a value near a point where `fun` changes sign.

`x = fzero(fun,x0)` where `x0` is a scalar value, uses `x0` as a starting guess. `fzero` looks for an interval containing a sign change for `fun` and containing `x0`. If no such interval is found, `NaN` is returned. In this case, the search terminates when the search interval is expanded until an `Inf`, `NaN`, or complex value is found.

`x = fzero(fun,x0,options)` minimizes with the optimization parameters specified in the structure `options`. You can define these parameters using the `optimset` function. `fzero` uses these `options` structure fields:

- `Display` – Level of display. `off` displays no output; `iter` displays output at each iteration; `final` displays just the final output.
- `TolX` – Termination tolerance on `x`.

`x = fzero(fun,x0,options,P1,P2,...)` provides for additional arguments passed to the function, `f=feval(fun,x,P1,P2,...)`. Pass an empty matrix for `options` to use the default values.

`[x,fval] = fzero(...)` returns the value of the objective function `fun` at the solution `x`.

`[x,fval,exitflag] = fzero(...)` returns a value `exitflag` that describes the exit condition of `fzero`:

- `> 0` indicates that the function found a zero `x`.
- `< 0` then no interval was found with a sign change, or `NaN` or `Inf` function value was encountered during search for an interval containing a sign change, or a complex function value was encountered during search for an interval containing a sign change.

`[x,fval,exitflag,output] = fzero(...)` returns a structure `output` that contains information about the optimization:

- `output.algorithm` – The algorithm used.
- `output.funcCount` – The number of function evaluations.
- `output.iterations` – The number of iterations taken.

NOTE For the purposes of this command, zeros are considered to be points where the function actually crosses, not just touches, the *x*-axis.

Arguments

`fun` is a string containing the name of a file in which an arbitrary function of one variable is defined. `fun` can also be an inline object.

Other arguments are described in the syntax descriptions above.

Examples

Calculate π by finding the zero of the sine function near 3.

```
x = fzero('sin',3)
x =
    3.1416
```

To find the zero of cosine between 1 and 2

```
x = fzero('cos',[1 2])
x =
     1.5708
```

Note that `cos(1)` and `cos(2)` differ in sign.

To find a zero of the function

$$f(x) = x^3 - 2x - 5$$

write an M-file called `f.m`.

```
function y = f(x)
y = x.^3-2*x-5;
```

To find the zero near 2

```
z = fzero('f',2)
z =
    2.0946
```

Because this function is a polynomial, the statement `roots([1 0 -2 -5])` finds the same real zero, and a complex conjugate pair of zeros.

```
     2.0946
    -1.0473 + 1.1359i
    -1.0473 - 1.1359i
```

`fzero('abs(x)+1', 1)` returns `NaN` since this function does not change sign anywhere on the real axis (and does not have a zero as well).

Algorithm

The `fzero` command is an M-file. The algorithm, which was originated by T. Dekker, uses a combination of bisection, secant, and inverse quadratic interpolation methods. An Algol 60 version, with some improvements, is given in [1]. A Fortran version, upon which the `fzero` M-file is based, is in [2].

Limitations

The `fzero` command defines a *zero* as a point where the function crosses the *x*-axis. Points where the function touches, but does not cross, the *x*-axis are not valid zeros. For example, `y = x.^2` is a parabola that touches the *x*-axis at 0. Because the function never crosses the *x*-axis, however, no zero is found. For functions with no valid zeros, `fzero` executes until `Inf`, `NaN`, or a complex value is detected.

See Also

`roots`, `fminbnd`, `inline`, `optimset`

References

[1] Brent, R., *Algorithms for Minimization Without Derivatives*, Prentice-Hall, 1973.

[2] Forsythe, G. E., M. A. Malcolm, and C. B. Moler, *Computer Methods for Mathematical Computations*, Prentice-Hall, 1976.

Purpose

Test matrices

Syntax

```
[A,B,C,...] = gallery('tmfun',P1,P2,...)
gallery(3)  a badly conditioned 3-by-3 matrix
gallery(5)  an interesting eigenvalue problem
```

Description

`[A,B,C,...] = gallery('tmfun',P1,P2,...)` returns the test matrices specified by string *tmfun*. *tmfun* is the name of a matrix family selected from the table below. `P1, P2, ...` are input parameters required by the individual matrix family. The number of optional parameters `P1,P2, ...` used in the calling syntax varies from matrix to matrix.The exact calling syntaxes are detailed in the individual matrix descriptions below.

The gallery holds over fifty different test matrix functions useful for testing algorithms and other purposes.

Test Matrices			
cauchy	chebspec	chebvand	chow
circul	clement	compar	condex
cycol	dorr	dramadah	fiedler
forsythe	frank	gearmat	grcar
hanowa	house	invhess	invol
ipjfact	jordbloc	kahan	kms
krylov	lauchli	lehmer	lesp
lotkin	minij	moler	neumann
orthog	parter	pei	poisson
prolate	rando	randhess	randsvd
redheff	riemann	ris	rosser
smoke	toeppd	tridiag	triw
vander	wathen	wilk	

cauchy—Cauchy matrix

`C = gallery('cauchy',x,y)` returns an `n`-by-`n` matrix, `C(i,j) = 1/(x(i)+y(j))`. Arguments `x` and `y` are vectors of length `n`. If you pass in scalars for `x` and `y`, they are interpreted as vectors `1:x` and `1:y`.

`C = gallery('cauchy',x)` returns the same as above with `y = x`. That is, the command returns `C(i,j) = 1/(x(i)+x(j))`.

Explicit formulas are known for the inverse and determinant of a Cauchy matrix. The determinant `det(C)` is nonzero if `x` and `y` both have distinct elements. `C` is totally positive if `0 < x(1) <... < x(n)` and `0 < y(1) < ... < y(n)`.

chebspec—Chebyshev spectral differentiation matrix

`C = gallery('chebspec',n,`*switch*`)` returns a Chebyshev spectral differentiation matrix of order `n`. Argument *switch* is a variable that determines the character of the output matrix. By default, *switch* = `0`.

For *switch* = `0` ("no boundary conditions"), `C` is nilpotent ($C^n = 0$) and has the null vector `ones(n,1)`. The matrix `C` is similar to a Jordan block of size `n` with eigenvalue zero.

For *switch* = `1`, `C` is nonsingular and well-conditioned, and its eigenvalues have negative real parts.

The eigenvector matrix `V` of the Chebyshev spectral differentiation matrix is ill-conditioned.

chebvand—Vandermonde-like matrix for the Chebyshev polynomials

`C = gallery('chebvand',p)` produces the (primal) Chebyshev Vandermonde matrix based on the vector of points `p`, which define where the Chebyshev polynomial is calculated.

`C = gallery('chebvand',m,p)` where `m` is scalar, produces a rectangular version of the above, with `m` rows.

If `p` is a vector, then $C(i, j) = T_{i-1}(p(j))$ where T_{i-1} is the Chebyshev polynomial of degree `i-1`. If `p` is a scalar, then `p` equally spaced points on the interval `[0,1]` are used to calculate `C`.

chow—Singular Toeplitz lower Hessenberg matrix

`A = gallery('chow',n,alpha,delta)` returns `A` such that `A = H(alpha) + delta*eye(n)`, where $H_{i,j}(\alpha) = \alpha^{(i-j+1)}$ and argument `n` is the order of the Chow matrix. `alpha` and `delta` are scalars with default values `1` and `0`, respectively.

`H(alpha)` has `p = floor(n/2)` eigenvalues that are equal to zero. The rest of the eigenvalues are equal to `4*alpha*cos(k*pi/(n+2))^2`, `k=1:n-p`.

circul—Circulant matrix

`C = gallery('circul',v)` returns the circulant matrix whose first row is the vector `v`.

A circulant matrix has the property that each row is obtained from the previous one by cyclically permuting the entries one step forward. It is a special Toeplitz matrix in which the diagonals "wrap around."

If `v` is a scalar, then `C = gallery('circul',1:v)`.

The eigensystem of `C` (`n`-by-`n`) is known explicitly: If `t` is an `n`th root of unity, then the inner product of `v` with $w = [1\ t\ t^2\ \ldots\ t^n]$ is an eigenvalue of `C` and `w(n:-1:1)` is an eigenvector.

clement—Tridiagonal matrix with zero diagonal entries

`A = gallery('clement',n,sym)` returns an `n` by `n` tridiagonal matrix with zeros on its main diagonal and known eigenvalues. It is singular if order `n` is odd. About 64 percent of the entries of the inverse are zero. The eigenvalues include plus and minus the numbers `n-1`, `n-3`, `n-5`, . . ., as well as (for odd `n`) a final eigenvalue of `1` or `0`.

Argument `sym` determines whether the Clement matrix is symmetric. For `sym = 0` (the default) the matrix is nonsymmetric, while for `sym = 1`, it is symmetric.

compar—Comparison matrices

`A = gallery('compar',A,1)` returns `A` with each diagonal element replaced by its absolute value, and each off-diagonal element replaced by minus the absolute value of the largest element in absolute value in its row. However, if `A` is triangular `compar(A,1)` is too.

`gallery('compar',A)` is `diag(B) - tril(B,-1) - triu(B,1)`, where `B = abs(A)`. `compar(A)` is often denoted by M(*A*) in the literature.

`gallery('compar',A,0)` is the same as `compar(A)`.

condex—Counter-examples to matrix condition number estimators

`A = gallery('condex',n,k,theta)` returns a "counter-example" matrix to a condition estimator. It has order `n` and scalar parameter `theta` (default 100).

The matrix, its natural size, and the estimator to which it applies are specified by `k` as follows:

`k = 1`	4-by-4	LINPACK (`rcond`)
`k = 2`	3-by-3	LINPACK (`rcond`)
`k = 3`	arbitrary	LINPACK (`rcond`) (independent of `theta`)
`k = 4`	$n \geq 4$	SONEST (Higham 1988) (default)

If `n` is not equal to the natural size of the matrix, then the matrix is padded out with an identity matrix to order `n`.

cycol—Matrix whose columns repeat cyclically

`A = gallery('cycol',[m n],k)` returns an `m`-by-`n` matrix with cyclically repeating columns, where one "cycle" consists of `randn(m,k)`. Thus, the rank of matrix `A` cannot exceed `k`. `k` must be a scalar.

Argument `k` defaults to `round(n/4)`, and need not evenly divide `n`.

`A = gallery('cycol',n,k)`, where `n` is a scalar, is the same as `gallery('cycol',[n n],k)`.

dorr—Diagonally dominant, ill-conditioned, tridiagonal matrix

`[c,d,e] = gallery('dorr',n,theta)` returns the vectors defining a row diagonally dominant, tridiagonal order `n` matrix that is ill-conditioned for small nonnegative values of `theta`. The default value of `theta` is `0.01`. The Dorr matrix itself is the same as `gallery('tridiag',c,d,e)`.

`A = gallery('dorr',n,theta)` returns the matrix itself, rather than the defining vectors.

dramadah—Matrix of zeros and ones whose inverse has large integer entries

`A = gallery('dramadah',n,k)` returns an `n`-by-`n` matrix of `0`'s and `1`'s for which `mu(A) = norm(inv(A),'fro')` is relatively large, although not necessarily maximal. An anti-Hadamard matrix `A` is a matrix with elements `0` or `1` for which `mu(A)` is maximal.

`n` and `k` must both be scalars. Argument `k` determines the character of the output matrix:

`k = 1`	Default. `A` is Toeplitz, with `abs(det(A)) = 1`, and `mu(A) > c(1.75)^n`, where `c` is a constant. The inverse of `A` has integer entries.
`k = 2`	`A` is upper triangular and Toeplitz. The inverse of `A` has integer entries.
`k = 3`	`A` has maximal determinant among lower Hessenberg (0,1) matrices. `det(A)` = the `n`th Fibonacci number. `A` is Toeplitz. The eigenvalues have an interesting distribution in the complex plane.

fiedler—Symmetric matrix

`A = gallery('fiedler',c)`, where `c` is a length `n` vector, returns the `n`-by-`n` symmetric matrix with elements `abs(n(i)–n(j))`. For scalar `c`, `A = gallery('fiedler',1:c)`.

Matrix `A` has a dominant positive eigenvalue and all the other eigenvalues are negative.

Explicit formulas for `inv(A)` and `det(A)` are given in [Todd, J., *Basic Numerical Mathematics*, Vol. 2: Numerical Algebra, Birkhauser, Basel, and Academic Press, New York, 1977, p. 159] and attributed to Fiedler. These indicate that `inv(A)` is tridiagonal except for nonzero `(1,n)` and `(n,1)` elements.

forsythe—Perturbed Jordan block

`A = gallery('forsythe',n,alpha,lambda)` returns the `n`-by-`n` matrix equal to the Jordan block with eigenvalue `lambda`, excepting that `A(n,1) = alpha`. The default values of scalars `alpha` and `lambda` are `sqrt(eps)` and `0`, respectively.

The characteristic polynomial of `A` is given by:

```
det(A-t*I) = (lambda-t)^N - alpha*(-1)^n.
```

frank—Matrix with ill-conditioned eigenvalues

`F = gallery('frank',n,k)` returns the Frank matrix of order `n`. It is upper Hessenberg with determinant `1`. If `k = 1`, the elements are reflected about the anti-diagonal `(1,n)`—`(n,1)`. The eigenvalues of `F` may be obtained in terms of the zeros of the Hermite polynomials. They are positive and occur in reciprocal pairs; thus if `n` is odd, `1` is an eigenvalue. `F` has `floor(n/2)` ill-conditioned eigenvalues—the smaller ones.

gearmat—Gear matrix

`A = gallery('gearmat',n,i,j)` returns the `n`-by-`n` matrix with ones on the sub- and super-diagonals, `sign(i)` in the `(1,abs(i))` position, `sign(j)` in the `(n,n+1-abs(j))` position, and zeros everywhere else. Arguments `i` and `j` default to `n` and `-n`, respectively.

Matrix `A` is singular, can have double and triple eigenvalues, and can be defective.

All eigenvalues are of the form `2*cos(a)` and the eigenvectors are of the form `[sin(w+a), sin(w+2a), ..., sin(w+Na)]`, where `a` and `w` are given in Gear, C. W., "A Simple Set of Test Matrices for Eigenvalue Programs", *Math. Comp.*, Vol. 23 (1969), pp. 119–125.

grcar—Toeplitz matrix with sensitive eigenvalues

`A = gallery('grcar',n,k)` returns an `n`-by-`n` Toeplitz matrix with `-1`s on the subdiagonal, `1`s on the diagonal, and `k` superdiagonals of `1`s. The default is `k = 3`. The eigenvalues are sensitive.

hanowa—Matrix whose eigenvalues lie on a vertical line in the complex plane

`A = gallery('hanowa',n,d)` returns an `n`-by-`n` block 2-by-2 matrix of the form:

```
[d*eye(m)   -diag(1:m)
diag(1:m)   d*eye(m)]
```

Argument `n` is an even integer `n=2*m`. Matrix `A` has complex eigenvalues of the form `d ± k*i`, for `1 <= k <= m`. The default value of `d` is `-1`.

house—Householder matrix

`[v, beta] = gallery('house',x)` takes `x`, a scalar or `n`-element column vector, and returns `v` and `beta` such that `eye(n,n) - beta*v*v'` is a Householder matrix. A Householder matrix `H` satisfies the relationship

```
H*x = -sign(x(1))*norm(x)*e1
```

where `e1` is the first column of `eye(n,n)`. Note that if `x` is complex, then `sign(x) = exp(i*arg(x))` (which equals `x./abs(x)` when `x` is nonzero).

If `x = 0`, then `v = 0` and `beta = 1`.

invhess—Inverse of an upper Hessenberg matrix

`A = gallery('invhess',x,y)`, where `x` is a length `n` vector and `y` a length `n-1` vector, returns the matrix whose lower triangle agrees with that of `ones(n,1)*x'` and whose strict upper triangle agrees with that of `[1 y]*ones(1,n)`.

The matrix is nonsingular if `x(1) ~= 0` and `x(i+1) ~= y(i)` for all `i`, and its inverse is an upper Hessenberg matrix. Argument `y` defaults to `-x(1:n-1)`.

If `x` is a scalar, `invhess(x)` is the same as `invhess(1:x)`.

invol—Involutory matrix

`A = gallery('invol',n)` returns an `n`-by-`n` involutory (`A*A = eye(n)`) and ill-conditioned matrix. It is a diagonally scaled version of `hilb(n)`.

`B = (eye(n)-A)/2` and `B = (eye(n)+A)/2` are idempotent (`B*B = B`).

ipjfact—Hankel matrix with factorial elements

`[A,d] = gallery('ipjfact',n,k)` returns `A`, an `n`-by-`n` Hankel matrix, and `d`, the determinant of `A`, which is known explicitly. If `k = 0` (the default), then the elements of `A` are `A(i,j) = (i+j)!` If `k = 1`, then the elements of `A` are `A(i,j) = 1/(i+j)`.

Note that the inverse of `A` is also known explicitly.

jordbloc—Jordan block

`A = gallery('jordbloc',n,lambda)` returns the `n`-by-`n` Jordan block with eigenvalue `lambda`. The default value for `lambda` is `1`.

kahan—Upper trapezoidal matrix

`A = gallery('kahan',n,theta,pert)` returns an upper trapezoidal matrix that has interesting properties regarding estimation of condition and rank.

If `n` is a two-element vector, then `A` is `n(1)`-by-`n(2)`; otherwise, `A` is `n`-by-`n`. The useful range of `theta` is `0 < theta < pi`, with a default value of `1.2`.

To ensure that the QR factorization with column pivoting does not interchange columns in the presence of rounding errors, the diagonal is perturbed by `pert*eps*diag([n:-1:1])`. The default `pert` is `25`, which ensures no interchanges for `gallery('kahan',n)` up to at least `n = 90` in IEEE arithmetic.

kms—Kac-Murdock-Szego Toeplitz matrix

`A = gallery('kms',n,rho)` returns the `n`-by-`n` Kac-Murdock-Szego Toeplitz matrix such that `A(i,j) = rho^(abs(i-j))`, for real `rho`.

For complex `rho`, the same formula holds except that elements below the diagonal are conjugated. `rho` defaults to 0.5.

The KMS matrix A has these properties:

- An LDL' factorization with `L = inv(triw(n,-rho,1)')`, and `D(i,i) = (1-abs(rho)^2)*eye(n)`, except `D(1,1) = 1`.
- Positive definite if and only if `0 < abs(rho) < 1`.
- The inverse `inv(A)` is tridiagonal.

krylov—Krylov matrix

`B = gallery('krylov',A,x,j)` returns the Krylov matrix

```
[x, Ax, A^2x, ..., A^(j-1)x]
```

where A is an n-by-n matrix and x is a length n vector. The defaults are `x = ones(n,1)`, and `j = n`.

`B = gallery('krylov',n)` is the same as `gallery('krylov',(randn(n))`.

lauchli—Rectangular matrix

`A = gallery('lauchli',n,mu)` returns the `(n+1)`-by-n matrix

```
[ones(1,n); mu*eye(n)]
```

The Lauchli matrix is a well-known example in least squares and other problems that indicates the dangers of forming `A'*A`. Argument `mu` defaults to `sqrt(eps)`.

lehmer—Symmetric positive definite matrix

`A = gallery('lehmer',n)` returns the symmetric positive definite n-by-n matrix such that `A(i,j) = i/j` for `j >= i`.

The Lehmer matrix A has these properties:

- A is totally nonnegative.
- The inverse `inv(A)` is tridiagonal and explicitly known.
- The order `n <= cond(A) <= 4*n*n`.

lesp—Tridiagonal matrix with real, sensitive eigenvalues

`A = gallery('lesp',n)` returns an `n`-by-`n` matrix whose eigenvalues are real and smoothly distributed in the interval approximately `[-2*N-3.5, -4.5]`.

The sensitivities of the eigenvalues increase exponentially as the eigenvalues grow more negative. The matrix is similar to the symmetric tridiagonal matrix with the same diagonal entries and with off-diagonal entries 1, via a similarity transformation with `D = diag(1!,2!,...,n!)`.

lotkin—Lotkin matrix

`A = gallery('lotkin',n)` returns the Hilbert matrix with its first row altered to all ones. The Lotkin matrix `A` is nonsymmetric, ill-conditioned, and has many negative eigenvalues of small magnitude. Its inverse has integer entries and is known explicitly.

minij—Symmetric positive definite matrix

`A = gallery('minij',n)` returns the `n`-by-`n` symmetric positive definite matrix with `A(i,j) = min(i,j)`.

The `minij` matrix has these properties:

- The inverse `inv(A)` is tridiagonal and equal to `-1` times the second difference matrix, except its `(n,n)` element is `1`.
- Givens' matrix, `2*A-ones(size(A))`, has tridiagonal inverse and eigenvalues `0.5*sec((2*r-1)*pi/(4*n))^2`, where `r=1:n`.
- `(n+1)*ones(size(A))-A` has elements that are `max(i,j)` and a tridiagonal inverse.

moler—Symmetric positive definite matrix

`A = gallery('moler',n,alpha)` returns the symmetric positive definite `n`-by-`n` matrix `U'*U`, where `U = triw(n,alpha)`.

For the default `alpha = -1`, `A(i,j) = min(i,j)-2`, and `A(i,i) = i`. One of the eigenvalues of `A` is small.

neumann—Singular matrix from the discrete Neumann problem (sparse)

`C = gallery('neumann',n)` returns the singular, row-diagonally dominant matrix resulting from discretizing the Neumann problem with the usual five-point operator on a regular mesh. Argument `n` is a perfect square integer $n = m^2$ or a two-element vector. `C` is sparse and has a one-dimensional null space with null vector `ones(n,1)`.

orthog—Orthogonal and nearly orthogonal matrices

`Q = gallery('orthog',n,k)` returns the kth type of matrix of order `n`, where `k > 0` selects exactly orthogonal matrices, and `k < 0` selects diagonal scalings of orthogonal matrices. Available types are:

`k = 1` `Q(i,j) = sqrt(2/(n+1)) * sin(i*j*pi/(n+1))`
Symmetric eigenvector matrix for second difference matrix. This is the default.

`k = 2` `Q(i,j) = 2/(sqrt(2*n+1)) * sin(2*i*j*pi/(2*n+1))`
Symmetric.

`k = 3` `Q(r,s) = exp(2*pi*i*(r-1)*(s-1)/n) / sqrt(n)`
Unitary, the Fourier matrix. Q^4 is the identity. This is essentially the same matrix as `fft(eye(n))/sqrt(n)`!

`k = 4` Helmert matrix: a permutation of a lower Hessenberg matrix, whose first row is `ones(1:n)/sqrt(n)`.

`k = 5` `Q(i,j) = sin(2*pi*(i-1)*(j-1)/n) + cos(2*pi*(i-1)*(j-1)/n)`
Symmetric matrix arising in the Hartley transform.

`k = -1` `Q(i,j) = cos((i-1)*(j-1)*pi/(n-1))`
Chebyshev Vandermonde-like matrix, based on extrema of `T(n-1)`.

`k = -2` `Q(i,j) = cos((i-1)*(j-1/2)*pi/n))`
Chebyshev Vandermonde-like matrix, based on zeros of `T(n)`.

parter—Toeplitz matrix with singular values near pi

`C = gallery('parter',n)` returns the matrix `C` such that `C(i,j) = 1/(i-j+0.5)`.

`C` is a Cauchy matrix and a Toeplitz matrix. Most of the singular values of `C` are very close to `pi`.

pei—Pei matrix

`A = gallery('pei',n,alpha)`, where `alpha` is a scalar, returns the symmetric matrix `alpha*eye(n) + ones(n)`. The default for `alpha` is 1. The matrix is singular for `alpha` equal to either `0` or `–n`.

poisson—Block tridiagonal matrix from Poisson's equation (sparse)

`A = gallery('poisson',n)` returns the block tridiagonal (sparse) matrix of order `n^2` resulting from discretizing Poisson's equation with the 5-point operator on an `n`-by-`n` mesh.

prolate—Symmetric, ill-conditioned Toeplitz matrix

`A = gallery('prolate',n,w)` returns the `n`-by-`n` prolate matrix with parameter `w`. It is a symmetric Toeplitz matrix.

If `0 < w < 0.5` then `A` is positive definite

- The eigenvalues of `A` are distinct, lie in `(0,1)`, and tend to cluster around `0` and `1`.
- The default value of `w` is 0.25.

randhess—Random, orthogonal upper Hessenberg matrix

`H = gallery('randhess',n)` returns an `n`-by-`n` real, random, orthogonal upper Hessenberg matrix.

`H = gallery('randhess',x)` if `x` is an arbitrary, real, length `n` vector with `n > 1`, constructs `H` nonrandomly using the elements of `x` as parameters.

Matrix `H` is constructed via a product of `n–1` Givens rotations.

rando—Random matrix composed of elements –1, 0 or 1

`A = gallery('rando',n,k)` returns a random `n`-by-`n` matrix with elements from one of the following discrete distributions:

`k = 1`	`A(i,j) = 0` or `1` with equal probability (default)
`k = 2`	`A(i,j) = –1` or `1` with equal probability
`k = 3`	`A(i,j) = –1`, `0` or `1` with equal probability

Argument `n` may be a two-element vector, in which case the matrix is `n(1)`-by-`n(2)`.

randsvd—Random matrix with preassigned singular values

`A = gallery('randsvd',n,kappa,mode,kl,ku)` returns a banded (multidiagonal) random matrix of order `n` with `cond(A) = kappa` and singular values from the distribution mode. If `n` is a two-element vector, `A` is `n(1)`-by-`n(2)`.

Arguments `kl` and `ku` specify the number of lower and upper off-diagonals, respectively, in `A`. If they are omitted, a full matrix is produced. If only `kl` is present, `ku` defaults to `kl`.

Distribution `mode` may be:

`1`	One large singular value
`2`	One small singular value
`3`	Geometrically distributed singular values (default)

`1`	One large singular value
`4`	Arithmetically distributed singular values
`5`	Random singular values with uniformly distributed logarithm
`< 0`	If `mode` is `-1`, `-2`, `-3`, `-4`, or `-5`, then `randsvd` treats `mode` as `abs(mode)`, except that in the original matrix of singular values the order of the diagonal entries is reversed: small to large instead of large to small.

Condition number `kappa` defaults to `sqrt(1/eps)`. In the special case where `kappa < 0`, `A` is a random, full, symmetric, positive definite matrix with `cond(A) = -kappa` and eigenvalues distributed according to `mode`. Arguments `kl` and `ku`, if present, are ignored.

redheff—Redheffer's matrix of 1s and 0s

`A = gallery('redheff',n)` returns an `n`-by-`n` matrix of `0`'s and `1`'s defined by `A(i,j) = 1`, if `j = 1` or if `i` divides `j`, and `A(i,j) = 0` otherwise.

The Redheffer matrix has these properties:

- `(n-floor(log2(n)))-1` eigenvalues equal to `1`
- A real eigenvalue (the spectral radius) approximately `sqrt(n)`
- A negative eigenvalue approximately `-sqrt(n)`
- The remaining eigenvalues are provably "small."
- The Riemann hypothesis is true if and only if `det(A)` = O(`n^(1/2+epsilon)`) for every epsilon `> 0`.

Barrett and Jarvis conjecture that "the small eigenvalues all lie inside the unit circle `abs(Z) = 1`," and a proof of this conjecture, together with a proof that some eigenvalue tends to zero as `n` tends to infinity, would yield a new proof of the prime number theorem.

riemann—Matrix associated with the Riemann hypothesis

`A = gallery('riemann',n)` returns an `n`-by-`n` matrix for which the Riemann hypothesis is true if and only if `det(A)` = O(`n! n^(-1/2+epsilon)`) for every epsilon `> 0`.

The Riemann matrix is defined by:

```
A = B(2:n+1,2:n+1)
```

where `B(i,j) = i-1` if `i` divides `j`, and `B(i,j) = -1` otherwise.

The Riemann matrix has these properties:

- Each eigenvalue `e(i)` satisfies `abs(e(i)) <= m-1/m`, where `m = n+1`.
- `i <= e(i) <= i+1` with at most `m-sqrt(m)` exceptions.
- All integers in the interval `(m/3, m/2]` are eigenvalues.

ris—Symmetric Hankel matrix

`A = gallery('ris',n)` returns a symmetric `n`-by-`n` Hankel matrix with elements

```
A(i,j) = 0.5/(n-i-j+1.5)
```

The eigenvalues of `A` cluster around $\pi/2$ and $-\pi/2$. This matrix was invented by F.N. Ris.

rosser—Classic symmetric eigenvalue test matrix

`A = rosser` returns the Rosser matrix. This matrix was a challenge for many matrix eigenvalue algorithms. But the Francis QR algorithm, as perfected by Wilkinson and implemented in EISPACK and MATLAB, has no trouble with it. The matrix is 8-by-8 with integer elements. It has:

- A double eigenvalue
- Three nearly equal eigenvalues
- Dominant eigenvalues of opposite sign
- A zero eigenvalue
- A small, nonzero eigenvalue

smoke—Complex matrix with a 'smoke ring' pseudospectrum

`A = gallery('smoke',n)` returns an `n`-by-`n` matrix with `1`'s on the superdiagonal, `1` in the `(n,1)` position, and powers of roots of unity along the diagonal.

`A = gallery('smoke',n,1)` returns the same except that element `A(n,1)` is zero.

The eigenvalues of `smoke(n,1)` are the nth roots of unity; those of `smoke(n)` are the *n*th roots of unity times `2^(1/n)`.

toeppd—Symmetric positive definite Toeplitz matrix

`A = gallery('toeppd',n,m,w,theta)` returns an `n`-by-`n` symmetric, positive semi-definite (SPD) Toeplitz matrix composed of the sum of `m` rank 2 (or, for certain `theta`, rank 1) SPD Toeplitz matrices. Specifically,

```
T = w(1)*T(theta(1)) + ... + w(m)*T(theta(m))
```

where `T(theta(k))` has `(i,j)` element `cos(2*pi*theta(k)*(i-j))`.

By default: `m = n`, `w = rand(m,1)`, and `theta = rand(m,1)`.

toeppen—Pentadiagonal Toeplitz matrix (sparse)

`P = gallery('toeppen',n,a,b,c,d,e)` returns the `n`-by-`n` sparse, pentadiagonal Toeplitz matrix with the diagonals: `P(3,1) = a`, `P(2,1) = b`, `P(1,1) = c`, `P(1,2) = d`, and `P(1,3) = e`, where `a`, `b`, `c`, `d`, and `e` are scalars.

By default, `(a,b,c,d,e) = (1,-10,0,10,1)`, yielding a matrix of Rutishauser. This matrix has eigenvalues lying approximately on the line segment `2*cos(2*t) + 20*i*sin(t)`.

tridiag—Tridiagonal matrix (sparse)

`A = gallery('tridiag',c,d,e)` returns the tridiagonal matrix with subdiagonal `c`, diagonal `d`, and superdiagonal `e`. Vectors `c` and `e` must have `length(d)-1`.

`A = gallery('tridiag',n,c,d,e)`, where `c`, `d`, and `e` are all scalars, yields the Toeplitz tridiagonal matrix of order `n` with subdiagonal elements `c`, diagonal elements `d`, and superdiagonal elements `e`. This matrix has eigenvalues

```
d + 2*sqrt(c*e)*cos(k*pi/(n+1))
```

where `k = 1:n`. (see [1].)

`A = gallery('tridiag',n)` is the same as
`A = gallery('tridiag',n,-1,2,-1)`, which is a symmetric positive definite M-matrix (the negative of the second difference matrix).

triw—Upper triangular matrix discussed by Wilkinson and others

`A = gallery('triw',n,alpha,k)` returns the upper triangular matrix with ones on the diagonal and `alpha`s on the first `k >= 0` superdiagonals.

Order `n` may be a 2-vector, in which case the matrix is `n(1)`-by-`n(2)` and upper trapezoidal.

Ostrowski ["On the Spectrum of a One-parametric Family of Matrices, *J. Reine Angew. Math.*, 1954] shows that

```
cond(gallery('triw',n,2)) = cot(pi/(4*n))^2,
```

and, for large `abs(alpha)`, `cond(gallery('triw',n,alpha))` is approximately `abs(alpha)^n*sin(pi/(4*n-2))`.

Adding `-2^(2-n)` to the `(n,1)` element makes `triw(n)` singular, as does adding `-2^(1-n)` to all the elements in the first column.

vander—Vandermonde matrix

`A = gallery('vander',c)` returns the Vandermonde matrix whose second to last column is `c`. The `j`th column of a Vandermonde matrix is given by `A(:,j) = C^(n-j)`.

wathen—Finite element matrix (sparse, random entries)

`A = gallery('wathen',nx,ny)` returns a sparse, random, `n`-by-`n` finite element matrix where

```
n = 3*nx*ny + 2*nx + 2*ny + 1.
```

Matrix `A` is precisely the "consistent mass matrix" for a regular `nx`-by-`ny` grid of 8-node (serendipity) elements in two dimensions. `A` is symmetric, positive definite for any (positive) values of the "density," `rho(nx,ny)`, which is chosen randomly in this routine.

`A = gallery('wathen',nx,ny,1)` returns a diagonally scaled matrix such that

```
0.25 <= eig(inv(D)*A) <= 4.5
```

where `D = diag(diag(A))` for any positive integers `nx` and `ny` and any densities `rho(nx,ny)`.

wilk—Various matrices devised or discussed by Wilkinson

`[A,b] = gallery('wilk',n)` returns a different matrix or linear system depending on the value of `n`:

n	MATLAB Code	Result
`n = 3`	`[A,b] = gallery('wilk',3)`	Upper triangular system `Ux=b` illustrating inaccurate solution.
`n = 4`	`[A,b] = gallery('wilk',4)`	Lower triangular system `Lx=b`, ill-conditioned.
`n = 5`	`A = gallery('wilk',5)`	`hilb(6)(1:5,2:6)*1.8144`. A symmetric positive definite matrix.
`n = 21`	`A = gallery('wilk',21)`	`W21+`, tridiagonal matrix. Eigenvalue problem.

See Also hadamard, hilb, invhilb, magic, wilkinson

References

The MATLAB gallery of test matrices is based upon the work of Nicholas J. Higham at the Department of Mathematics, University of Manchester, Manchester, England. Additional detail on these matrices is documented in *The Test Matrix Toolbox for MATLAB (Version 3.0)* by N. J. Higham, September, 1995. To obtain this report in pdf format, enter the doc command at the MATLAB prompt and select the item Related Papers > Test Matrix Toolbox under the Full Documentation Set entry on the Help Desk main screen. This report is also available via anonymous ftp from The MathWorks at /pub/contrib/linalg/testmatrix/testmatrix.ps or World Wide Web (ftp://ftp.ma.man.ac.uk/pub/narep or http://www.ma.man.ac.uk/MCCM/MCCM.html). Further background may be found in the book *Accuracy and Stability of Numerical Algorithms*, Nicholas J. Higham, SIAM, 1996.

Purpose

Gamma functions

Syntax

`Y = gamma(A)`	Gamma function
`Y = gammainc(X,A)`	Incomplete gamma function
`Y = gammaln(A)`	Logarithm of gamma function

Definition

The gamma function is defined by the integral:

$$\Gamma(a) = \int_0^\infty e^{-t}\, t^{a-1}\, dt$$

The gamma function interpolates the factorial function. For integer `n`:

```
gamma(n+1) = n! = prod(1:n)
```

The incomplete gamma function is:

$$P(x, a) = \frac{1}{\Gamma(a)} \int_0^x e^{-t} t^{a-1} dt$$

Description

`Y = gamma(A)` returns the gamma function at the elements of `A`. `A` must be real.

`Y = gammainc(X,A)` returns the incomplete gamma function of corresponding elements of `X` and `A`. Arguments `X` and `A` must be real and the same size (or either can be scalar).

`Y = gammaln(A)` returns the logarithm of the gamma function, `gammaln(A) = log(gamma(A))`. The `gammaln` command avoids the underflow and overflow that may occur if it is computed directly using `log(gamma(A))`.

Algorithm

The computations of `gamma` and `gammaln` are based on algorithms outlined in [1]. Several different minimax rational approximations are used depending upon the value of `A`. Computation of the incomplete gamma function is based on the algorithm in [2].

References

[1] Cody, J., *An Overview of Software Development for Special Functions*, Lecture Notes in Mathematics, 506, Numerical Analysis Dundee, G. A. Watson (ed.), Springer Verlag, Berlin, 1976.

[2] Abramowitz, M. and I.A. Stegun, *Handbook of Mathematical Functions*, National Bureau of Standards, Applied Math. Series #55, Dover Publications, 1965, sec. 6.5.

Purpose

Greatest common divisor

Syntax

```
G = gcd(A,B)
[G,C,D] = gcd(A,B)
```

Description

`G = gcd(A,B)` returns an array containing the greatest common divisors of the corresponding elements of integer arrays `A` and `B`. By convention, `gcd(0,0)` returns a value of `0`; all other inputs return positive integers for `G`.

`[G,C,D] = gcd(A,B)` returns both the greatest common divisor array `G`, and the arrays `C` and `D`, which satisfy the equation: `A(i).*C(i) + B(i).*D(i) = G(i)`. These are useful for solving Diophantine equations and computing elementary Hermite transformations.

Examples

The first example involves elementary Hermite transformations.

For any two integers `a` and `b` there is a 2-by-2 matrix `E` with integer entries and determinant = `1` (a *unimodular* matrix) such that:

```
E * [a;b] = [g,0],
```

where `g` is the greatest common divisor of `a` and `b` as returned by the command `[g,c,d] = gcd(a,b)`.

The matrix `E` equals:

```
c       d
-b/g    a/g
```

In the case where `a = 2` and `b = 4`:

```
[g,c,d] = gcd(2,4)
g =
     2
c =
     1
d =
     0
```

So that:

```
E =
    1     0
   -2     1
```

In the next example, we solve for x and y in the Diophantine equation 30x + 56y = 8.

```
[g,c,d] = gcd(30,56)
g =
     2
c =
   -13
d =
     7
```

By the definition, for scalars c and d:

```
30(-13) + 56(7) = 2,
```

Multiplying through by 8/2:

```
30(-13*4) + 56(7*4) = 8
```

Comparing this to the original equation, a solution can be read by inspection:

```
x = (-13*4) = -52; y = (7*4) = 28
```

See Also

lcm

References

[1] Knuth, Donald, *The Art of Computer Programming*, Vol. 2, Addison-Wesley: Reading MA, 1973. Section 4.5.2, Algorithm X.

Purpose

Get field of structure array

Syntax

```
f = getfield(s,'field')
f = getfield(s,{i,j},'field',{k})
```

Description

`f = getfield(s,'field')`, where `s` is a 1-by-1 structure, returns the contents of the specified field. This is equivalent to the syntax `f = s.field`.

`f = getfield(s,{i,j},'field',{k})` returns the contents of the specified field. This is equivalent to the syntax `f = s(i,j).field(k)`. All subscripts must be passed as cell arrays—that is, they must be enclosed in curly braces (similar to`{i,j}` and `{k}` above). Pass field references as strings.

Examples

Given the structure:

```
mystr(1,1).name = 'alice';
mystr(1,1).ID = 0;
mystr(2,1).name = 'gertrude';
mystr(2,1).ID = 1
```

Then the command `f = getfield(mystr,{2,1},'name')` yields

```
f =

gertrude
```

To list the contents of all `name` (or other) fields, embed `getfield` in a loop:

```
for i = 1:2
    name{i} = getfield(mystr,{i,1},'name');
end
name

name =

    'alice'    'gertrude'
```

See Also

`setfield`

global

Purpose

Define a global variable

Syntax

```
global X Y Z
```

Description

`global X Y Z` defines `X`, `Y`, and `Z` as global in scope.

Ordinarily, each MATLAB function, defined by an M-file, has its own local variables, which are separate from those of other functions, and from those of the base workspace and nonfunction scripts. However, if several functions, and possibly the base workspace, all declare a particular name as global, they all share a single copy of that variable. Any assignment to that variable, in any function, is available to all the functions declaring it global.

If the global variable does not exist the first time you issue the `global` statement, it is initializied to the empty matrix.

If a variable with the same name as the global variable already exists in the current workspace, MATLAB issues a warning and changes the value of that variable to match the global.

Remarks

Use `clear global` *`variable`* to clear a global variable from the global workspace. Use `clear` *`variable`* to clear the global link from the current workspace without affecting the value of the global.

To use a global within a callback, declare the global, use it, then clear the global link from the workspace. This avoids declaring the global after it has been referenced. For example:

```
uicontrol('style','pushbutton',’CallBack’,...
'global MY_GLOBAL,disp(MY_GLOBAL),MY_GLOBAL = MY_GLOBAL+1,clear MY_GLOBAL',...
'string','count')
```

Examples

Here is the code for the functions `tic` and `toc` (some comments abridged). These functions manipulate a stopwatch-like timer. The global variable `TICTOC`

is shared by the two functions, but it is invisible in the base workspace or in any other functions that do not declare it.

```
function tic
%    TIC Start a stopwatch timer.
%        TIC; any stuff; TOC
%    prints the time required.
%    See also: TOC, CLOCK.
global TICTOC
TICTOC = clock;

function t = toc
%    TOC Read the stopwatch timer.
%    TOC prints the elapsed time since TIC was used.
%    t = TOC; saves elapsed time in t, does not print.
%    See also: TIC, ETIME.
global TICTOC
if nargout < 1
    elapsed_time = etime(clock,TICTOC)
else
    t = etime(clock,TICTOC);
end
```

See Also

`clear`, `isglobal`, `who`

gmres

Purpose

Generalized Minimum Residual method (with restarts)

Syntax

```
x = gmres(A,b,restart)
gmres(A,b,restart,tol)
gmres(A,b,restart,tol,maxit)
gmres(A,b,restart,tol,maxit,M)
gmres(A,b,restart,tol,maxit,M1,M2)
gmres(A,b,restart,tol,maxit,M1,M2,x0)
x = gmres(A,b,restart,tol,maxit,M1,M2,x0)
[x,flag] = gmres(A,b,restart,tol,maxit,M1,M2,x0)
[x,flag,relres] = gmres(A,b,restart,tol,maxit,M1,M2,x0)
[x,flag,relres,iter] = gmres(A,b,restart,tol,maxit,M1,M2,x0)
[x,flag,relres,iter,resvec] =
   gmres(A,b,restart,tol,maxit,M1,M2,x0)
```

Description

`x = gmres(A,b,restart)` attempts to solve the system of linear equations `A*x = b` for `x`. The coefficient matrix `A` must be square and the column vector `b` must have length `n`, where `A` is `n`-by-`n`. When `A` is not explicitly available as a matrix, you can express `A` as an operator `afun` that returns the matrix-vector product `A*x` for `afun(x)`. This operator can be the name of an M-file, a string expression, or an inline object. In this case `n` is taken to be the length of the column vector `b`.

`gmres` will start iterating from an initial estimate that, by default, is an all zero vector of length `n`. `gmres` will restart itself every `restart` iterations using the last iterate from the previous outer iteration as the initial guess for the next outer iteration. Iterates are produced until the method either converges, fails, or has computed the maximum number of iterations. Convergence is achieved when an iterate `x` has relative residual `norm(b-A*x)/norm(b)` less than or equal to the tolerance of the method. The default tolerance is `1e-6`. The default maximum number of iterations is the minimum of `n/restart` and 10. No preconditioning is used.

`gmres(A,b,restart,tol)` specifies the tolerance of the method, `tol`.

`gmres(A,b,restart,tol,maxit)` additionally specifies the maximum number of iterations, `maxit`.

`gmres(A,b,restart,tol,maxit,M)` and `gmres(A,b,restart,tol,maxit,M1,M2)` use left preconditioner `M` or `M = M1*M2` and effectively solve the system `inv(M)*A*x = inv(M)*b` for `x`. You can replace the matrix `M` with a function `mfun` such that `mfun(x)` returns `M\x`. If `M1` or `M2` is given as the empty matrix (`[]`), it is considered to be the identity matrix, equivalent to no preconditioning at all. Since systems of equations of the form `M*y = r` are solved using backslash within `gmres`, it is wise to factor preconditioners into their LU factors first. For example, replace `gmres(A,b,restart,tol,maxit,M)` with:

```
[M1,M2] = lu(M);
gmres(A,b,restart,tol,maxit,M1,M2).
```

`gmres(A,b,restart,tol,maxit,M1,M2,x0)` specifies the first initial estimate `x0`. If `x0` is given as the empty matrix (`[]`), the default all zero vector is used.

`x = gmres(A,b,restart,tol,maxit,M1,M2,x0)` returns a solution `x`. If `gmres` converged, a message to that effect is displayed. If `gmres` failed to converge after the maximum number of iterations or halted for any reason, a warning message is printed displaying the relative residual `norm(b-A*x)/norm(b)` and the iteration number at which the method stopped or failed.

`[x,flag] = gmres(A,b,restart,tol,maxit,M1,M2,x0)` returns a solution `x` and a flag that describes the convergence of `gmres`.

Flag	Convergence
`0`	`gmres` converged to the desired tolerance `tol` within `maxit` iterations without failing for any reason.
`1`	`gmres` iterated `maxit` times but did not converge.
`2`	One of the systems of equations of the form `M*y = r` involving the preconditioner was ill-conditioned and did not return a useable result when solved by \ (backslash).
`3`	The method stagnated. (Two consecutive iterates were the same.)

Whenever `flag` is not `0`, the solution `x` returned is that with minimal norm residual computed over all the iterations. No messages are displayed if the `flag` output is specified.

`[x,flag,relres] = gmres(A,b,restart,tol,maxit,M1,M2,x0)` also returns the relative residual `norm(b-A*x)/norm(b)`. If `flag` is `0`, then `relres` $\leq$ `tol`.

`[x,flag,relres,iter] = gmres(A,b,restart,tol,maxit,M1,M2,x0)` also returns both the outer and inner iteration numbers at which `x` was computed. The outer iteration number `iter(1)` is an integer between 0 and `maxit`. The inner iteration number `iter(2)` is an integer between `0` and `restart`.

`[x,flag,relres,iter,resvec] = gmres(A,b,restart,tol,maxit,M1,M2,x0)` also returns a vector of the residual norms at each inner iteration, starting from `resvec(1) = norm(b-A*x0)`. If `flag` is `0` and `iter = [i j]`, `resvec` is of length `(i-1)*restart+j+1` and `resvec(end)` $\leq$ `tol*norm(b)`.

Examples

```
load west0479
A = west0479
b = sum(A,2)
[x,flag] = gmres(A,b,5)
```

`flag` is `1` since $gmres(5)$ will not converge to the default tolerance `1e-6` within the default 10 outer iterations.

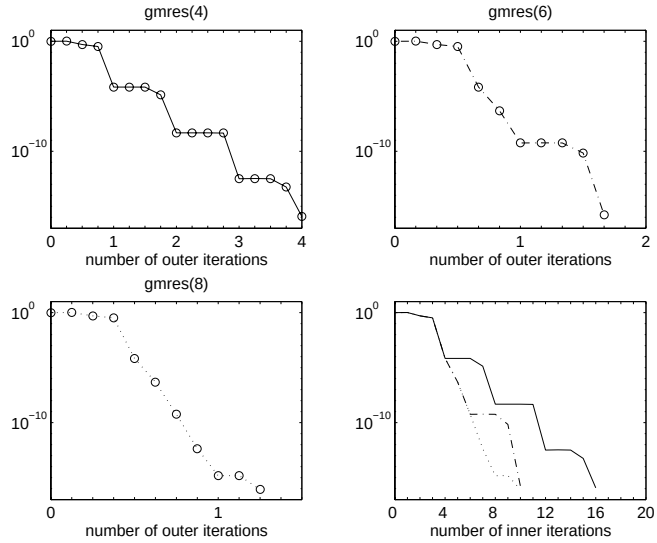
```
[L1,U1] = luinc(A,1e-5);
[x1,flag1] = gmres(A,b,5,1e-6,5,L1,U1);
```

`flag1` is `2` since the upper triangular `U1` has a zero on its diagonal so $gmres(5)$ fails in the first iteration when it tries to solve a system such as `U1*y = r` for `y` with backslash.

```
[L2,U2] = luinc(A,1e-6);
tol = 1e-15;
[x4,flag4,relres4,iter4,resvec4] = gmres(A,b,4,tol,5,L2,U2);
[x6,flag6,relres6,iter6,resvec6] = gmres(A,b,6,tol,3,L2,U2);
[x8,flag8,relres8,iter8,resvec8] = gmres(A,b,8,tol,3,L2,U2);
```

`flag4`, `flag6`, and `flag8` are all `0` since `gmres` converged when restarted at iterations 4, 6, and 8 while preconditioned by the incomplete LU factorization

with a drop tolerance of `1e-6`. This is verified by the plots of outer iteration number against relative residual. A combined plot of all three clearly shows the restarting at iterations 4 and 6. The total number of iterations computed may be more for lower values of `restart`, but the number of length `n` vectors stored is fewer, and the amount of work done in the method decreases proportionally.



See Also

`bicg`, `bicgstab`, `cgs`, `luinc`, `pcg`, `qmr`

The arithmetic operator \

References

Saad, Youcef and Martin H. Schultz, "GMRES: A generalized minimal residual algorithm for solving nonsymmetric linear systems", *SIAM* J. Sci. Stat. Comput., July 1986, Vol. 7, No. 3, pp. 856-869.

"Templates for the Solution of Linear Systems: Building Blocks for Iterative Methods", *SIAM*, Philadelphia, 1994.

gradient

Purpose

Numerical gradient

Syntax

```
FX = gradient(F)
[FX,FY] = gradient(F)
[Fx,Fy,Fz,...] = gradient(F)
[...] = gradient(F,h)
[...] = gradient(F,h1,h2,...)
```

Definition

The *gradient* of a function of two variables, *F(x,y)*, is defined as:

$$\nabla F = \frac{\partial F}{\partial x}\hat{i} + \frac{\partial F}{\partial y}\hat{j}$$

and can be thought of as a collection of vectors pointing in the direction of increasing values of F. In MATLAB, numerical gradients (differences) can be computed for functions with any number of variables. For a function of N variables, *F(x,y,z,...)*,

$$\nabla F = \frac{\partial F}{\partial x}\hat{i} + \frac{\partial F}{\partial y}\hat{j} + \frac{\partial F}{\partial z}\hat{k} + \ldots$$

Description

`FX = gradient(F)` where `F` is a vector returns the one-dimensional numerical gradient of `F`. `FX` corresponds to $\partial F/\partial x$, the differences in the x direction.

`[FX,FY] = gradient(F)` where `F` is a matrix returns the x and y components of the two-dimensional numerical gradient. `FX` corresponds to $\partial F/\partial x$, the differences in the `x` (column) direction. `FY` corresponds to $\partial F/\partial y$, the differences in the y (row) direction. The spacing between points in each direction is assumed to be one.

`[FX,FY,FZ,...] = gradient(F)` where `F` has `N dimensions` returns the `N` components of the gradient of `F`. There are two ways to control the spacing between values in `F`:

- A single spacing value, `h`, specifies the spacing between points in every direction.
- `N` spacing values (`h1,h2,...`) specifies the spacing for each dimension of `F`. Scalar spacing parameters specify a constant spacing for each dimension.

Vector parameters specify the coordinates of the values along corresponding dimensions of F. In this case, the length of the vector must match the size of the corresponding dimension.

`[...] = gradient(F,h)` where `h` is a scalar uses `h` as the spacing between points in each direction.

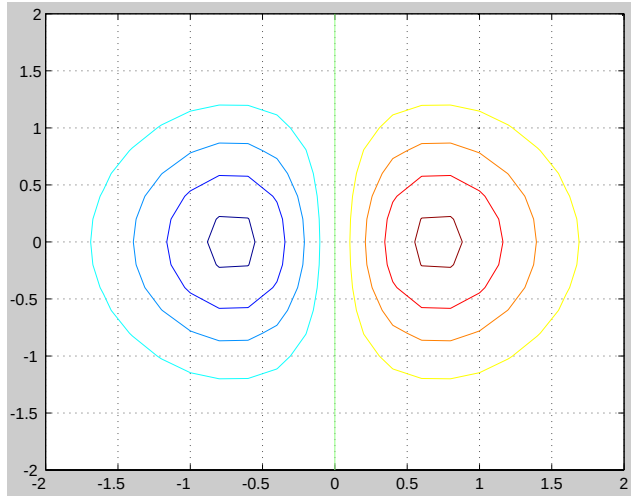
`[...] = gradient(F,h1,h2,...)` with `N` spacing parameters specifies the spacing for each dimension of `F`.

Examples

The statements

```
v = -2:0.2:2;
[x,y] = meshgrid(v);
z = x .* exp(-x.^2 - y.^2);
[px,py] = gradient(z,.2,.2);
contour(v,v,z), hold on, quiver(px,py), hold off
```

produce



Given,

```
F(:,:,1) = magic(3); F(:,:,2) = pascal(3);
```

`gradient(F)` takes `dx = dy = dz = 1`.

`[PX,PY,PZ] = gradient(F,0.2,0.1,0.2)` takes `dx = 0.2, dy = 0.1,` and `dz = 0.2`.

See Also del2, diff

Purpose

Data gridding

Syntax

```
ZI = griddata(x,y,z,XI,YI)
[XI,YI,ZI] = griddata(x,y,z,xi,yi)
[...] = griddata(...,method)
```

Description

`ZI = griddata(x,y,z,XI,YI)` fits a surface of the form `z = f(x,y)` to the data in the (usually) nonuniformly spaced vectors `(x,y,z)`. `griddata` interpolates this surface at the points specified by `(XI,YI)` to produce `ZI`. The surface always passes through the data points. `XI` and `YI` usually form a uniform grid (as produced by `meshgrid`).

`XI` can be a row vector, in which case it specifies a matrix with constant columns. Similarly, `YI` can be a column vector, and it specifies a matrix with constant rows.

`[XI,YI,ZI] = griddata(x,y,z,xi,yi)` returns the interpolated matrix `ZI` as above, and also returns the matrices `XI` and `YI` formed from row vector `xi` and column vector `yi`. These latter are the same as the matrices returned by `meshgrid`.

`[...] = griddata(...,`*method*`)` uses the specified interpolation method:

`'linear'`	Triangle-based linear interpolation (default)
`'cubic'`	Triangle-based cubic interpolation
`'nearest'`	Nearest neighbor interpolation
`'v4'`	MATLAB 4 `griddata` method

The *method* defines the type of surface fit to the data. The `'cubic'` and `'v4'` methods produce smooth surfaces while `'linear'` and `'nearest'` have discontinuities in the first and zero'th derivatives, respectively. All the methods except `'v4'` are based on a Delaunay triangulation of the data.

Remarks

`XI` and `YI` can be matrices, in which case `griddata` returns the values for the corresponding points `(XI(i,j),YI(i,j))`. Alternatively, you can pass in the row and column vectors `xi` and `yi`, respectively. In this case, `griddata`

interprets these vectors as if they were matrices produced by the command `meshgrid(xi,yi)`.

Algorithm

The `griddata(...,'v4')` command uses the method documented in [1]. The other methods are based on Delaunay triangulation (see `delaunay`).

Examples

Sample a function at 100 random points between ±`2.0`:

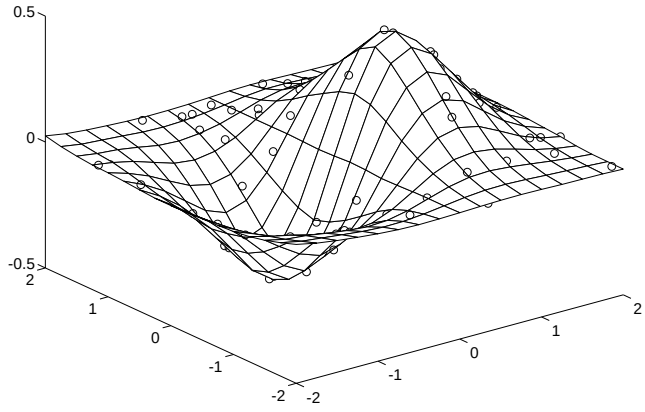
```
rand('seed',0)
x = rand(100,1)*4-2; y = rand(100,1)*4-2;
z = x.*exp(-x.^2-y.^2);
```

x, y, and z are now vectors containing nonuniformly sampled data. Define a regular grid, and grid the data to it:

```
ti = -2:.25:2;
[XI,YI] = meshgrid(ti,ti);
ZI = griddata(x,y,z,XI,YI);
```

Plot the gridded data along with the nonuniform data points used to generate it:

```
mesh(XI,YI,ZI), hold
plot3(x,y,z,'o'), hold off
```



See Also

`delaunay`, `interp2`, `meshgrid`

References

[1] Sandwell, David T., “Biharmonic Spline Interpolation of GEOS-3 and SEASAT Altimeter Data”, *Geophysical Research Letters*, 2, 139-142,1987.

[2] Watson, David E., *Contouring: A Guide to the Analysis and Display of Spatial Data*, Tarrytown, NY: Pergamon (Elsevier Science, Inc.): 1992.

gsvd

Purpose

Generalized singular value decomposition

Syntax

```
[U,V,X,C,S] = gsvd(A,B)
[U,V,X,C,S] = gsvd(A,B,0)
sigma = gsvd(A,B)
```

Description

`[U,V,X,C,S] = gsvd(A,B)` returns unitary matrices `U` and `V`, a (usually) square matrix `X`, and nonnegative diagonal matrices `C` and `S` so that

```
A = U*C*X'
B = V*S*X'
C'*C + S'*S = I
```

`A` and `B` must have the same number of columns, but may have different numbers of rows. If `A` is `m`-by-`p` and `B` is `n`-by-`p`, then `U` is `m`-by-`m`, `V` is `n`-by-`n` and `X` is `p`-by-`q` where `q = min(m+n,p)`.

`sigma = gsvd(A,B)` returns the vector of generalized singular values, `sqrt(diag(C'*C)./diag(S'*S))`.

The nonzero elements of `S` are always on its main diagonal. If `m >= p` the nonzero elements of `C` are also on its main diagonal. But if `m < p`, the nonzero diagonal of `C` is `diag(C,p-m)`. This allows the diagonal elements to be ordered so that the generalized singular values are nondecreasing.

`gsvd(A,B,0)`, with three input arguments and either `m` or `n >= p`, produces the "economy-sized" decomposition where the resulting `U` and `V` have at most `p` columns, and `C` and `S` have at most `p` rows. The generalized singular values are `diag(C)./diag(S)`.

When `B` is square and nonsingular, the generalized singular values, `gsvd(A,B)`, are equal to the ordinary singular values, `svd(A/B)`, but they are sorted in the opposite order. Their reciprocals are `gsvd(B,A)`.

In this formulation of the `gsvd`, no assumptions are made about the individual ranks of `A` or `B`. The matrix `X` has full rank if and only if the matrix `[A;B]` has full rank. In fact, `svd(X)` and `cond(X)` are are equal to `svd([A;B])` and `cond([A;B])`. Other formulations, eg. G. Golub and C. Van Loan [1], require that `null(A)` and `null(B)` do not overlap and replace `X` by `inv(X)` or `inv(X')`.

Note, however, that when `null(A)` and `null(B)` do overlap, the nonzero elements of `C` and `S` are not uniquely determined.

Examples

In the first example, the matrices have at least as many rows as columns.

```
A = reshape(1:15,5,3)
B = magic(3)
```

```
A =
     1     6    11
     2     7    12
     3     8    13
     4     9    14
     5    10    15

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

The statement

```
[U,V,X,C,S] = gsvd(A,B)
```

produces a 5-by-5 orthogonal `U`, a 3-by-3 orthogonal `V`, a 3-by-3 nonsingular `X`,

```
X =
   -2.8284    9.3761   -6.9346
    5.6569    8.3071  -18.3301
   -2.8284    7.2381  -29.7256
```

and

```
C =
    0.0000         0         0
         0    0.3155         0
         0         0    0.9807
         0         0         0
         0         0         0

S =
    1.0000         0         0
         0    0.9489         0
         0         0    0.1957
```

Since `A` is rank deficient, the first diagonal element of `C` is zero.

The economy sized decomposition,

```
[U,V,X,C,S] = gsvd(A,B,0)
```

produces a 5-by-3 matrix `U` and a 3-by-3 matrix `C`.

```
U =
       -0.3736   -0.6457   -0.4279
       -0.0076   -0.3296   -0.4375
        0.8617   -0.0135   -0.4470
       -0.2063    0.3026   -0.4566
       -0.2743    0.6187   -0.4661

C =
        0.0000         0         0
             0    0.3155         0
             0         0    0.9807
```

The other three matrices, `V`, `X`, and `S` are the same as those obtained with the full decomposition.

The generalized singular values are the ratios of the diagonal elements of `C` and `S`.

```
sigma = gsvd(A,B)

sigma =
        0.0000
        0.3325
        5.0123
```

These values are a reordering of the ordinary singular values

```
svd(A/B)

ans =
        5.0123
        0.3325
        0.0000
```

In the second example, the matrices have at least as many columns as rows.

```
A = reshape(1:15,3,5)
B = magic(5)
```

```
A =

     1     4     7    10    13
     2     5     8    11    14
     3     6     9    12    15

B =

    17    24     1     8    15
    23     5     7    14    16
     4     6    13    20    22
    10    12    19    21     3
    11    18    25     2     9
```

The statement

```
[U,V,X,C,S] = gsvd(A,B)
```

produces a 3-by-3 orthogonal `U`, a 5-by-5 orthogonal `V`, a 5-by-5 nonsingular `X` and

```
C =
          0         0    0.0000         0         0
          0         0         0    0.0439         0
          0         0         0         0    0.7432

S =
    1.0000         0         0         0         0
         0    1.0000         0         0         0
         0         0    1.0000         0         0
         0         0         0    0.9990         0
         0         0         0         0    0.6690
```

In this situation, the nonzero diagonal of `C` is `diag(C,2)`. The generalized singular values include three zeros.

```
sigma = gsvd(A,B)

sigma =
             0
             0
        0.0000
        0.0439
        1.1109
```

Reversing the roles of `A` and `B` reciprocates these values, producing three infinities.

```
gsvd(B,A)

ans =
        0.9001
       22.7610
           Inf
           Inf
           Inf
```

Algorithm

The generalized singular value decomposition uses the C-S decomposition described in [1], as well as the built-in `svd` and `qr` functions. The C-S decomposition is implemented in a subfunction in the `gsvd` M-file.

Diagnostics

The only warning or error message produced by `gsvd` itself occurs when the two input arguments do not have the same number of columns.

Reference

[1] Golub, Gene H. and Charles Van Loan, *Matrix Computations*, Third Edition, Johns Hopkins University Press, Baltimore, 1996

See Also

`svd`

Purpose

Hadamard matrix

Syntax

```
H = hadamard(n)
```

Description

`H = hadamard(n)` returns the Hadamard matrix of order `n`.

Definition

Hadamard matrices are matrices of `1`'s and `–1`'s whose columns are orthogonal,

```
H'*H = n*I
```

where `[n n] = size(H)` and `I = eye(n,n)`.

They have applications in several different areas, including combinatorics, signal processing, and numerical analysis, [1], [2].

An `n`-by-`n` Hadamard matrix with `n > 2` exists only if `rem(n,4) = 0`. This function handles only the cases where `n`, `n/12`, or `n/20` is a power of 2.

Examples

The command `hadamard(4)` produces the 4-by-4 matrix:

```
1    1    1    1
1   -1    1   -1
1    1   -1   -1
1   -1   -1    1
```

See Also

`compan`, `hankel`, `toeplitz`

References

[1] Ryser, H. J., *Combinatorial Mathematics*, John Wiley and Sons, 1963.

[2] Pratt, W. K., *Digital Signal Processing*, John Wiley and Sons, 1978.

hankel

Purpose

Hankel matrix

Syntax

```
H = hankel(c)
H = hankel(c,r)
```

Description

`H = hankel(c)` returns the square Hankel matrix whose first column is `c` and whose elements are zero below the first anti-diagonal.

`H = hankel(c,r)` returns a Hankel matrix whose first column is `c` and whose last row is `r`. If the last element of `c` differs from the first element of `r`, the last element of `c` prevails.

Definition

A Hankel matrix is a matrix that is symmetric and constant across the anti-diagonals, and has elements `h(i,j) = p(i+j–1)`, where vector `p = [c r(2:end)]` completely determines the Hankel matrix.

Examples

A Hankel matrix with anti-diagonal disagreement is

```
c = 1:3; r = 7:10;
h = hankel(c,r)
h =
    1    2    3    8
    2    3    8    9
    3    8    9   10

p = [1 2 3 8 9 10]
```

See Also

`hadamard`, `toeplitz`

Purpose

HDF interface

Syntax

```
hdf*(functstr,param1,param2,...)
```

Description

MATLAB provides a set of functions that enable you to access the HDF library developed and supported by the National Center for Supercomputing Applications (NCSA). MATLAB supports all or a portion of these HDF interfaces: SD, V, VS, AN, DRF8, DF24, H, HE, and HD.

To use these functions you must be familiar with the HDF library. Documentation for the library is available on the NCSA HDF Web page at `http://hdf.ncsa.uiuc.edu`. MATLAB additionally provides extensive command line help for each of the provided functions.

This table lists the interface-specific HDF functions in MATLAB.

Function	Interface
`hdfan`	Multifile annotation
`hdfdf24`	24-bit raster image
`hdfdfr8`	8-bit raster image
`hdfgd`	HDF-EOS GD interface
`hdfh`	HDF H interface
`hdfhd`	HDF HD interface
`hdfhe`	HDF HE interface
`hdfml`	Gateway utilities
`hdfpt`	HDF-EOS PT interface
`hdfsd`	Multifile scientific data set
`hdfsw`	HDF-EOS SW interface
`hdfv`	Vgroup
`hdfvf`	Vdata VF functions

Function	Interface
hdfvh	Vdata VH functions
hdfvs	Vdata VS functions

See Also

imfinfo, imread, imwrite, int8, int16, int32, single, uint8, uint16, uint32

Purpose

Display online help for MATLAB functions and M-files

Syntax

```
help
help topic
```

Description

`help` lists all primary help topics. Each main help topic corresponds to a directory name on MATLAB's search path.

`help topic` gives help on the specified topic. The topic can be a function name, a directory name, or a `MATLABPATH` relative partial pathname If it is a function name, `help` displays information about that function. If it is a directory name, `help` displays the contents file for the specified directory. It is not necessary to give the full pathname of the directory; the last component, or the last several components, is sufficient.

It is possible to write help text for your own M-files and toolboxes; see "Remarks".

Remarks

MATLAB's help system, like MATLAB itself, is highly extensible. You can write help descriptions for your own M-files and toolboxes using the same self-documenting method that MATLAB's M-files and toolboxes use.

The command `help` lists all help topics by displaying the first line (the H1 line) of the contents files in each directory on MATLAB's search path. The contents files are the M-files named `Contents.m` within each directory.

The command `help topic`, where `topic` is a directory name, displays the comment lines in the `Contents.m` file located in that directory. If a contents file does not exist, `help` displays the H1 lines of all the files in the directory.

The command `help topic`, where `topic` is a function name, displays help for the function by listing the first contiguous comment lines in the M-file `topic.m`.

Creating Online Help for Your Own M-Files

Create self-documenting online help for your own M-files by entering text on one or more contiguous comment lines, beginning with the second line of the file

(first line if it is a script). For example, an abridged version of the M-file `angle.m` provided with MATLAB could contain

```
function p = angle(h)
% ANGLE Polar angle.
% ANGLE(H) returns the phase angles, in radians, of a matrix
% with complex elements. Use ABS for the magnitudes.
p = atan2(imag(h),real(h));
```

When you execute `help angle`, lines 2, 3, and 4 display. These lines are the first block of contiguous comment lines. The help system ignores comment lines that appear later in an M-file, after any executable statements or after a blank line.

The first comment line in any M-file (the H1 line) is special. It should contain the function name and a brief description of the function. The `lookfor` command searches and displays this line, and `help` displays these lines in directories that do not contain a `Contents.m` file.

Creating Contents Files for Your Own M-File Directories

A `Contents.m` file is provided for each M-file directory included with the MATLAB software. If you create directories in which to store your own M-files, you should create `Contents.m` files for them too. To do so, simply follow the format used in an existing `Contents.m` file.

Examples

The command

```
help datafun
```

gives help for the `datafun` directory.

To prevent long descriptions from scrolling off the screen before you have time to read them, enter `more on`; then enter the `help` command.

See Also

`dir`, `doc`, `helpdesk`, `helpwin`, `lookfor`, `more`, `partialpath`, `path`, `what`, `which`

Purpose

Display Help Desk page in a Web browser, providing access to extensive help

Syntax

```
helpdesk
```

Description

`helpdesk` displays the Help Desk page in a Web browser. The Help Desk page provides direct access to a comprehensive library of online help, including reference pages and manuals.

Remarks

On Windows platforms, you can also access the Help Desk by selecting the **Help Desk** option under the **Help** menu.

You specify where the help information will be located when you install MATLAB. It can be on a disk or CD-ROM in your local system.

- On Windows, you can see the help location by selecting **Preferences** from the **File** menu – see the **Help Directory** entry under the **General** tab in the **Preferences** dialog box. If you relocate your online help directory, for example, to a network location, be sure to update the **Help Directory** location in the **Preferences** dialog box.
- On UNIX, the help location is specified in the `docopt` M-file. If you relocate your online help directory, be sure to update the location in `docopt.m`.

HTML Documents

Many of the documents use the HyperText Markup Language (HTML) and are accessed with an Internet Web browser such as Netscape Navigator or Microsoft Internet Explorer. All of MATLAB's operators and functions have online reference pages in HTML format, which you can access from the Help Desk. These reference pages often provide more details and examples than the `help` command for a function.

Use the search engine provided to query all the online HTML material. To use this search utility, your browser must support Java and it must be enabled.

PDF-Formatted Documentation

Most MATLAB documentation is available in Portable Document Format (PDF) through the Help Desk. You view this documentation using Adobe's Acrobat Reader. PDF documents reproduce the look and feel of the printed page, complete with fonts, graphics, formatting, and images. Use links from the

table of contents or index of a manual, as well as internal links, to go directly to the page of interest.

Print selected pages within a document using Acrobat. This is the best way to get printed copies of the online MATLAB Function Reference, which is not otherwise available in hardcopy form.

Use the Acrobat search tool to query a single document or the entire set of documents.

MathWorks Web Site

If your computer is connected to the Internet, the Help Desk provides connections to The MathWorks Web site. Use electronic mail to ask questions, make suggestions, and report possible bugs. Use the Solution Search Engine to query an up-to-date data base of technical support information.

Alternatively, you can point your Web browser directly at `www.mathworks.com` to access The MathWorks Web site.

See Also

`doc`, `docopt`, `help`, `helpwin`, `lookfor`, `web`

Purpose

Display Help Window, which provides access to help for all commands

Syntax

```
helpwin
helpwin topic
```

Description

`helpwin` displays the Help Window, which lists all commands, grouped by topic. From it you can see brief descriptions of commands, as well as get more help for any command.

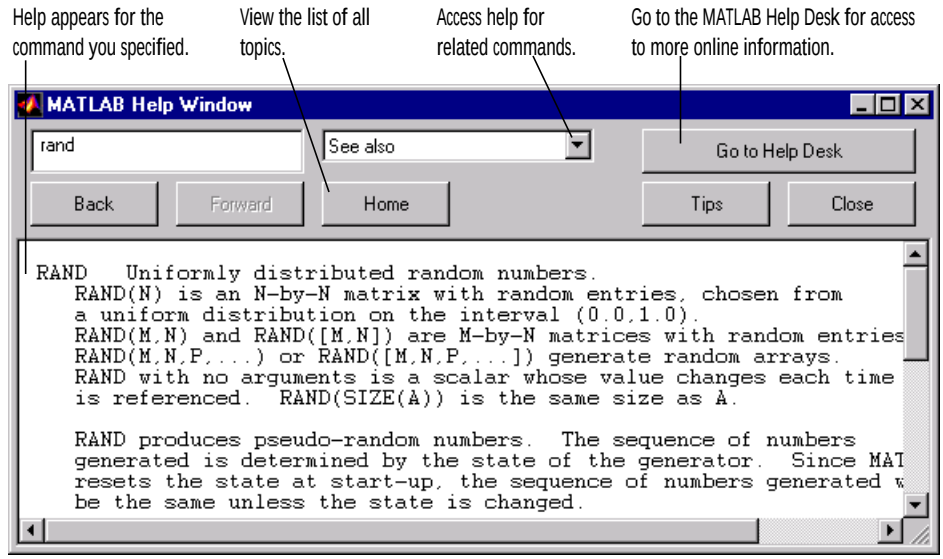
`helpwin topic` displays the Help Window, listing all commands in the directory `topic`. If `topic` is a command, the Help Window displays help for that command.

Remarks

On Windows platforms, you can also access the Help Window by selecting the **Help Window** option under the **Help** menu, or by clicking the question mark button on the menu bar.

In the Help Window, double-click on a directory. A list of the commands in that directory appears, along with a brief description for each command.

Double-click on a command in the list of commands; help for that command appears. This is the same help information you see if you type `help` for a specific command.



See Also

`doc`, `docopt`, `help`, `helpdesk`, `lookfor`, `web`

Purpose

Hessenberg form of a matrix

Syntax

```
[P,H] = hess(A)
H = hess(A)
```

Description

`H = hess(A)` finds `H`, the Hessenberg form of matrix `A`.

`[P,H] = hess(A)` produces a Hessenberg matrix `H` and a unitary matrix `P` so that `A = P*H*P'` and `P'*P = eye(size(A))`.

Definition

A Hessenberg matrix is zero below the first subdiagonal. If the matrix is symmetric or Hermitian, the form is tridiagonal. This matrix has the same eigenvalues as the original, but less computation is needed to reveal them.

Examples

`H` is a 3-by-3 eigenvalue test matrix:

```
H =
   -149    -50   -154
    537    180    546
    -27     -9    -25
```

Its Hessenberg form introduces a single zero in the (3,1) position:

```
hess(H) =
   -149.0000    42.2037   -156.3165
   -537.6783   152.5511   -554.9272
           0     0.0728      2.4489
```

Algorithm

For real matrices, `hess` uses the EISPACK routines `ORTRAN` and `ORTHES`. `ORTHES` converts a real general matrix to Hessenberg form using orthogonal similarity transformations. `ORTRAN` accumulates the transformations used by `ORTHES`.

When `hess` is used with a complex argument, the solution is computed using the QZ algorithm by the EISPACK routines `QZHES`. It has been modified for complex problems and to handle the special case $B = I$.

For detailed write-ups on these algorithms, see the *EISPACK Guide*.

See Also

`eig`, `qz`, `schur`

References

[1] Smith, B. T., J. M. Boyle, J. J. Dongarra, B. S. Garbow, Y. Ikebe, V. C. Klema, and C. B. Moler, *Matrix Eigensystem Routines – EISPACK Guide*, Lecture Notes in Computer Science, Vol. 6, second edition, Springer-Verlag, 1976.

[2] Garbow, B. S., J. M. Boyle, J. J. Dongarra, and C. B. Moler, *Matrix Eigensystem Routines – EISPACK Guide Extension*, Lecture Notes in Computer Science, Vol. 51, Springer-Verlag, 1977.

[3] Moler, C.B. and G. W. Stewart, "An Algorithm for Generalized Matrix Eigenvalue Problems," *SIAM J. Numer. Anal.*, Vol. 10, No. 2, April 1973.

Purpose

IEEE hexadecimal to decimal number conversion

Syntax

```
d = hex2dec('hex_value')
```

Description

`d = hex2dec('hex_value')` converts *hex_value* to its floating-point integer representation. The argument *hex_value* is a hexadecimal integer stored in a MATLAB string. If *hex_value* is a character array, each row is interpreted as a hexadecimal string.

Examples

```
hex2dec('3ff')

ans =

        1023
```

For a character array `S`

```
S =
0FF
2DE
123

hex2dec(S)

ans =

    255
    734
    291
```

See Also

`dec2hex`, `format`, `hex2num`, `sprintf`

hex2num

Purpose

Hexadecimal to double number conversion

Syntax

```
f = hex2num('hex_value')
```

Description

`f = hex2num('hex_value')` converts *hex_value* to the IEEE double precision floating-point number it represents. `NaN`, `Inf`, and denormalized numbers are all handled correctly. Fewer than 16 characters are padded on the right with zeros.

Examples

```
f = hex2num('400921fb54442d18')

f =

    3.14159265358979
```

Limitations

`hex2num` only works for IEEE numbers; it does not work for the floating-point representation of the VAX or other non-IEEE computers.

See Also

`format`, `hex2dec`, `sprintf`

Purpose

Hilbert matrix

Syntax

```
H = hilb(n)
```

Description

`H = hilb(n)` returns the Hilbert matrix of order `n`.

Definition

The Hilbert matrix is a notable example of a poorly conditioned matrix [1]. The elements of the Hilbert matrices are: $H(i, j) = 1/(i+j-1)$.

Examples

Even the fourth-order Hilbert matrix shows signs of poor conditioning.

```
cond(hilb(4)) =
    1.5514e+04
```

Algorithm

See the M-file for a good example of efficient MATLAB programming where conventional `for` loops are replaced by vectorized statements.

See Also

`invhilb`

References

[1] Forsythe, G. E. and C. B. Moler, *Computer Solution of Linear Algebraic Systems*, Prentice-Hall, 1967, Chapter 19.

home

Purpose

Send the cursor home

Syntax

```
home
```

Description

`home` returns the cursor to the upper-left corner of the command window.

Examples

Display a sequence of random matrices at the same location in the command window:

```
clc
for i =1:25
    home
    A = rand(5)
end
```

See Also

`clc`

Purpose

Imaginary unit

Syntax

```
i
a+bi
x+i*y
```

Description

As the basic imaginary unit `sqrt(-1)`, `i` is used to enter complex numbers. Since `i` is a function, it can be overridden and used as a variable. This permits you to use `i` as an index in `for` loops, etc.

If desired, use the character `i` without a multiplication sign as a suffix in forming a complex numerical constant.

You can also use the character `j` as the imaginary unit.

Examples

```
Z = 2+3i
Z = x+i*y
Z = r*exp(i*theta)
```

See Also

`conj`, `imag`, `j`, `real`

if

Purpose

Conditionally execute statements

Syntax

```
if expression
    statements
end
if expression1
    statements
elseif expression2
    statements
else
    statements
end
```

Description

`if` conditionally executes statements.

The simple form is:

```
if expression
    statements
end
```

More complicated forms use `else` or `elseif`. Each `if` must be paired with a matching `end`.

Arguments

expression — A MATLAB expression, usually consisting of smaller expressions or variables joined by relational operators (==, <, >, <=, >=, or ~=). Two examples are: `count < limit` and `(height - offset) >= 0`.
Expressions may also include logical functions, as in: `isreal(A)`.
Simple expressions can be combined by logical operators (&,|,~) into compound expressions such as: `(count < limit) & ((height - offset) >= 0)`.

statements — One or more MATLAB statements to be executed only if the *expression* is *true* (or nonzero). See Examples for information about how nonscalar variables are evaluated.

Examples

Here is an example showing `if`, `else`, and `elseif`:

```
for i = 1:n
    for j = 1:n
        if i == j
            a(i,j) = 2;
        elseif abs([i j]) == 1
            a(i,j) = 1;
        else
            a(i,j) = 0;
        end
    end
end
```

Such expressions are evaluated as *false* unless every element-wise comparison evaluates as *true*. Thus, given matrices `A` and `B`:

```
A =                 B =
     1     0             1     1
     2     3             3     4
```

The expression:

`A < B`	Evaluates as *false*	Since `A(1,1)` is not less than `B(1,1)`.
`A < (B+1)`	Evaluates as *true*	Since no element of `A` is greater than the corresponding element of `B`.
`A & B`	Evaluates as *false*	Since `A(1,2) | B(1,2)` is *false*.
`5 > B`	Evaluates as *true*	Since every element of `B` is less than `5`.

See Also

`break`, `else`, `end`, `for`, `return`, `switch`, `while`

ifft

Purpose

Inverse one-dimensional fast Fourier transform

Syntax

```
y = ifft(X)
y = ifft(X,n)
y = ifft(X,[],dim)
y = ifft(X,n,dim)
```

Description

`y = ifft(X)` returns the inverse fast Fourier transform of vector `X`.

If `X` is a matrix, `ifft` returns the inverse Fourier transform of each column of the matrix.

If `X` is a multidimensional array, `ifft` operates on the first non-singleton dimension.

`y = ifft(X,n)` returns the `n`-point inverse fast Fourier transform of vector `X`.

`y = ifft(X,[],dim)` and `y = ifft(X,n,dim)` return the inverse discrete Fourier transform of `X` across the dimension *dim*.

Examples

For any `x`, `ifft(fft(x))` equals `x` to within roundoff error. If `x` is real, `ifft(fft(x))` may have small imaginary parts.

Algorithm

The algorithm for `ifft(x)` is the same as the algorithm for `fft(x)`, except for a sign change and a scale factor of `n = length(x)`. So the execution time is fastest when `n` is a power of 2 and slowest when `n` is a large prime.

See Also

`dftmtx` and `freqz`, in the Signal Processing Toolbox, and:

`fft`, `fft2`, `fftshift`

Purpose

Inverse two-dimensional fast Fourier transform

Syntax

```
Y = ifft2(X)
Y = ifft2(X,m,n)
```

Description

`Y = ifft2(X)` returns the two-dimensional inverse fast Fourier transform of matrix `X`.

`Y = ifft2(X,m,n)` returns the `m`–by–`n` inverse fast Fourier transform of matrix `X`.

Examples

For any `X`, `ifft2(fft2(X))` equals `X` to within roundoff error. If `X` is real, `ifft2(fft2(X))` may have small imaginary parts.

Algorithm

The algorithm for `ifft2(X)` is the same as the algorithm for `fft2(X)`, except for a sign change and scale factors of `[m,n] = size(X)`. The execution time is fastest when `m` and `n` are powers of 2 and slowest when they are large primes.

See Also

`dftmtx` and `freqz` in the Signal Processing Toolbox, and:

`fft2`, `fftshift`, `ifft`

ifftn

Purpose

Inverse multidimensional fast Fourier transform

Syntax

```
Y = ifftn(X)
Y = ifftn(X,siz)
```

Description

`Y = ifftn(X)` performs the N-dimensional inverse fast Fourier transform. The result `Y` is the same size as `X`.

`Y = ifftn(X,siz)` pads `X` with zeros, or truncates `X`, to create a multidimensional array of size `siz` before performing the inverse transform. The size of the result `Y` is `siz`.

Remarks

For any `X`, `ifftn(fftn(X))` equals `X` within roundoff error. If `X` is real, `ifftn(fftn(X))` may have small imaginary parts.

Algorithm

`ifftn(X)` is equivalent to

```
Y = X;
for p = 1:length(size(X))
    Y = ifft(Y,[],p);
end
```

This computes in-place the one-dimensional inverse fast Fourier transform along each dimension of `X`. The time required to compute `ifftn(X)` depends strongly on the number of prime factors of the dimensions of `X`. It is fastest when all of the dimensions are powers of 2.

See Also

`fft`, `fft2`, `fftn`

Purpose

Inverse FFT shift

Syntax

```
ifftshift(X)
```

Description

`ifftshift` undoes the results of `fftshift`.

If `X` is a vector, `iffshift(X)` swaps the left and right halves of `X`. For matrices, `ifftshift(X)` swaps the first quadrant with the third and the second quadrant with the fourth. If `X` is a multidimensional array, `ifftshift(X)` swaps half-spaces of `X` along each dimension.

See Also

`fft`, `fft2`, `fftn`, `fftshift`

imag

Purpose Imaginary part of a complex number

Syntax `Y = imag(Z)`

Description `Y = imag(Z)` returns the imaginary part of the elements of array `Z`.

Examples

```
imag(2+3i)

ans =

    3
```

See Also `conj`, `i`, `j`, `real`

Purpose

Return information about a graphics file

Synopsis

```
info = imfinfo(filename,fmt)
info = imfinfo(filename)
```

Description

`info = imfinfo(filename,fmt)` returns a structure whose fields contain information about an image in a graphics file. `filename` is a string that specifies the name of the graphics file, and `fmt` is a string that specifies the format of the file. The file must be in the current directory or in a directory on the MATLAB path. If `imfinfo` cannot find a file named `filename`, it looks for a file named `filename.fmt`.

This table lists the possible values for `fmt`:

Format	File type
`'bmp'`	Windows Bitmap (BMP)
`'hdf'`	Hierarchical Data Format (HDF)
`'jpg'` or `'jpeg'`	Joint Photographic Experts Group (JPEG)
`'pcx'`	Windows Paintbrush (PCX)
`'png'`	Portable Network Graphics (PNG)
`'tif'` or `'tiff'`	Tagged Image File Format (TIFF)
`'xwd'`	X Windows Dump (XWD)

If `filename` is a TIFF or HDF file containing more than one image, `info` is a structure array with one element (i.e., an individual structure) for each image in the file. For example, `info(3)` would contain information about the third image in the file.

The set of fields in `info` depends on the individual file and its format. However, the first nine fields are always the same. This table lists these fields and describes their values:

Field	Value
`Filename`	A string containing the name of the file; if the file is not in the current directory, the string contains the full pathname of the file
`FileModDate`	A string containing the date when the file was last modified
`FileSize`	An integer indicating the size of the file in bytes
`Format`	A string containing the file format, as specified by `fmt`; for JPEG and TIFF files, the three-letter variant is returned
`FormatVersion`	A string or number describing the version of the format
`Width`	An integer indicating the width of the image in pixels
`Height`	An integer indicating the height of the image in pixels
`BitDepth`	An integer indicating the number of bits per pixel
`ColorType`	A string indicating the type of image; either `'truecolor'` for a truecolor RGB image, `'grayscale'` for a grayscale intensity image, or `'indexed'` for an indexed image

`info = imfinfo(filename)` attempts to infer the format of the file from its content.

Example

```
info = imfinfo('flowers.bmp')

info =

             Filename: 'flowers.bmp'
          FileModDate: '16-Oct-1996 11:41:38'
             FileSize: 182078
               Format: 'bmp'
        FormatVersion: 'Version 3 (Microsoft Windows 3.x)'
                Width: 500
               Height: 362
             BitDepth: 8
            ColorType: 'indexed'
      FormatSignature: 'BM'
    NumColormapEntries: 256
             Colormap: [256x3  double]
              RedMask: []
            GreenMask: []
             BlueMask: []
       ImageDataOffset: 1078
      BitmapHeaderSize: 40
             NumPlanes: 1
       CompressionType: 'none'
            BitmapSize: 181000
         HorzResolution: 0
         VertResolution: 0
          NumColorsUsed: 256
    NumImportantColors: 0
```

See Also

imread, imwrite

imread

Purpose

Read image from graphics file

Synopsis

```
A = imread(filename,fmt)
[X,map] = imread(filename,fmt)
[...] = imread(filename)
[...] = imread(...,idx)  (TIFF only)
[...] = imread(...,ref)  (HDF only)
[...] = imread(...,'BackgroundColor',BG)  (PNG only)
[A,map,alpha] = imread(...)  (PNG only)
```

Description

`A = imread(filename,fmt)` reads a grayscale or truecolor image named `filename` into `A`. If the file contains a grayscale intensity image, `A` is a two-dimensional array. If the file contains a truecolor (RGB) image, `A` is a three-dimensional (`m`-by-`n`-by-3) array.

`[X,map] = imread(filename,fmt)` reads the indexed image in `filename` into `X` and its associated colormap into `map`. The colormap values are rescaled to the range [0,1]. `A` and `map` are two-dimensional arrays.

`[...] = imread(filename)` attempts to infer the format of the file from its content.

`filename` is a string that specifies the name of the graphics file, and `fmt` is a string that specifies the format of the file. If the file is not in the current directory or in a directory in the MATLAB path, specify the full pathname for a location on your system. If `imread` cannot find a file named `filename`, it looks for a file named `filename.fmt`. If you do not specify a string for `fmt`, the toolbox will try to discern the format of the file by checking the file header.

This table lists the possible values for `fmt`:

Format	File type
`'bmp'`	Windows Bitmap (BMP)
`'hdf'`	Hierarchical Data Format (HDF)
`'jpg'` or `'jpeg'`	Joint Photographic Experts Group (JPEG)
`'pcx'`	Windows Paintbrush (PCX)

Format	File type
'png'	Portable Network Graphics (PNG)
'tif' or 'tiff'	Tagged Image File Format (TIFF)
'xwd'	X Windows Dump (XWD)

Special Case Syntax

TIFF-Specific Syntax

`[...] = imread(...,idx)` reads in one image from a multi-image TIFF file. `idx` is an integer value that specifies the order in which the image appears in the file. For example, if `idx` is 3, `imread` reads the third image in the file. If you omit this argument, `imread` reads the first image in the file. To read all ages of a TIFF file, omit the `idx` argument.

PNG-Specific Syntax

The discussion in this section is only relevant to PNG files that contain transparent pixels. A PNG file does not necessarily contain transparency data. Transparent pixels, when they exist, will be identified by one of two components: a *transparency chunk* or an *alpha channel*. (A PNG file can only have one of these components, not both.)

The transparency chunk identifies which pixel values will be treated as transparent, e.g., if the value in the transparency chunk of an 8-bit image is 0.5020, all pixels in the image with the color 0.5020 can be displayed as transparent. An alpha channel is an array with the same number of pixels as are in the image, which indicates the transparency status of each corresponding pixel in the image (transparent or nontransparent).

Another potential PNG component related to transparency is the *background color chunk*, which (if present) defines a color value that can be used behind all transparent pixels. This section identifies the default behavior of the toolbox for reading PNG images that contain either a transparency chunk or an alpha channel, and describes how you can override it.

Case 1. You do not ask to output the alpha channel and do not specify a background color to use. For example,

```
[a,map] = imread(filename);
a = imread(filename);
```

If the PNG file contains a background color chunk, the transparent pixels will be composited against the specified background color.

If the PNG file does not contain a background color chunk, the transparent pixels will be composited against `0` for grayscale (black), `1` for indexed (first color in map), or `[0 0 0]` for RGB (black).

Case 2. You do not ask to output the alpha channel but you specify the background color parameter in your call. For example,

```
[...] = imread(...,'BackgroundColor',bg);
```

The transparent pixels will be composited against the specified color. The form of `bg` depends on whether the file contains an indexed, intensity (grayscale), or RGB image. If the input image is indexed, `bg` should be an integer in the range `[1,P]` where `P` is the colormap length. If the input image is intensity, `bg` should be an integer in the range `[0,1]`. If the input image is RGB, `bg` should be a 3-element vector whose values are in the range `[0,1]`.

There is one exception to the toolbox's behavior of using your background color. If you set background to `'none'` no compositing will be performed. For example,

```
[...] = imread(...,'Back','none');
```

Note: If you specify a background color, you *cannot* output the alpha channel.

Case 3. You ask to get the alpha channel as an output variable. For example,

```
[a,map,alpha] = imread(filename);
[a,map,alpha] = imread(filename,fmt);
```

No compositing is performed; the alpha channel will be stored separately from the image (not merged into the image as in cases 1 and 2). This form of `imread` returns the alpha channel if one is present, and also returns the image and any associated colormap. If there is no alpha channel, `alpha` returns `[]`. If there is no colormap, or the image is grayscale or truecolor, `map` may be empty.

HDF-Specific Syntax

`[...] = imread(...,ref)` reads in one image from a multi-image HDF file. `ref` is an integer value that specifies the reference number used to identify the image. For example, if `ref` is 12, `imread` reads the image whose reference number is 12. (Note that in an HDF file the reference numbers do not necessarily correspond to the order of the images in the file. You can use `imfinfo` to match up image order with reference number.) If you omit this argument, `imread` reads the first image in the file.

This table summarizes the types of images that `imread` can read:

Format	Variants
BMP	1-bit, 4-bit, 8-bit, and 24-bit uncompressed images; 4-bit and 8-bit run-length encoded (RLE) images
HDF	8-bit raster image datasets, with or without associated colormap; 24-bit raster image datasets
JPEG	Any baseline JPEG image; JPEG images with some commonly used extensions
PCX	1-bit, 8-bit, and 24-bit images
PNG	Any PNG image, including 1-bit, 2-bit, 4-bit, 8-bit, and 16-bit grayscale images; 8-bit and 16-bit indexed images; 24-bit and 48-bit RGB images
TIFF	Any baseline TIFF image, including 1-bit, 8-bit, and 24-bit uncompressed images; 1-bit, 8-bit, and 24-bit images with packbit compression; 1-bit images with CCITT compression; also 16-bit grayscale, 16-bit indexed, and 48-bit RGB images.
XWD	1-bit and 8-bit ZPixmaps; XYBitmaps; 1-bit XYPixmaps

Class Support

In most of the image file formats supported by `imread`, pixels are stored using eight or fewer bits per color plane. When reading such a file, the class of the output (`a` or `x`) is `uint8`. `imread` also supports reading 16-bit-per-pixel data from TIFF and PNG files; for such image files, the class of the output (`a` or `x`) is

uint16. Note that for indexed images, imread always reads the colormap into an array of class double, even though the image array itself may be of class uint8 or uint16.

Examples

This example reads the sixth image in a TIFF file:

```
[X,map] = imread('flowers.tif',6);
```

This example reads the fourth image in an HDF file:

```
info = imfinfo('skull.hdf');
[X,map] = imread('skull.hdf',info(4).Reference);
```

This example reads a 24-bit PNG image and sets any of its fully transparent (alpha channel) pixels to red.

```
bg = [255 0 0];
A = imread('image.png','BackgroundColor',bg);
```

This example returns the alpha channel (if any) of a PNG image.

```
[A,map,alpha] = imread('image.png');
```

See Also

double, fread, imfinfo, imwrite, uint8, uint16

Purpose

Write an image to a graphics file

Synopsis

```
imwrite(A,filename,fmt)
imwrite(X,map,filename,fmt)
imwrite(...,filename)
imwrite(...,Param1,Val1,Param2,Val2...)
```

Description

`imwrite(A,filename,fmt)` writes the image in `A` to `filename`. `filename` is a string that specifies the name of the output file, and `fmt` is a string that specifies the format of the file. If `A` is a grayscale intensity image or a truecolor (RGB) image of class `uint8`, `imwrite` writes the actual values in the array to the file. If `A` is of class `double`, `imwrite` rescales the values in the array before writing, using `uint8(round(255*A))`. This operation converts the floating-point numbers in the range [0, 1] to 8-bit integers in the range [0, 255].

`imwrite(X,map,filename,fmt)` writes the indexed image in `X` and its associated colormap `map` to `filename`. If `X` is of class `uint8` or `uint16`, `imwrite` writes the actual values in the array to the file. If `X` is of class `double`, `imwrite` offsets the values in the array before writing using `uint8(X–1)`. (See note below for an exception.) `map` must be a valid MATLAB colormap of class `double`; `imwrite` rescales the values in `map` using `uint8(round(255*map))`. Note that most image file formats do not support colormaps with more than 256 entries.

Note: If the image is `double`, and you specify PNG as the output format and a bit depth of 16 bpp, the values in the array will be offset using `uint16(X-1)`.

`imwrite(...,filename)` writes the image to `filename`, inferring the format to use from the filename's extension. The extension must be one of the legal values for `fmt`.

`imwrite(...,Param1,Val1,Param2,Val2...)` specifies parameters that control various characteristics of the output file. Parameter settings can currently be made for HDF, JPEG, and TIFF files. For example, if you are writing a JPEG file, you can set the "quality" of the JPEG compression. For the full list of parameters available per format, see the tables of parameters.

`filename` is a string that specifies the name of the output file, and `fmt` is a string that specifies the format of the file.

This table lists the possible values for `fmt`:

Format	File type
`'bmp'`	Windows Bitmap (BMP)
`'hdf'`	Hierarchical Data Format (HDF)
`'jpg'` or `'jpeg'`	Joint Photographers Expert Group (JPEG)
`'pcx'`	Windows Paintbrush (PCX)
`'png'`	Portable Network Graphics (PNG)
`'tif'` or `'tiff'`	Tagged Image File Format (TIFF)
`'xwd'`	X Windows Dump (XWD)

This table describes the available parameters for HDF files:

Parameter	Values	Default
`'Compression'`	One of these strings: `'none'`, `'rle'`, `'jpeg'`. `'rle'` is valid only for grayscale and indexed images. `'jpeg'` is valid only for grayscale and RGB images.	`'rle'`
`'Quality'`	A number between 0 and 100; this parameter applies only if `'Compression'` is `'jpeg'`. A number between 0 and 100; higher numbers mean higher *quality* (less image degradation due to compression), but the resulting file size is larger.	75
`'WriteMode'`	One of these strings: `'overwrite'`, `'append'`	`'overwrite'`

This table describes the available parameters for JPEG files:

Parameter	Values	Default
`'Quality'`	A number between 0 and 100; higher numbers mean quality is better (less image degradation due to compression), but the resulting file size is larger.	75

This table describes the available parameters for TIFF files:

Parameter	Values	Default
`'Compression'`	One of these strings: `'none'`, `'packbits'`, `'ccitt'`; `'ccitt'` is valid for binary images only. `'packbits'` is the default for nonbinary images; `'ccitt'` is the default for binary images.	`'ccitt'` for binary images; `'packbits'` for all other images
`'Description'`	Any string; fills in the `ImageDescription` field returned by `imfinfo`.	empty
`'Resolution'`	A scalar value that is used to set the resolution of the output file in both the `x` and `y` directions.	72

This table describes the available parameters for PNG files.

Parameter	Values	Default
'Author'	A string	Empty
'Description'	A string	Empty
'Copyright'	A string	Empty
'CreationTime'	A string	Empty
'Software'	A string	Empty
'Disclaimer'	A string	Empty
'Warning'	A string	Empty
'Source'	A string	Empty
'Comment'	A string	Empty
'InterlaceType'	Either 'none' or 'adam7'	'none'
'BitDepth'	A scalar value indicating desired bit depth. For grayscale images this can be 1, 2, 4, 8, or 16. For grayscale images with an alpha channel this can be 8 or 16. For indexed images this can be 1, 2, 4, or 8. For truecolor images with or without an alpha channel this can be 8 or 16.	8 bits per pixel if image is double or uint8. 16 bits per pixel if image is uint16. 1 bit per pixel if image is logical.

Parameter	Values	Default
'Transparency'	This value is used to indicate transparency information only when no alpha channel is used. Set to the value that indicates which pixels should be considered transparent. (If the image uses a colormap, this value will represent an index number to the colormap.) For indexed images: a Q-element vector in the range [0,1] where Q is no larger than the colormap length and each value indicates the transparency associated with the corresponding colormap entry. In most cases, Q=1. For grayscale images: a scalar in the range [0,1]. For truecolor images: a 3-element vector in the range [0,1]. You cannot specify 'Transparency' and 'Alpha' at the same time.	Empty
'Background'	The value specifies background color to be used when compositing transparent pixels. For indexed images: an integer in the range [1,P], where P is the colormap length. For grayscale images: a scalar in the range [0,1]. For truecolor images: a 3-element vector in the range [0,1].	Empty
'Gamma'	A nonnegative scalar indicating the file gamma	Empty

Parameter	Values	Default
'Chromaticities'	An 8-element vector [wx wy rx ry gx gy bx by] that specifies the reference white point and the primary chromaticities	Empty
'XResolution'	A scalar indicating the number of pixels/unit in the horizontal direction	Empty
'YResolution'	A scalar indicating the number of pixels/unit in the vertical direction	Empty
'ResolutionUnit'	Either 'unknown' or 'meter'	Empty
'Alpha'	A matrix specifying the transparency of each pixel individually. The row and column dimensions must be the same as the data array; they can be uint8, uint16, or double, in which case the values should be in the range [0,1].	Empty
'SignificantBits'	A scalar or vector indicating how many bits in the data array should be regarded as significant; values must be in the range [1,bitdepth]. For indexed images: a 3-element vector. For grayscale images: a scalar. For grayscale images with an alpha channel: a 2-element vector. For truecolor images: a 3-element vector. For truecolor images with an alpha channel: a 4-element vector	Empty

In addition to these PNG parameters, you can use any parameter name that satisfies the PNG specification for keywords, including only printable characters, 80 characters or fewer, and no leading or trailing spaces. The value corresponding to these user-specified parameters must be a string that contains no control characters other than linefeed.

This table summarizes the types of images that `imwrite` can write:

Format	Variants
BMP	8-bit uncompressed images with associated colormap; 24-bit uncompressed images
HDF	8-bit raster image datasets, with or without associated colormap; 24-bit raster image datasets
JPEG	Baseline JPEG images 8 or 24-bit). **Note:** Indexed images are converted to RGB before writing out JPEG files, because the JPEG format does not support indexed images.
PCX	8-bit images
PNG	1-bit, 2-bit, 4-bit, 8-bit, and 16-bit grayscale images; 8-bit and 16-bit grayscale images with alpha channels; 1-bit, 2-bit, 4-bit, and 8-bit indexed images; 24-bit and 48-bit truecolor images with or without alpha channels
TIFF	Baseline TIFF images, including 1-bit, 8-bit, and 24-bit uncompressed images; 1-bit, 8-bit, and 24-bit images with packbits compression; 1-bit images with CCITT compression
XWD	8-bit ZPixmaps

Class Support

Most of the supported image file formats store `uint8` data. PNG and TIFF additionally support `uint16` data. For grayscale and RGB images, if the data array is `double`, the assumed dynamic range is `[0,1]`. The data array is automatically scaled by 255 before being written out as `uint8`. If the data array is `uint8` or `uint16` (PNG and TIFF only), then it is written out without scaling as `uint8` or `uint16`, respectively.

Example

```
imwrite(X,map,'flowers.hdf','Compression','none',...
'WriteMode','append')
```

See Also `fwrite`, `imfinfo`, `imread`

Purpose

Subscripts from linear index

Syntax

```
[I,J] = ind2sub(siz,IND)
[I1,I2,I3,...,In] = ind2sub(siz,IND)
```

Description

The `ind2sub` command determines the equivalent subscript values corresponding to a single index into an array.

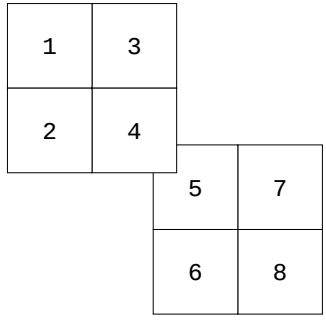
`[I,J] = ind2sub(siz,IND)` returns the arrays `I` and `J` containing the equivalent row and column subscripts corresponding to the index matrix `IND` for a matrix of size *siz*.

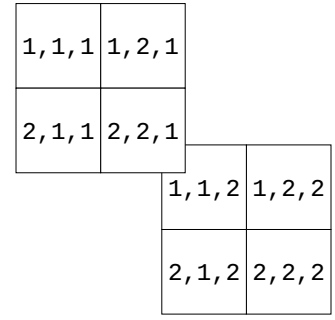
For matrices, `[I,J] = ind2sub(size(A),find(A>5))` returns the same values as
`[I,J] = find(A>5)`.

`[I1,I2,I3,...,In] = ind2sub(siz,IND)` returns `n` subscript arrays `I1,I2,..,In` containing the equivalent multidimensional array subscripts equivalent to `IND` for an array of size *siz*.

Examples

The mapping from linear indexes to subscript equivalents for a 2-by-2-by-2 array is:





See Also

`sub2ind`, `find`

Inf

Purpose

Infinity

Syntax

```
Inf
```

Description

`Inf` returns the IEEE arithmetic representation for positive infinity. Infinity results from operations like division by zero and overflow, which lead to results too large to represent as conventional floating-point values.

Examples

`1/0`, `1.e1000`, `2^1000`, and `exp(1000)` all produce `Inf`.

`log(0)` produces `-Inf`.

`Inf-Inf` and `Inf/Inf` both produce `NaN`, Not-a-Number.

See Also

`is*`, `NaN`

Purpose

Inferior class relationship

Syntax

```
inferiorto('class1','class2',...)
```

Description

The `inferiorto` function establishes a hierarchy which determines the order in which MATLAB calls object methods.

`inferiorto('class1','class2',...)` invoked within a class constructor method (say `myclass.m`) indicates that `myclass`'s method should not be invoked if a function is called with an object of class `myclass` and one or more objects of class `class1`, `class2`, and so on.

Remarks

Suppose `A` is of class `'class_a'`, `B` is of class `'class_b'` and `C` is of class `'class_c'`. Also suppose the constructor `class_c.m` contains the statement: `inferiorto('class_a')`. Then `e = fun(a,c)` or `e = fun(c,a)` invokes `class_a/fun`.

If a function is called with two objects having an unspecified relationship, the two objects are considered to have equal precedence, and the leftmost object's method is called. So, `fun(b,c)` calls `class_b/fun`, while `fun(c,b)` calls `class_c/fun`.

See Also

`superiorto`

inline

Purpose

Construct an inline object

Syntax

```
g = inline(expr)
g = inline(expr,arg1,arg2, ...)
g = inline(expr,n)
```

Description

`inline(`*`expr`*`)` constructs an inline function object from the MATLAB expression contained in the string *`expr`*. The input argument to the inline function is automatically determined by searching *`expr`* for an isolated lower case alphabetic character, other than `i` or `j`, that is not part of a word formed from several alphabetic characters. If no such character exists, `x` is used. If the character is not unique, the one closest to `x` is used. If two characters are found, the one later in the alphabet is chosen.

`inline(`*`expr`*`,`*`arg1`*`,`*`arg2`*`, ...)` constructs an inline function whose input arguments are specified by the strings *`arg1`*, *`arg2`*,.... Multicharacter symbol names may be used.

`inline(`*`expr`*`,n)`, where `n` is a scalar, constructs an inline function whose input arguments are `x`, `P1`, `P2`, ...

Remarks

Three commands related to `inline` allow you to examine an inline function object and determine how it was created.

`char(`*`fun`*`)` converts the inline function into a character array. This is identical to `formula(`*`fun`*`)`.

`argnames(`*`fun`*`)` returns the names of the input arguments of the inline object *`fun`* as a cell array of strings.

`formula(`*`fun`*`)` returns the formula for the inline object *`fun`*.

A fourth command `vectorize(`*`fun`*`)` inserts a `.` before any `^`, `*` or `/` in the formula for *`fun`*. The result is a vectorized version of the inline function.

Examples

This example creates a simple inline function to square a number.

```
g = inline('t^2')

g =

     Inline function:
     g(t) = t^2
```

You can convert the result to a string using the `char` function.

```
char(g)

ans =

t^2
```

This example creates an inline function to represent the formula $f = 3\sin(2x^2)$. The resulting inline function can be evaluated with the `argnames` and `formula` functions.

```
f = inline('3*sin(2*x.^2)')

f =

     Inline function:
     f(x) = 3*sin(2*x.^2)

argnames(f)

ans =

    'x'

formula(f)

ans =

3*sin(2*x.^2)ans =
```

This call to `inline` defines the function `f` to be dependent on two variables, `alpha` and `x`:

```
f = inline('sin(alpha*x)')

f =

     Inline function:
     f(alpha,x) = sin(alpha*x)
```

If `inline` does not return the desired function variables or if the function variables are in the wrong order, you can specify the desired variables explicitly with the `inline` argument list.

```
g = inline('sin(alpha*x)','x','alpha')

g =

     Inline function:
     g(x,alpha) = sin(alpha*x)
```

Purpose

Functions in memory

Syntax

```
M = inmem
[M,X] = inmem
```

Description

`M = inmem` returns a cell array of strings containing the names of the M-files that are in the P-code buffer.

`[M,X] = inmem` returns an additional cell array, `X`, containing the names of the MEX-files that have been loaded.

Examples

This example lists the M-files that are required to run `erf`.

```
clear all;        % clear the workspace
erf(0.5);
M = inmem

M =

    'repmat'
    'erfcore'
    'erf'
```

See Also

`clear`

inpolygon

Purpose

Detect points inside a polygonal region

Syntax

```
IN = inpolygon(X,Y,xv,yv)
```

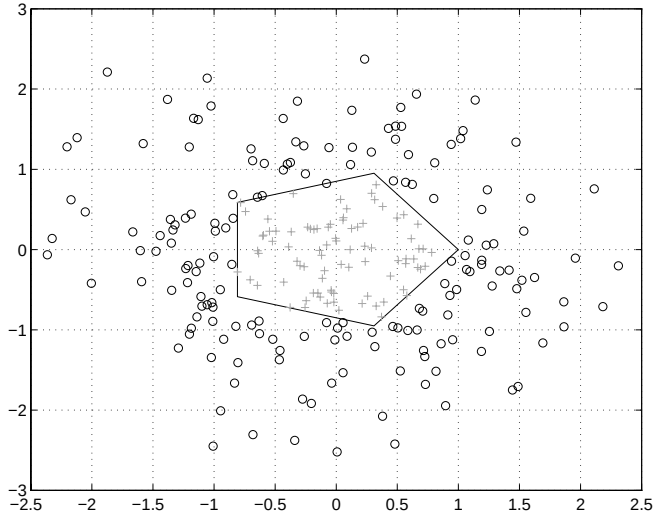
Description

`IN = inpolygon(X,Y,xv,yv)` returns a matrix `IN` the same size as `X` and `Y`. Each element of `IN` is assigned one of the values 1, 0.5 or 0, depending on whether the point `(X(p,q),Y(p,q))` is inside the polygonal region whose vertices are specified by the vectors xv and yv. In particular:

`IN(p,q) = 1`	If `(X(p,q),Y(p,q))` is inside the polygonal region
`IN(p,q) = 0.5`	If `(X(p,q),Y(p,q))` is on the polygon boundary
`IN(p,q) = 0`	If `(X(p,q),Y(p,q))` is outside the polygonal region

Examples

```
L = linspace(0,2.*pi,6); xv = cos(L)';yv = sin(L)';
xv = [xv ; xv(1)]; yv = [yv ; yv(1)];
x = randn(250,1); y = randn(250,1);
in = inpolygon(x,y,xv,yv);
plot(xv,yv,x(in),y(in),'r+',x(~in),y(~in),'bo')
```



Purpose

Request user input

Syntax

```
user_entry = input('prompt')
user_entry = input('prompt','s')
```

Description

The response to the `input` prompt can be any MATLAB expression, which is evaluated using the variables in the current workspace.

`user_entry = input('prompt')` displays *prompt* as a prompt on the screen, waits for input from the keyboard, and returns the value entered in `user_entry`.

`user_entry = input('prompt','s')` returns the entered string as a text variable rather than as a variable name or numerical value.

Remarks

If you press the **Return** key without entering anything, `input` returns an empty matrix.

The text string for the prompt may contain one or more `'\n'` characters. The `'\n'` means to skip to the next line. This allows the prompt string to span several lines. To display just a backslash, use `'\\'`.

Examples

Press **Return** to select a default value by detecting an empty matrix:

```
i = input('Do you want more? Y/N [Y]: ','s');
if isempty(i)
    i = 'Y';
end
```

See Also

`keyboard`, `menu`, `ginput`, `uicontrol`

inputname

Purpose

Input argument name

Syntax

`inputname(`*`argnum`*`)`

Description

This command can be used only inside the body of a function.

`inputname(`*`argnum`*`)` returns the workspace variable name corresponding to the argument number *`argnum`*. If the input argument has no name (for example, if it is an expression instead of a variable), the `inputname` command returns the empty string (`''`).

Examples

Suppose the function `myfun.m` is defined as:

```
function c = myfun(a,b)
disp(sprintf('First calling variable is "%s".',inputname(1))
```

Then

```
x = 5; y = 3; myfun(x,y)
```

produces

```
First calling variable is "x".
```

But

```
myfun(pi+1,pi–1)
```

produces

```
First calling variable is "".
```

See Also

`nargin`, `nargout`, `nargchk`

Purpose

Convert to signed integer

Syntax

```
i = int8(x)
i = int16(x)
i = int32(x)
```

Description

`i = int*(x)` converts the vector `x` into a signed integer. `x` can be any numeric object (such as a `double`). The results of an `int*` operation are shown in the next table.

Operation	Output Range	Output Type	Bytes per Element	Output Class
`int8`	-128 to 127	Signed 8-bit integer	1	`int8`
`int16`	-32768 to 32767	Signed 16-bit integer	2	`int16`
`int32`	-2147483648 to 2147483647	Signed 32-bit integer	4	`int32`

A value of `x` above or below the range for a class is mapped to one of the endpoints of the range. If `x` is already a signed integer of the same class, `int*` has no effect.

The `int*` class is primarily meant to store integer values. Most operations that manipulate arrays without changing their elements are defined (examples are `reshape`, `size`, the logical and relational operators, subscripted assignment, and subscripted reference). No math operations except for `sum` are defined for `int*` since such operations are ambiguous on the boundary of the set (for example, they could wrap or truncate there). You can define your own methods for `int*` (as you can for any object) by placing the appropriately named method in an `@int*` directory within a directory on your path.

Type `help datatypes` for the names of the methods you can overload.

See Also

`double`, `single`, `uint8`, `uint16`, `uint32`

Purpose

Integer to string conversion

Syntax

```
str = int2str(N)
```

Description

`str = int2str(N)` converts an integer to a string with integer format. The input `N` can be a single integer or a vector or matrix of integers. Noninteger inputs are rounded before conversion.

Examples

`int2str(2+3)` is the string `'5'`.

One way to label a plot is

```
title(['case number ' int2str(n)])
```

For matrix or vector inputs, `int2str` returns a string matrix:

```
int2str(eye(3))

ans =

1  0  0
0  1  0
0  0  1
```

See Also

`fprintf`, `num2str`, `sprintf`

interp1

Purpose

One-dimensional data interpolation (table lookup)

Syntax

```
yi = interp1(x,Y,xi)
yi = interp1(x,Y,xi,method)
```

Description

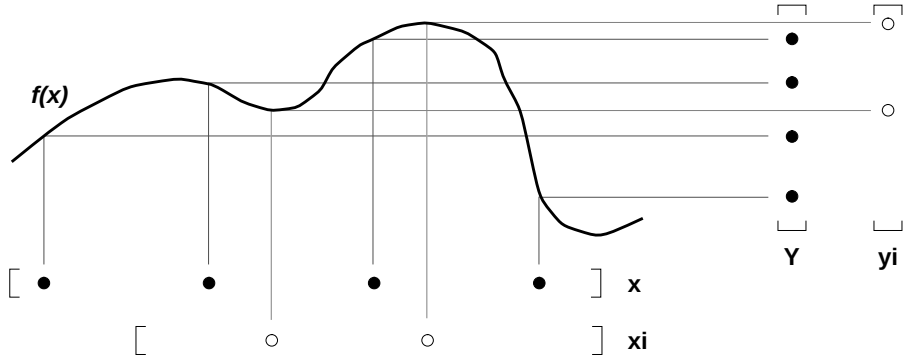
`yi = interp1(x,Y,xi)` returns vector `yi` containing elements corresponding to the elements of `xi` and determined by interpolation within vectors `x` and `Y`. The vector `x` specifies the points at which the data `Y` is given. If `Y` is a matrix, then the interpolation is performed for each column of `Y` and `yi` will be `length(xi)`-by-`size(Y,2)`. Out of range values are returned as `NaNs`.

`yi = interp1(x,Y,xi,method)` interpolates using alternative methods:

- `'nearest'` for nearest neighbor interpolation
- `'linear'` for linear interpolation
- `'spline'` for cubic spline interpolation
- `'cubic'` for cubic interpolation

All the interpolation methods require that `x` be monotonic. For faster interpolation when `x` is equally spaced, use the methods `'*linear'`, `'*cubic'`, `'*nearest'`, or `'*spline'`.

The `interp1` command interpolates between data points. It finds values of a one-dimensional function *f(x)* underlying the data at intermediate points. This is shown below, along with the relationship between vectors `x`, `Y`, `xi`, and `yi`.



Interpolation is the same operation as *table lookup*. Described in table lookup terms, the *table* is `tab = [x,y]` and `interp1` *looks up* the elements of `xi` in `x`,

and, based upon their locations, returns values `yi` interpolated within the elements of `y`.

Examples

Here are two vectors representing the census years from 1900 to 1990 and the corresponding United States population in millions of people.

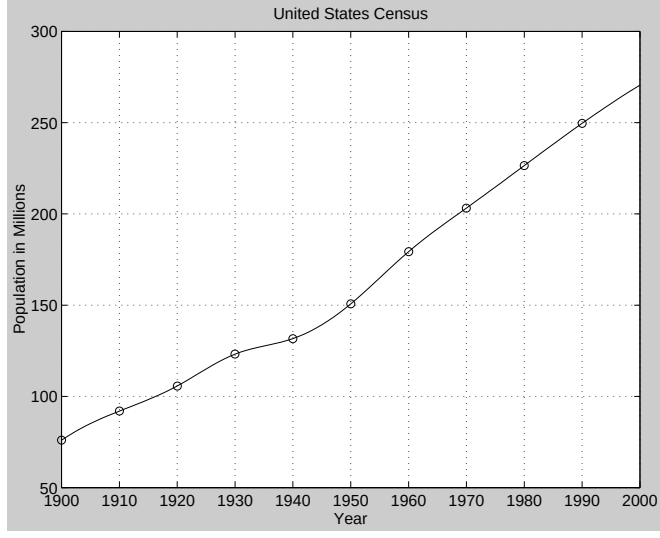
```
t = 1900:10:1990;
p = [75.995  91.972  105.711  123.203  131.669...
     150.697  179.323  203.212  226.505  249.633];
```

The expression `interp1(t,p,1975)` interpolates within the census data to estimate the population in 1975. The result is

```
ans =
    214.8585
```

Now interpolate within the data at every year from 1900 to 2000, and plot the result.

```
x = 1900:1:2000;
y = interp1(t,p,x,'spline');
plot(t,p,'o',x,y)
```



Sometimes it is more convenient to think of interpolation in table lookup terms where the data are stored in a single table. If a portion of the census data is stored in a single 5-by-2 table,

```
tab =
    1950    150.697
    1960    179.323
    1970    203.212
    1980    226.505
    1990    249.633
```

then the population in 1975, obtained by table lookup within the matrix `tab`, is

```
p = interp1(tab(:,1),tab(:,2),1975)
p =
    214.8585
```

Algorithm

The `interp1` command is a MATLAB M-file. The `'nearest'`, `'linear'` and `'cubic'` methods have fairly straightforward implementations. For the `'spline'` method, `interp1` calls a function `spline` that uses the M-files `ppval`, `mkpp`, and `unmkpp`. These routines form a small suite of functions for working with piecewise polynomials. `spline` uses them in a fairly simple fashion to perform cubic spline interpolation. For access to the more advanced features, see these M-files and the Spline Toolbox.

See Also

`interpft`, `interp2`, `interp3`, `interpn`, `spline`

References

[1] de Boor, C. *A Practical Guide to Splines*, Springer-Verlag, 1978.

Purpose

Two-dimensional data interpolation (table lookup)

Syntax

```
ZI = interp2(X,Y,Z,XI,YI)
ZI = interp2(Z,XI,YI)
ZI = interp2(Z,ntimes)
ZI = interp2(X,Y,Z,XI,YI,method)
```

Description

`ZI = interp2(X,Y,Z,XI,YI)` returns matrix `ZI` containing elements corresponding to the elements of `XI` and `YI` and determined by interpolation within the two-dimensional function specified by matrices `X`, `Y`, and `Z`. `X` and `Y` must be monotonic, and have the same format ("plaid") as if they were produced by `meshgrid`. Matrices `X` and `Y` specify the points at which the data `Z` is given. Out of range values are returned as `NaN`s.

`XI` and `YI` can be matrices, in which case `interp2` returns the values of `Z` corresponding to the points `(XI(i,j),YI(i,j))`. Alternatively, you can pass in the row and column vectors `xi` and `yi`, respectively. In this case, `interp2` interprets these vectors as if you issued the command `meshgrid(xi,yi)`.

`ZI = interp2(Z,XI,YI)` assumes that `X = 1:n` and `Y = 1:m`, where `[m,n] = size(Z)`.

`ZI = interp2(Z,ntimes)` expands `Z` by interleaving interpolates between every element, working recursively for `ntimes`. `interp2(Z)` is the same as `interp2(Z,1)`.

`ZI = interp2(X,Y,Z,XI,YI,`*method*`)` specifies an alternative interpolation method:

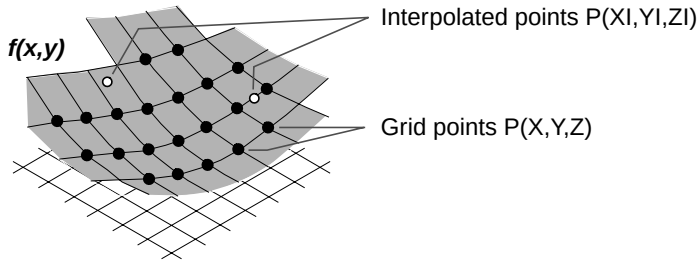
- `'linear'` for bilinear interpolation (default)
- `'nearest'` for nearest neighbor interpolation
- `'spline'` for cubic spline interpolation
- `'cubic'` for bicubic interpolation

All interpolation methods require that `X` and `Y` be monotonic, and have the same format ("plaid") as if they were produced by `meshgrid`. Variable spacing is handled by mapping the given values in `X`, `Y`, `XI`, and `YI` to an equally spaced domain before interpolating. For faster interpolation when `X` and `Y` are equally

spaced and monotonic, use the methods `'*linear'`, `'*cubic'`, `'*spline'`, or `'*nearest'`.

Remarks

The `interp2` command interpolates between data points. It finds values of a two-dimensional function *f(x,y)* underlying the data at intermediate points.

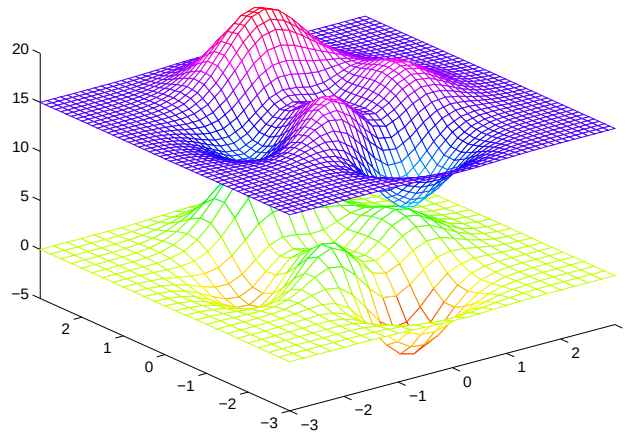


Interpolation is the same operation as table lookup. Described in table lookup terms, the table is `tab = [NaN,Y; X,Z]` and `interp2` looks up the elements of `XI` in `X`, `YI` in `Y`, and, based upon their location, returns values `ZI` interpolated within the elements of `Z`.

Examples

Interpolate the peaks function over a finer grid:

```
[X,Y] = meshgrid(-3:.25:3);
Z = peaks(X,Y);
[XI,YI] = meshgrid(-3:.125:3);
ZI = interp2(X,Y,Z,XI,YI);
mesh(X,Y,Z), hold, mesh(XI,YI,ZI+15)
hold off
axis([-3 3 -3 3 -5 20])
```



Given this set of employee data,

```
years = 1950:10:1990;
service = 10:10:30;
wage = [150.697 199.592 187.625
        179.323 195.072 250.287
        203.212 179.092 322.767
        226.505 153.706 426.730
        249.633 120.281 598.243];
```

it is possible to interpolate to find the wage earned in 1975 by an employee with 15 years' service:

```
w = interp2(service,years,wage,15,1975)
w =
  190.6287
```

See Also griddata, interp1, interp3, interpn, meshgrid

Purpose

Three-dimensional data interpolation (table lookup)

Syntax

```
VI = interp3(X,Y,Z,V,XI,YI,ZI)
VI = interp3(V,XI,YI,ZI)
VI = interp3(V,ntimes)
VI = interp3(...,method)
```

Description

`VI = interp3(X,Y,Z,V,XI,YI,ZI)` interpolates to find `VI`, the values of the underlying three-dimensional function `V` at the points in matrices `XI`,`YI` and `ZI`. Matrices `X`,`Y` and `Z` specify the points at which the data `V` is given. Out of range values are returned as `NaN`.

`XI`, `YI`, and `ZI` can be matrices, in which case `interp3` returns the values of `Z` corresponding to the points `(XI(i,j),YI(i,j),ZI(i,j))`. Alternatively, you can pass in the vectors `xi`, `yi`, and `zi`. Vector arguments that are not the same size are interpreted as if you called `meshgrid`.

`VI = interp3(V,XI,YI,ZI)` assumes `X=1:N`, `Y=1:M`, `Z=1:P` where `[M,N,P]=size(V)`.

`VI = interp3(V,`*ntimes*`)` expands `V` by interleaving interpolates between every element, working recursively for *ntimes* iterations. The command `interp3(V,1)` is the same as `interp3(V)`.

`VI = interp3(...,`*method*`)` specifies alternative methods:

- `'linear'` for linear interpolation (default)
- `'cubic'` for cubic interpolation
- `'spline'` for cubic spline interpolation
- `'nearest'` for nearest neighbor interpolation

Discussion

All the interpolation methods require that `X`,`Y` and `Z` be monotonic and have the same format ("plaid") as if they were produced by `meshgrid`. Variable spacing is handled by mapping the given values in `X`,`Y`,`Z`,`XI`,`YI` and `ZI` to an equally spaced domain before interpolating. For faster interpolation when `X`, `Y`, and `Z` are equally spaced and monotonic, use the methods '`*linear`', '`*cubic`', '`*spline`', or '`*nearest`'.

Examples

To generate a course approximation of `flow` and interpolate over a finer mesh:

```
[x,y,z,v] = flow(10);
[xi,yi,zi] = meshgrid(.1:.25:10, –3:.25:3, –3:.25:3);
vi = interp3(x,y,z,v,xi,yi,zi); % V is 31-by-41-by-27
slice(xi,yi,zi,vi,[6 9.5],2,[–2 .2]) shading flat
```

See Also

`interp1`, `interp2`, `interpn`, `meshgrid`

Purpose

One-dimensional interpolation using the FFT method

Syntax

```
y = interpft(x,n)
y = interpft(x,n,dim)
```

Description

`y = interpft(x,n)` returns the vector `y` that contains the value of the periodic function `x` resampled to `n` equally spaced points.

If `length(x) = m`, and `x` has sample interval `dx`, then the new sample interval for `y` is `dy = dx*m/n`. Note that `n` cannot be smaller than `m`.

If `X` is a matrix, `interpft` operates on the columns of `X`, returning a matrix `Y` with the same number of columns as `X`, but with `n` rows.

`y = interpft(x,n,dim)` operates along the specified dimension.

Algorithm

The `interpft` command uses the FFT method. The original vector `x` is transformed to the Fourier domain using `fft` and then transformed back with more points.

See Also

`interp1`

interpn

Purpose

Multidimensional data interpolation (table lookup)

Syntax

```
VI = interpn(X1,X2,X3,...,V,Y1,Y2,Y3,...)
VI = interpn(V,Y1,Y2,Y3,...)
VI = interpn(V,ntimes)
VI = interpn(...,method)
```

Description

`VI = interpn(X1,X2,X3,...,V,Y1,Y2,Y3,...)` interpolates to find `VI`, the values of the underlying multidimensional function `V` at the points in the arrays `Y1`, `Y2`, `Y3`, etc. For a multidimensional `V`, you should call `interpn` with `2*N+1` arguments, where `N` is the number of dimensions in `V`. Arrays `X1,X2,X3,...` specify the points at which the data `V` is given. Out of range values are returned as `NaN`.

`Y1`, `Y2`, `Y3`,... can be matrices, in which case `interpn` returns the values of `VI` corresponding to the points `(Y1(i,j),Y2(i,j),Y3(i,j),...)`. Alternatively, you can pass in the vectors `y1`, `y2`, `y3`,... In this case, `interpn` interprets these vectors as if you issued the command `ndgrid(y1,y2,y3,...)`.

`VI = interpn(V,Y1,Y2,Y3,...)` interpolates as above, assuming `X1 = 1:size(V,1)`, `X2 = 1:size(V,2)`, `X3 = 1:size(V,3)`, and so on.

`VI = interpn(V,ntimes)` expands `V` by interleaving interpolates between each element, working recursively for `ntimes` iterations. `interpn(V,1)` is the same as `interpn(V)`.

`VI = interpn(...,method)` specifies alternative methods:

- `'linear'` for linear interpolation (default)
- `'cubic'` for cubic interpolation
- `'spline'` for cubic spline interpolation
- `'nearest'` for nearest neighbor interpolation

Discussion

All the interpolation methods require that `X`,`Y` and `Z` be monotonic and have the same format (“plaid”) as if they were produced by `ndgrid`. Variable spacing is handled by mapping the given values in `X1,X2,X3,...` and `Y1,Y2,Y3,...` to an equally spaced domain before interpolating. For faster interpolation when `X1,X2,Y3`, and so on are equally spaced and monotonic, use the methods '`*linear`', '`*cubic`', '`*spline`', or '`*nearest`'.

See Also `interp1`, `interp2`, `ndgrid`

intersect

Purpose

Set intersection of two vectors

Syntax

```
c = intersect(a,b)
c = intersect(A,B,'rows')
[c,ia,ib] = intersect(...)
```

Description

`c = intersect(a,b)` returns the values common to both `a` and `b`. The resulting vector is sorted in ascending order. In set theoretic terms, this is $a \cap b$. `a` and `b` can be cell arrays of strings.

`c = intersect(A,B,'rows')` when `A` and `B` are matrices with the same number of columns returns the rows common to both `A` and `B`.

`[c,ia,ib] = intersect(a,b)` also returns column index vectors `ia` and `ib` such that `c = a(ia)` and `c = b(ib)` (or `c = a(ia,:)` and `c = b(ib,:)`).

Examples

```
A = [1 2 3 6]; B = [1 2 3 4 6 10 20];
[c,ia,ib] = intersect(A,B);
disp([c;ia;ib])
     1     2     3     6
     1     2     3     4
     1     2     3     5
```

See Also

`ismember`, `setdiff`, `setxor`, `union`, `unique`

Purpose

Matrix inverse

Syntax

```
Y = inv(X)
```

Description

`Y = inv(X)` returns the inverse of the square matrix `X`. A warning message is printed if `X` is badly scaled or nearly singular.

In practice, it is seldom necessary to form the explicit inverse of a matrix. A frequent misuse of `inv` arises when solving the system of linear equations $Ax = b$. One way to solve this is with `x = inv(A)*b`. A better way, from both an execution time and numerical accuracy standpoint, is to use the matrix division operator `x = A\b`. This produces the solution using Gaussian elimination, without forming the inverse. See `\` and `/` for further information.

Examples

Here is an example demonstrating the difference between solving a linear system by inverting the matrix with `inv(A)*b` and solving it directly with `A\b`. A matrix `A` of order 100 has been constructed so that its condition number, `cond(A)`, is `1.e10`, and its norm, `norm(A)`, is `1`. The exact solution `x` is a random vector of length 100 and the right-hand side is `b = A*x`. Thus the system of linear equations is badly conditioned, but consistent.

On a 20 MHz 386SX notebook computer, the statements

```
tic, y = inv(A)*b, toc
err = norm(y-x)
res = norm(A*y-b)
```

produce

```
elapsed_time =
    9.6600
err =
    2.4321e-07
res =
    1.8500e-09
```

while the statements

```
tic, z = A\b, toc
err = norm(z-x)
res = norm(A*z-b)
```

produce

```
elapsed_time =
    3.9500
err =
    6.6161e-08
res =
    9.1103e-16
```

It takes almost two and one half times as long to compute the solution with `y = inv(A)*b` as with `z = A\b`. Both produce computed solutions with about the same error, `1.e-7`, reflecting the condition number of the matrix. But the size of the residuals, obtained by plugging the computed solution back into the original equations, differs by several orders of magnitude. The direct solution produces residuals on the order of the machine accuracy, even though the system is badly conditioned.

The behavior of this example is typical. Using `A\b` instead of `inv(A)*b` is two to three times as fast and produces residuals on the order of machine accuracy, relative to the magnitude of the data.

Algorithm

The `inv` command uses the subroutines `ZGEDI` and `ZGEFA` from LINPACK. For more information, see the *LINPACK Users' Guide*.

Diagnostics

From `inv`, if the matrix is singular,

```
Matrix is singular to working precision.
```

On machines with IEEE arithmetic, this is only a warning message. `inv` then returns a matrix with each element set to `Inf`. On machines without IEEE arithmetic, like the VAX, this is treated as an error.

If the inverse was found, but is not reliable, this message is displayed.

```
Warning: Matrix is close to singular or badly scaled.
    Results may be inaccurate. RCOND = xxx
```

See Also

`det`, `lu`, `rref`

The arithmetic operators \, /

References

[1] Dongarra, J.J., J.R. Bunch, C.B. Moler, and G.W. Stewart, *LINPACK Users' Guide*, SIAM, Philadelphia, 1979.

invhilb

Purpose

Inverse of the Hilbert matrix

Syntax

```
H = invhilb(n)
```

Description

`H = invhilb(n)` generates the exact inverse of the exact Hilbert matrix for `n` less than about 15. For larger `n`, `invhilb(n)` generates an approximation to the inverse Hilbert matrix.

Limitations

The exact inverse of the exact Hilbert matrix is a matrix whose elements are large integers. These integers may be represented as floating-point numbers without roundoff error as long as the order of the matrix, `n`, is less than 15.

Comparing `invhilb(n)` with `inv(hilb(n))` involves the effects of two or three sets of roundoff errors:

- The errors caused by representing `hilb(n)`
- The errors in the matrix inversion process
- The errors, if any, in representing `invhilb(n)`

It turns out that the first of these, which involves representing fractions like 1/3 and 1/5 in floating-point, is the most significant.

Examples

`invhilb(4)` is

```
    16   -120    240   -140
  -120   1200  -2700   1680
   240  -2700   6480  -4200
  -140   1680  -4200   2800
```

See Also

`hilb`

References

[1] Forsythe, G. E. and C. B. Moler, *Computer Solution of Linear Algebraic Systems*, Prentice-Hall, 1967, Chapter 19.

Purpose

Inverse permute the dimensions of a multidimensional array

Syntax

```
A = ipermute(B,order)
```

Description

`A = ipermute(B,order)` is the inverse of `permute`. `ipermute` rearranges the dimensions of `B` so that `permute(A,order)` will produce `B`. `B` has the same values as `A` but the order of the subscripts needed to access any particular element are rearranged as specified by *order*. All the elements of *order* must be unique.

Remarks

`permute` and `ipermute` are a generalization of transpose (`.'`) for multidimensional arrays.

Examples

Consider the 2-by-2-by-3 array `a`:

```
a = cat(3,eye(2),2*eye(2),3*eye(2))

a(:,:,1) =             a(:,:,2) =
     1     0                2     0
     0     1                0     2

a(:,:,3) =
     3     0
     0     3
```

Permuting and inverse permuting `a` in the same fashion restores the array to its original form:

```
B = permute(a,[3 2 1]);
C = ipermute(B,[3 2 1]);
isequal(a,C)
ans=

   1
```

See Also

`permute`

Purpose

Detect state

Syntax

```
k = iscell(C)
k = iscellstr(S)
k = ischar(S)
k = isempty(A)
k = isequal(A,B,...)
k = isfield(S,'field')
TF = isfinite(A)
k = isglobal(NAME)
TF = ishandle(H)
k = ishold
k = isieee
TF = isinf(A)
TF = isletter('str')
k = islogical(A)
TF = isnan(A)
k = isnumeric(A)
k = isobject(A)
TF = isprime(A)
k = isreal(A)
TF = isspace('str')
k = issparse(S)
k = isstruct(S)
k = isstudent
k = isunix
k = isvms
```

Description

`k = iscell(C)` returns logical true (`1`) if `C` is a cell array and logical false (`0`) otherwise.

`k = iscellstr(S)` returns logical true (`1`) if `S` is a cell array of strings and logical false (`0`) otherwise. A cell array of strings is a cell array where every element is a character array.

`k = ischar(S)` returns logical true (`1`) if `S` is a character array and logical false (`0`) otherwise.

`k = isempty(A)` returns logical true (`1`) if `A` is an empty array and logical false (`0`) otherwise. An empty array has at least one dimension of size zero, for example, 0-by-0 or 0-by-5.

`k = isequal(A,B,...)` returns logical true (`1`) if the input arrays are the same type and size and hold the same contents, and logical false (`0`) otherwise.

`k = isfield(S,'field')` returns logical true (`1`) if *field* is the name of a field in the structure array `S`.

`TF = isfinite(A)` returns an array the same size as `A` containing logical true (`1`) where the elements of the array `A` are finite and logical false (`0`) where they are infinite or `NaN`.

For any A, exactly one of the three quantities `isfinite(A)`, `isinf(A)`, and `isnan(A)` is equal to one.

`k = isglobal(NAME)` returns logical true (`1`) if `NAME` has been declared to be a global variable, and logical false (`0`) if it has not been so declared.

`TF = ishandle(H)` returns an array the same size as `H` that contains logical true (`1`) where the elements of `H` are valid graphics handles and logical false (`0`)where they are not.

`k = ishold` returns logical true (`1`) if `hold` is `on`, and logical false (`0`) if it is `off`. When `hold` is `on`, the current plot and all axis properties are held so that subsequent graphing commands add to the existing graph. `hold on` means the `NextPlot` property of both figure and axes is set to `add`.

`k = isieee` returns logical true (`1`) on machines with IEEE arithmetic (e.g., IBM PC and most UNIX workstations) and logical false (`0`) on machines without IEEE arithmetic (e.g., VAX, Cray).

`TF = isinf(A)` returns an array the same size as `A` containing logical true (`1`) where the elements of `A` are `+Inf` or `–Inf` and logical false (`0`) where they are not.

`TF = isletter('str')` returns an array the same size as `'str'` containing logical true (`1`) where the elements of *str* are letters of the alphabet and logical false (`0`) where they are not.

`k = islogical(A)` returns logical true (`1`) if `A` is a logical array and logical false (`0`) otherwise.

`TF = isnan(A)` returns an array the same size as `A` containing logical true (`1`) where the elements of `A` are `NaN`s and logical false (`0`) where they are not.

`k = isnumeric(A)` returns logical true (`1`) if A is a numeric array and logical false (`0`) otherwise. For example, sparse arrays, and double precision arrays are numeric while strings, cell arrays, and structure arrays are not.

`k = isobject(A)` returns logical true (`1`) if A is an object and logical false (`0`) otherwise.

`TF = isprime(A)` returns an array the same size as `A` containing logical true (`1`) for the elements of `A` which are prime, and logical false (`0`) otherwise.

`k = isreal(A)` returns logical true (`1`) if all elements of `A` are real numbers, and logical false (`0`) if either `A` is not a numeric array, or if any element of `A` has a nonzero imaginary component. Since strings are a subclass of numeric arrays, `isreal` always returns `1` for a string input.

Because MATLAB supports complex arithmetic, certain of its functions can introduce significant imaginary components during the course of calculations that appear to be limited to real numbers. Thus, you should use `isreal` with discretion.

`TF = isspace('str')` returns an array the same size as `'str'` containing logical true (`1`) where the elements of *str* are ASCII white spaces and logical false (`0`) where they are not. White spaces in ASCII are space, newline, carriage return, tab, vertical tab, or formfeed characters.

`k = issparse(S)` returns logical true (`1`) if the storage class of `S` is sparse and logical false (`0`) otherwise.

`k = isstruct(S)` returns logical true (`1`) if `S` is a structure and logical false (`0`) otherwise.

`k = isstudent` returns logical true (`1`) for student editions of MATLAB and logical false (`0`) for commercial editions.

`k = isunix` returns logical true (`1`) for UNIX versions of MATLAB and logical false (`0`) otherwise.

`k = isvms` returns logical true (`1`) for VMS versions of MATLAB and logical false (`0`) otherwise.

Examples

```
s = 'A1,B2,C3';

isletter(s)
ans =
     1   0   0   1   0   0   1   0

B = rand(2,2,2);
B(:,:,:) = [];

isempty(B)
ans =
     1
```

Given,

```
A =            B =            C =
     1     0        1     0     1     0
     0     1        0     1     0     0
```

`isequal(A,B,C)` returns `0`, and `isequal(A,B)` returns `1`.

Let

```
a = [-2  -1  0  1  2]
```

Then

```
isfinite(1./a) =  [1  1  0  1  1]
isinf(1./a)  =  [0  0  1  0  0]
isnan(1./a)  =  [0  0  0  0  0]
```

and

```
isfinite(0./a) =  [1  1  0  1  1]
isinf(0./a)  =  [0  0  0  0  0]
isnan(0./a)  =  [0  0  1  0  0]
```

isa

Purpose

Detect an object of a given class

Syntax

```
K = isa(obj,'class_name')
```

Description

`K = isa(obj,'class_name')` returns logical true (`1`) if `obj` is of class (or a subclass of) *class_name*, and logical false (`0`) otherwise.

The argument *class_name* is the name of a user-defined or pre-defined class of objects. Predefined MATLAB classes include:

`cell`	Multidimensional cell array
`double`	Multidimensional double precision array
`sparse`	Two-dimensional real (or complex) sparse array
`char`	Array of alphanumeric characters
`struct`	Structure
`'class_name'`	User-defined object class

Examples

```
isa(rand(3,4),'double')

ans =

     1
```

See Also

`class`

Purpose

Detect members of a set

Syntax

```
k = ismember(a,S)
k = ismember(A,S,'rows')
```

Description

`k = ismember(a,S)` returns an vector the same length as `a` containing logical true (`1`) where the elements of `a` are in the set `S`, and logical false (`0`) elsewhere. In set theoretic terms, `k` is 1 where $a \in S$. `a` and `S` can be cell arrays of strings.

`k = ismember(A,S,'rows')` when `A` and `S` are matrices with the same number of columns returns a vector containing `1` where the rows of `A` are also rows of `S` and `0` otherwise.

Examples

```
set = [0 2 4 6 8 10 12 14 16 18 20];
a = reshape(1:5,[5 1])

a =

     1
     2
     3
     4
     5

ismember(a,set)

ans =

     0
     1
     0
     1
     0
```

See Also

`intersect`, `setdiff`, `setxor`, `union`, `unique`

isstr

Purpose Detect strings

Description This MATLAB 4 function has been renamed `ischar` in MATLAB 5.

See Also `is*`

Purpose

Imaginary unit

Syntax

```
j
x+yj
x+j*y
```

Description

Use the character `j` in place of the character `i`, if desired, as the imaginary unit.

As the basic imaginary unit `sqrt(-1)`, `j` is used to enter complex numbers. Since `j` is a function, it can be overridden and used as a variable. This permits you to use `j` as an index in `for` loops, etc.

It is possible to use the character `j` without a multiplication sign as a suffix in forming a numerical constant.

Examples

```
Z = 2+3j
Z = x+j*y
Z = r*exp(j*theta)
```

See Also

`conj`, `i`, `imag`, `real`

keyboard

Purpose

Invoke the keyboard in an M-file

Syntax

```
keyboard
```

Description

`keyboard` , when placed in an M-file, stops execution of the file and gives control to the keyboard. The special status is indicated by a `K` appearing before the prompt. You can examine or change variables; all MATLAB commands are valid. This keyboard mode is useful for debugging your M-files.

To terminate the keyboard mode, type the command:

```
return
```

then press the **Return** key.

See Also

`dbstop`, `input`, `quit`, `return`

Purpose

Kronecker tensor product

Syntax

```
K = kron(X,Y)
```

Description

`K = kron(X,Y)` returns the Kronecker tensor product of `X` and `Y`. The result is a large array formed by taking all possible products between the elements of `X` and those of `Y`. If `X` is `m`-by-`n` and `Y` is `p`-by-`q`, then `kron(X,Y)` is `m*p`-by-`n*q`.

Examples

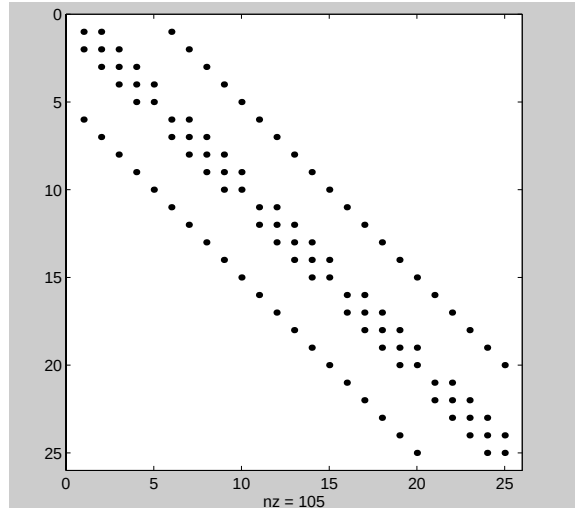
If `X` is 2-by-3, then `kron(X,Y)` is

```
[ X(1,1)*Y X(1,2)*Y X(1,3)*Y
  X(2,1)*Y X(2,2)*Y X(2,3)*Y ]
```

The matrix representation of the discrete Laplacian operator on a two-dimensional, `n`-by-`n` grid is a `n^2`-by-`n^2` sparse matrix. There are at most five nonzero elements in each row or column. The matrix can be generated as the Kronecker product of one-dimensional difference operators with these statements:

```
I = speye(n,n);
E = sparse(2:n,1:n-1,1,n,n);
D = E+E'-2*I;
A = kron(D,I)+kron(I,D);
```

Plotting this with the spy function for `n = 5` yields:



lasterr

Purpose

Last error message

Syntax

```
str = lasterr
lasterr('')
```

Description

`str = lasterr` returns the last error message generated by MATLAB.

`lasterr('')` resets `lasterr` so it returns an empty matrix until the next error occurs.

Examples

Here is a function that examines the `lasterr` string and displays its own message based on the error that last occurred. This example deals with two cases, each of which is an error that can result from a matrix multiply.

```
function catchfcn
l = lasterr;
j = findstr(l,'Inner matrix dimensions');
if j~=[]
    disp('Wrong dimensions for matrix multiply')
else
    k = findstr(l,'Undefined function or variable')
    if (k~=[])
        disp('At least one operand does not exist')
    end
end
```

The `lasterr` function is useful in conjunction with the two-argument form of the `eval` function:

```
eval('string','catchstr')
```

or the `try ... catch...end` statements. The `catch` action examines the `lasterr` string to determine the cause of the error and takes appropriate action.

The eval function evaluates *string* and returns if no error occurs. If an error occurs, eval executes *catchstr*. Using eval with the catchfcn function above:

```
clear
A = [1  2  3; 6  7  2; 0  -1  5];
B = [9  5  6; 0  4  9];
eval('A*B','catch')
```

MATLAB responds with `Wrong dimensions for matrix multiply`.

See Also

error, eval

lastwarn

Purpose

Last warning message

Syntax

```
lastwarn
lastwarn('')
lastwarn('string')
```

Description

`lastwarn` returns a string containing the last warning message issued by MATLAB.

`lastwarn('')` resets the `lastwarn` function so that it will return an empty string matrix until the next warning is encountered.

`lastwarn('string')` sets the last warning message to `'string'`. The last warning message is updated regardless of whether `warning` is `on` or `off`.

See Also

`lasterr`, `warning`

Purpose

Least common multiple

Syntax

```
L = lcm(A,B)
```

Description

`L = lcm(A,B)` returns the least common multiple of corresponding elements of arrays `A` and `B`. Inputs `A` and `B` must contain positive integer elements and must be the same size (or either can be scalar).

Examples

```
lcm(8,40)

ans =

    40

lcm(pascal(3),magic(3))

ans =
     8     1     6
     3    10    21
     4     9     6
```

See Also

`gcd`

legendre

Purpose

Associated Legendre functions

Syntax

```
P = legendre(n,X)
S = legendre(n,X,'sch')
```

Definition

The Legendre functions are defined by:

$$P_n^m(x) = (-1)^m(1-x^2)^{m/2}\frac{d^m}{dx^m}P_n(x)$$

where

$P_n(x)$

is the Legendre polynomial of degree n:

$$P_n(x) = \frac{1}{2^n n!}\left[\frac{d^n}{dx}(x^2-1)^n\right]$$

The Schmidt seminormalized associated Legendre functions are related to the nonnormalized associated Legendre functions $P_n^m(x)$ by:

$$S_n^m(x) = (-1)^m\sqrt{\frac{2(n-m)!}{(n+m)!}}\,P_n^m(x)$$

where $m > 0$.

Description

`P = legendre(n,X)` computes the associated Legendre functions of degree `n` and order `m = 0,1,...,n`, evaluated at `X`. Argument `n` must be a scalar integer less than 256, and `X` must contain real values in the domain $-1 \le x \le 1$.

The returned array `P` has one more dimension than `X`, and each element `P(m+1,d1,d2...)` contains the associated Legendre function of degree `n` and order `m` evaluated at `X(d1,d2...)`.

If `X` is a vector, then `P` is a matrix of the form:

$$\begin{matrix} P_2^0(x(1)) & P_2^0(x(2)) & P_2^0(x(3)) & \ldots \\ P_2^1(x(1)) & P_2^1(x(2)) & P_2^1(x(3)) & \ldots \\ P_2^2(x(1)) & P_2^2(x(2)) & P_2^2(x(3)) & \ldots \end{matrix}$$

`S = legendre(...,'sch')` computes the Schmidt seminormalized associated Legendre functions $S_n^m(x)$.

Examples

The statement `legendre(2,0:0.1:0.2)` returns the matrix:

	x = 0	x = 0.1	x = 0.2
m = 0	-0.5000	-0.4850	-0.4400
m = 1	0	-0.2985	-0.5879
m = 2	3.0000	2.9700	2.8800

Note that this matrix is of the form shown at the bottom of the previous page.

Given,

```
X = rand(2,4,5); N = 2;
P = legendre(N,X)
```

Then `size(P)` is 3-by-2-by-4-by-5, and `P(:,1,2,3)` is the same as `legendre(n,X(1,2,3))`.

length

Purpose

Length of vector

Syntax

```
n = length(X)
```

Description

The statement `length(X)` is equivalent to `max(size(X))` for nonempty arrays and `0` for empty arrays.

`n = length(X)` returns the size of the longest dimension of `X`. If `X` is a vector, this is the same as its length.

Examples

```
x = ones(1,8);
n = length(x)

n =

     8

x = rand(2,10,3);
n = length(x)

n =

    10
```

See Also

`ndims`, `size`

Purpose

Convert linear audio signal to mu-law

Syntax

```
mu = lin2mu(y)
```

Description

`mu = lin2mu(y)` converts linear audio signal amplitudes in the range $-1 \le Y \le 1$ to mu-law encoded "flints" in the range $0 \le u \le 255$.

See Also

`auwrite`, `mu2lin`

linspace

Purpose

Generate linearly spaced vectors

Syntax

```
y = linspace(a,b)
y = linspace(a,b,n)
```

Description

The `linspace` function generates linearly spaced vectors. It is similar to the colon operator ":", but gives direct control over the number of points.

`y = linspace(a,b)` generates a row vector `y` of 100 points linearly spaced between `a` and `b`.

`y = linspace(a,b,n)` generates `n` points.

See Also

`logspace`

The colon operator `:`

Purpose

Retrieve variables from disk

Syntax

```
load
load filename
load ('filename')
load filename.ext
load filename –ascii
load filename –mat
S = load(...)
```

Description

The load and save commands retrieve and store MATLAB variables on disk.

`load` loads all the variables saved in the file `'matlab.mat'`.

`load filename` retrieves the variables from `filename.mat` given a full pathname or a `MATLABPATH` relative partial pathname.

`load ('filename')` loads a file whose name is stored in `filename`. The statements

```
str = 'filename.mat'; load (str)
```

retrieve the variables from the binary file `'filename.mat'`.

`load filename.ext` reads ASCII files that contain rows of space-separated values. The resulting data is placed into an variable with the same name as the file (without the extension). ASCII files may contain MATLAB comments (lines that begin with `%`).

`load filename –ascii` or `load filename –mat` can be used to force `load` to treat the file as either an ASCII file or a MAT-file.

`S = load(...)` returns the contents of a MAT-file as a structure instead of directly loading the file into the workspace. The field names in `S` match the names of the variables that were retrieved. When the file is ASCII, `S` is a double-precision array.

Remarks

MAT-files are double-precision binary MATLAB format files created by the `save` command and readable by the `load` command. They can be created on one machine and later read by MATLAB on another machine with a different

floating-point format, retaining as much accuracy and range as the disparate formats allow. They can also be manipulated by other programs, external to MATLAB.

The Application Program Interface Libraries contain C- and Fortran-callable routines to read and write MAT-files from external programs.

See Also

`fprintf`, `fscanf`, `partialpath`, `save`, `spconvert`

Purpose

User-defined extension of the load function for user objects

Syntax

```
b = loadobj(a)
```

Description

`b = loadobj(a)` extends the `load` function for user objects. When an object is loaded from a MAT file, the `load` function calls the `loadobj` method for the object's class if it is defined. The `loadobj` method must have the calling sequence shown; the input argument `a` is the object as loaded from the MAT file and the output argument `b` is the object that the `load` function will load into the workspace.

These steps describe how an object is loaded from a MAT file into the workspace:

1. The `load` function detects the object `a` in the MAT file.
2. The `load` function looks in the current workspace for an object of the same class as the object `a`. If there isn't an object of the same class in the workspace, `load` calls the default constructor, registering an object of that class in the workspace. The default constructor is the constructor function called with no input arguments.
3. The `load` function checks to see if the structure of the object `a` matches the structure of the object registered in the workspace. If the objects match, `a` is loaded. If the objects don't match, `load` converts `a` to a structure variable.
4. The `load` function calls the `loadobj` method for the object's class if it is defined. `load` passes the object `a` to the `loadobj` method as an input argument. Note, the format of the object `a` is dependent on the results of step **3** (object or structure). The output argument of `loadobj`, `b`, is loaded into the workspace in place of the object `a`.

Remarks

`loadobj` can be overloaded only for user objects. `load` will not call `loadobj` for built-in datatypes (such as `double`).

`loadobj` is invoked separately for each object in the MAT file. The `load` function recursively descends cell arrays and structures applying the `loadobj` method to each object encountered.

See Also

`load`, `save`, `saveobj`

log

Purpose

Natural logarithm

Syntax

```
Y = log(X)
```

Description

The log function operates element-wise on arrays. Its domain includes complex and negative numbers, which may lead to unexpected results if used unintentionally.

`Y = log(X)` returns the natural logarithm of the elements of `X`. For complex or negative *z*, where $z = x + y*i$, the complex logarithm is returned:

```
log(z) = log(abs(z)) + i*atan2(y,x)
```

Examples

The statement `abs(log(-1))` is a clever way to generate π:

```
ans =

    3.1416
```

See Also

`exp`, `log10`, `log2`, `logm`

Purpose

Base 2 logarithm and dissect floating-point numbers into exponent and mantissa

Syntax

```
Y = log2(X)
[F,E] = log2(X)
```

Description

`Y = log2(X)` computes the base 2 logarithm of the elements of `X`.

`[F,E] = log2(X)` returns arrays `F` and `E`. Argument `F` is an array of real values, usually in the range $0.5 \le \text{abs}(F) < 1$. For real `X`, `F` satisfies the equation: `X = F.*2.^E`. Argument `E` is an array of integers that, for real `X`, satisfy the equation: `X = F.*2.^E`.

Remarks

This function corresponds to the ANSI C function `frexp()` and the IEEE floating-point standard function `logb()`. Any zeros in `X` produce `F = 0` and `E = 0`.

Examples

For IEEE arithmetic, the statement `[F,E] = log2(X)` yields the values:

X	F	E
1	1/2	1
pi	pi/4	2
–3	–3/4	2
eps	1/2	–51
realmax	1–eps/2	1024
realmin	1/2	–1021

See Also

log, pow2

log10

Purpose

Common (base 10) logarithm

Syntax

```
Y = log10(X)
```

Description

The `log10` function operates element-by-element on arrays. Its domain includes complex numbers, which may lead to unexpected results if used unintentionally.

`Y = log10(X)` returns the base 10 logarithm of the elements of `X`.

Examples

On a computer with IEEE arithmetic

```
log10(realmax) is 308.2547
```

and

```
log10(eps) is -15.6536
```

See Also

`exp`, `log`, `log2`, `logm`

Purpose

Convert numeric values to logical

Syntax

```
K = logical(A)
```

Description

`K = logical(A)` returns an array that can be used for logical indexing or logical tests.

`A(B)`, where `B` is a logical array, returns the values of `A` at the indices where the real part of `B` is nonzero. `B` must be the same size as `A`.

Remarks

Logical arrays are also created by the relational operators (==,<,>,~, etc.) and functions like `any`, `all`, `isnan`, `isinf`, and `isfinite`.

Examples

Given `A = [1 2 3; 4 5 6; 7 8 9]`, the statement `B = logical(eye(3))` returns a logical array

```
B =
   1   0   0
   0   1   0
   0   0   1
```

which can be used in logical indexing that returns `A`'s diagonal elements:

```
A(B)

ans =
     1
     5
     9
```

However, attempting to index into `A` using the *numeric* array `eye(3)` results in:

```
A(eye(3))
??? Index into matrix is negative or zero.
```

See Also

The logical operators `&`, `|`, `~`

logm

Purpose

Matrix logarithm

Syntax

```
Y = logm(X)
[Y,esterr] = logm(X)
```

Description

`Y = logm(X)` returns the matrix logarithm: the inverse function of `expm(X)`. Complex results are produced if `X` has negative eigenvalues. A warning message is printed if the computed `expm(Y)` is not close to `X`.

`[Y,esterr] = logm(X)` does not print any warning message, but returns an estimate of the relative residual, `norm(expm(Y)-X)/norm(X)`.

Remarks

If `X` is real symmetric or complex Hermitian, then so is `logm(X)`.

Some matrices, like `X = [0 1; 0 0]`, do not have any logarithms, real or complex, and `logm` cannot be expected to produce one.

Limitations

For most matrices:

```
logm(expm(X)) = X = expm(logm(X))
```

These identities may fail for some `X`. For example, if the computed eigenvalues of `X` include an exact zero, then `logm(X)` generates infinity. Or, if the elements of `X` are too large, `expm(X)` may overflow.

Examples

Suppose `A` is the 3-by-3 matrix

```
     1     1     0
     0     0     2
     0     0    -1
```

and `X = expm(A)` is

```
X =

    2.7183    1.7183    1.0862
         0    1.0000    1.2642
         0         0    0.3679
```

Then `A = logm(X)` produces the original matrix `A`.

```
A =

    1.0000    1.0000    0.0000
         0         0    2.0000
         0         0   -1.0000
```

But `log(X)` involves taking the logarithm of zero, and so produces

```
ans =

    1.0000    0.5413    0.0826
      -Inf         0    0.2345
      -Inf      -Inf   -1.0000
```

Algorithm

The matrix functions are evaluated using an algorithm due to Parlett, which is described in [1]. The algorithm uses the Schur factorization of the matrix and may give poor results or break down completely when the matrix has repeated eigenvalues. A warning message is printed when the results may be inaccurate.

See Also

`expm`, `funm`, `sqrtm`

References

[1] Golub, G. H. and C. F. Van Loan, *Matrix Computation*, Johns Hopkins University Press, 1983, p. 384.

[2] Moler, C. B. and C. F. Van Loan, “Nineteen Dubious Ways to Compute the Exponential of a Matrix,” *SIAM Review* 20, 1979,pp. 801-836.

logspace

Purpose

Generate logarithmically spaced vectors

Syntax

```
y = logspace(a,b)
y = logspace(a,b,n)
y = logspace(a,pi)
```

Description

The `logspace` function generates logarithmically spaced vectors. Especially useful for creating frequency vectors, it is a logarithmic equivalent of `linspace` and the ":" or colon operator.

`y = logspace(a,b)` generates a row vector `y` of 50 logarithmically spaced points between decades `10^a` and `10^b`.

`y = logspace(a,b,n)` generates `n` points between decades `10^a` and `10^b`.

`y = logspace(a,pi)` generates the points between `10^a` and `pi`, which is useful for digital signal processing where frequencies over this interval go around the unit circle.

Remarks

All the arguments to `logspace` must be scalars.

See Also

`linspace`

The colon operator `:`

Purpose

Search for keyword through all help entries

Syntax

```
lookfor topic
lookfor topic -all
```

Description

`lookfor topic` searches for the string `topic` in the first comment line (the H1 line) of the help text in all M-files found on MATLAB's search path. For all files in which a match occurs, `lookfor` displays the H1 line.

`lookfor topic -all` searches the entire first comment block of an M-file looking for `topic`.

Examples

For example

```
lookfor inverse
```

finds at least a dozen matches, including H1 lines containing "inverse hyperbolic cosine," "two-dimensional inverse FFT," and "pseudoinverse." Contrast this with

```
which inverse
```

or

```
what inverse
```

These commands run more quickly, but probably fail to find anything because MATLAB does not ordinarily have a function `inverse`.

In summary, `what` lists the functions in a given directory, `which` finds the directory containing a given function or file, and `lookfor` finds all functions in all directories that might have something to do with a given keyword.

See Also

`dir`, `doc`, `help`, `helpdesk`, `helpwin`, `what`, `which`, `who`

lower

Purpose

Convert string to lower case

Syntax

```
t = lower('str')
B = lower(A)
```

Description

`t = lower('str')` returns the string formed by converting any upper-case characters in *str* to the corresponding lower-case characters and leaving all other characters unchanged.

`B = lower(A)` when `A` is a cell array of strings, returns a cell array the same size as `A` containing the result of applying `lower` to each string within `A`.

Examples

`lower('MathWorks')` is `mathworks`.

Remarks

Character sets supported:

- PC: Windows Latin-1
- Other: ISO Latin-1 (ISO 8859-1)

See Also

`upper`

Purpose List directory on UNIX

Syntax `ls`

Description `ls` displays the results of the `ls` command on UNIX. You can pass any flags to `ls` that your operating system supports. On UNIX, `ls` returns a `\n` delimited string of filenames. On all other platforms, `ls` executes `dir`.

See Also `dir`

lscov

Purpose

Least squares solution in the presence of known covariance

Syntax

```
x = lscov(A,b,V)
[x,dx] = lscov(A,b,V)
```

Description

`x = lscov(A,b,V)` returns the vector `x` that solves `A*x = b + e` where `e` is normally distributed with zero mean and covariance `V`. Matrix `A` must be `m`-by-`n` where `m > n`. This is the over-determined least squares problem with covariance `V`. The solution is found without inverting `V`.

`[x,dx] = lscov(A,b,V)` returns the standard errors of `x` in `dx`. The standard statistical formula for the standard error of the coefficients is:

```
mse = B'*(inv(V)-inv(V)*A*inv(A'*inv(V)*A)*A'*inv(V))*B./(m-n)
dx = sqrt(diag(inv(A'*inv(V)*A)*mse))
```

Algorithm

The vector `x` minimizes the quantity `(A*x-b)'*inv(V)*(A*x-b)`. The classical linear algebra solution to this problem is

```
x = inv(A'*inv(V)*A)*A'*inv(V)*b
```

but the `lscov` function instead computes the QR decomposition of `A` and then modifies `Q` by `V`.

See Also

`lsqnonneg`, `qr`

The arithmetic operator `\`

Reference

Strang, G., *Introduction to Applied Mathematics*, Wellesley-Cambridge, 1986, p. 398.

Purpose

Linear least squares with nonnegativity constraints

Syntax

```
x = lsqnonneg(C,d)
x = lsqnonneg(C,d,x0)
x = lsqnonneg(C,d,x0,options)
[x,resnorm] = lsqnonneg(...)
[x,resnorm,residual] = lsqnonneg(...)
[x,resnorm,residual,exitflag] = lsqnonneg(...)
[x,resnorm,residual,exitflag,output] = lsqnonneg(...)
[x,resnorm,residual,exitflag,output,lambda] = lsqnonneg(...)
```

Description

`x = lsqnonneg(C,d)` returns the vector `x` that minimizes `norm(C*x-d)` subject to `x >= 0`. `C` and `d` must be real.

`x = lsqnonneg(C,d,x0)` uses `x0` as the starting point if all `x0 >= 0`; otherwise, the default is used. The default start point is the origin (the default is used when `x0==[ ]` or when only two input arguments are provided).

`x = lsqnonneg(C,d,x0,options)` minimizes with the optimization parameters specified in the structure `options`. You can define these parameters using the `optimset` function. `lsqnonneg` uses these `options` structure fields:

- `Display` – Level of display. `off` displays no output; `iter` displays output at each iteration; `final` displays just the final output.
- `TolX` – Termination tolerance on `x`.

`[x,resnorm] = lsqnonneg(...)` returns the value of the squared 2-norm of the residual: `norm(C*x-d)^2`.

`[x,resnorm,residual] = lsqnonneg(...)` returns the residual, `C*x-d`.

`[x,resnorm,residual,exitflag] = lsqnonneg(...)` returns a value `exitflag` that describes the exit condition of `lsqnonneg`:

- `> 0` indicates that the function converged to a solution `x`.
- `0` indicates that the iteration count was exceeded. Increasing the tolerance (`TolX` parameter in `options`) may lead to a solution.
- `< 0` indicates that the function did not converge to a solution.

`[x,resnorm,residual,exitflag,output] = lsqnonneg(...)` returns a structure `output` that contains information about the operation:

- `output.iterations` – The number of iterations taken.
- `output.algorithm` – The algorithm used.

`[x,resnorm,residual,exitflag,output,lambda] = lsqnonneg(...)` returns the dual vector `lambda`, where `lambda(i)<=0` when `x(i)` is (approximately) `0`, and `lambda(i)` is (approximately) `0` when `x(i)>0`.

Examples

Compare the unconstrained least squares solution to the `lsqnonneg` solution for a 4-by-2 problem:

```
C =
    0.0372    0.2869
    0.6861    0.7071
    0.6233    0.6245
    0.6344    0.6170

d =
    0.8587
    0.1781
    0.0747
    0.8405

[C\d lsqnonneg(C,d)] =
   -2.5627         0
    3.1108    0.6929

[norm(C*(C\d)-d) norm(C*lsqnonneg(C,d)-d)] =
    0.6674    0.9118
```

The solution from `lsqnonneg` does not fit as well (has a larger residual), but has no negative components.

Algorithm

`lsqnonneg` uses the algorithm described in [1]. The algorithm starts with a set of possible basis vectors and computes the associated dual vector `lambda`. It then selects the basis vector corresponding to the maximum value in `lambda` in order to swap out of the basis in exchange for another possible candidate. This continues until `lambda <= 0`.

See Also

The arithmetic operator \, `optimset`

References

[1] Lawson, C.L. and R.J. Hanson, *Solving Least Squares Problems*, Prentice-Hall, 1974, Chapter 23, p. 161.

lu

Purpose

LU matrix factorization

Syntax

```
[L,U] = lu(X)
[L,U,P] = lu(X)
lu(X)
```

Description

The `lu` function expresses any square matrix `X` as the product of two essentially triangular matrices, one of them a permutation of a lower triangular matrix and the other an upper triangular matrix. The factorization is often called the *LU*, or sometimes the *LR*, factorization.

`[L,U] = lu(X)` returns an upper triangular matrix in `U` and a psychologically lower triangular matrix (i.e., a product of lower triangular and permutation matrices) in `L`, so that `X = L*U`.

`[L,U,P] = lu(X)` returns an upper triangular matrix in `U`, a lower triangular matrix in `L`, and a permutation matrix in `P`, so that `L*U = P*X`.

`lu(X)` returns the output from the LINPACK routine `ZGEFA`.

Remarks

Most of the algorithms for computing LU factorization are variants of Gaussian elimination. The factorization is a key step in obtaining the inverse with `inv` and the determinant with `det`. It is also the basis for the linear equation solution or matrix division obtained with `\` and `/`.

Arguments

`L` A factor of `X`. Depending on the form of the function, `L` is either lower triangular, or else the product of a lower triangular matrix with a permutation matrix `P`.

`U` An upper triangular matrix that is a factor of `X`.

`P` The permutation matrix satisfying the equation `L*U = P*X`.

Examples

Start with

```
A =
     1     2     3
     4     5     6
     7     8     0
```

To see the LU factorization, call lu with two output arguments:

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

L =

    0.1429    1.0000         0
    0.5714    0.5000    1.0000
    1.0000         0         0

U =

    7.0000    8.0000    0.0000
         0    0.8571    3.0000
         0         0    4.5000
```

Notice that L is a permutation of a lower triangular matrix that has 1's on the permuted diagonal, and that U is upper triangular. To check that the factorization does its job, compute the product:

```
L*U
```

which returns the original A. Using three arguments on the left-hand side to get the permutation matrix as well

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

returns the same value of `U`, but `L` is reordered:

```
L =

    1.0000         0         0
    0.1429    1.0000         0
    0.5714    0.5000    1.0000

U =

    7.0000    8.0000         0
         0    0.8571    3.0000
         0         0    4.5000

P =

    0    0    1
    1    0    0
    0    1    0
```

To verify that `L*U` is a permuted version of `A`, compute `L*U` and subtract it from `P*A`:

```
P*A – L*U
```

The inverse of the example matrix, `X = inv(A)`, is actually computed from the inverses of the triangular factors:

```
X = inv(U)*inv(L)
```

The determinant of the example matrix is

```
d = det(A)

d =

    27
```

It is computed from the determinants of the triangular factors:

```
d = det(L)*det(U)
```

The solution to $Ax = b$ is obtained with matrix division:

```
x = A\b
```

The solution is actually computed by solving two triangular systems:

```
y = L\b, x = U\y
```

Algorithm

`lu` uses the subroutines `ZGEDI` and `ZGEFA` from LINPACK. For more information, see the *LINPACK Users' Guide*.

See Also

`cond`, `det`, `inv`, `qr`, `rref`

The arithmetic operators \ and /

References

[1] Dongarra, J.J., J.R. Bunch, C.B. Moler, and G.W. Stewart, *LINPACK Users' Guide*, SIAM, Philadelphia, 1979.

luinc

Purpose

Incomplete LU matrix factorizations

Syntax

```
luinc(X,'0')
[L,U] = luinc(X,'0')
[L,U,P] = luinc(X,'0')
luinc(X,droptol)
luinc(X,options)
[L,U] = luinc(X,options)
[L,U] = luinc(X,droptol)
[L,U,P] = luinc(X,options)
[L,U,P] = luinc(X,droptol)
```

Description

`luinc` produces a unit lower triangular matrix, an upper triangular matrix, and a permutation matrix.

`luinc(X,'0')` computes the incomplete LU factorization of level 0 of a square sparse matrix. The triangular factors have the same sparsity pattern as the permutation of the original sparse matrix `X`, and their product agrees with the permutated `X` over its sparsity pattern. `luinc(X,'0')` returns the strict lower triangular part of the factor and the upper triangular factor embedded within the same matrix. The permutation information is lost, but `nnz(luinc(X,'0')) = nnz(X)`, with the possible exception of some zeros due to cancellation.

`[L,U] = luinc(X,'0')` returns the product of permutation matrices and a unit lower triangular matrix in `L` and an upper triangular matrix in `U`. The exact sparsity patterns of `L`, `U`, and `X` are not comparable but the number of nonzeros is maintained with the possible exception of some zeros in `L` and `U` due to cancellation:

`nnz(L)+nnz(U) = nnz(X)+n`, where `X` is `n-by-n`.

The product `L*U` agrees with `X` over its sparsity pattern. `(L*U).*spones(X)–X` has entries of the order of `eps`.

`[L,U,P] = luinc(X,'0')` returns a unit lower triangular matrix in `L`, an upper triangular matrix in `U` and a permutation matrix in `P`. `L` has the same sparsity pattern as the lower triangle of the permuted `X`

`spones(L) = spones(tril(P*X))`

with the possible exceptions of 1's on the diagonal of L where P*X may be zero, and zeros in L due to cancellation where P*X may be nonzero. U has the same sparsity pattern as the upper triangle of P*X

```
spones(U) = spones(triu(P*X))
```

with the possible exceptions of zeros in U due to cancellation where P*X may be nonzero. The product L*U agrees within rounding error with the permuted matrix P*X over its sparsity pattern. (L*U).*spones(P*X)–P*X has entries of the order of eps.

luinc(X,droptol) computes the incomplete LU factorization of any sparse matrix using a drop tolerance. droptol must be a non-negative scalar. luinc(X,droptol) produces an approximation to the complete LU factors returned by lu(X). For increasingly smaller values of the drop tolerance, this approximation improves, until the drop tolerance is 0, at which time the complete LU factorization is produced, as in lu(X).

As each column j of the triangular incomplete factors is being computed, the entries smaller in magnitude than the local drop tolerance (the product of the drop tolerance and the norm of the corresponding column of X)

```
droptol*norm(X(:,j))
```

are dropped from the appropriate factor.

The only exceptions to this dropping rule are the diagonal entries of the upper triangular factor, which are preserved to avoid a singular factor.

luinc(X,options) specifies a structure with up to four fields that may be used in any combination: droptol, milu, udiag, thresh. Additional fields of options are ignored.

droptol is the drop tolerance of the incomplete factorization.

If milu is 1, luinc produces the modified incomplete LU factorization that subtracts the dropped elements in any column from the diagonal element of the upper triangular factor. The default value is 0.

If udiag is 1, any zeros on the diagonal of the upper triangular factor are replaced by the local drop tolerance. The default is 0.

thresh is the pivot threshold between 0 (forces diagonal pivoting) and 1, the default, which always chooses the maximum magnitude entry in the column to be the pivot. thresh is desribed in greater detail in lu.

luinc(X,options) is the same as luinc(X,droptol) if options has droptol as its only field.

[L,U] = luinc(X,options) returns a permutation of a unit lower triangular matrix in L and an upper trianglar matrix in U. The product L*U is an approximation to X. luinc(X,options) returns the strict lower triangular part of the factor and the upper triangular factor embedded within the same matrix. The permutation information is lost.

[L,U] = luinc(X,options) is the same as luinc(X,droptol) if options has droptol as its only field.

[L,U,P] = luinc(X,options) returns a unit lower triangular matrix in L, an upper triangular matrix in U, and a permutation matrix in P. The nonzero entries of U satisfy

```
abs(U(i,j)) >= droptol*norm((X:,j)),
```

with the possible exception of the diagonal entries which were retained despite not satisfying the criterion. The entries of L were tested against the local drop tolerance before being scaled by the pivot, so for nonzeros in L

```
abs(L(i,j)) >= droptol*norm(X(:,j))/U(j,j).
```

The product L*U is an approximation to the permuted P*X.

[L,U,P] = luinc(X,options) is the same as [L,U,P] = luinc(X,droptol) if options has droptol as its only field.

Remarks

These incomplete factorizations may be useful as preconditioners for solving large sparse systems of linear equations. The lower triangular factors all have 1's along the main diagonal but a single 0 on the diagonal of the upper triangular factor makes it singular. The incomplete factorization with a drop tolerance prints a warning message if the upper triangular factor has zeros on the diagonal. Similarly, using the udiag option to replace a zero diagonal only gets rid of the symptoms of the problem but does not solve it. The preconditioner may not be singular, but it probably is not useful and a warning message is printed.

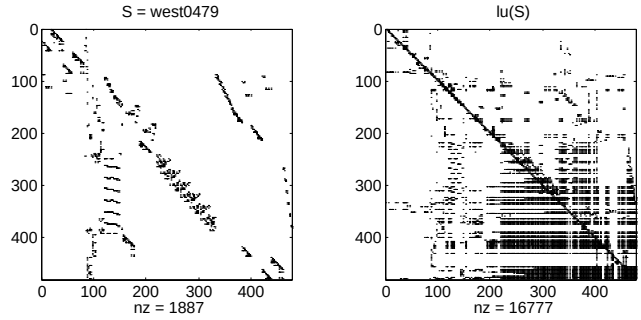
Limitations

`luinc(X,'0')` works on square matrices only.

Examples

Start with a sparse matrix and compute its LU factorization.

```
load west0479;
S = west0479;
LU = lu(S);
```

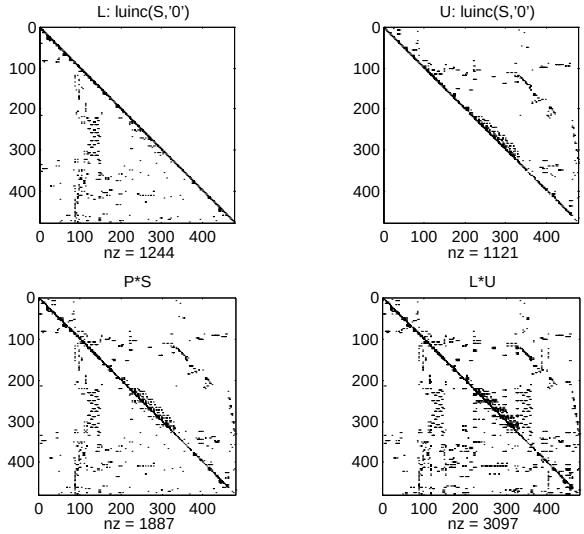


Compute the incomplete LU factorization of level 0.

```
[L,U,P] = luinc(S,'0');
D = (L*U).*spones(P*S)-P*S;
```

`spones(U)` and `spones(triu(P*S))` are identical.

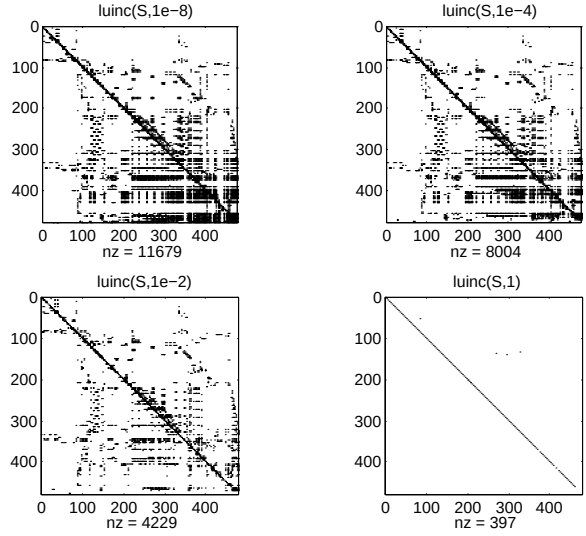
`spones(L)` and `spones(tril(P*S))` disagree at 73 places on the diagonal, where `L` is `1` and `P*S` is `0`, and also at position (206,113), where `L` is `0` due to cancellation, and `P*S` is `-1`. `D` has entries of the order of eps.

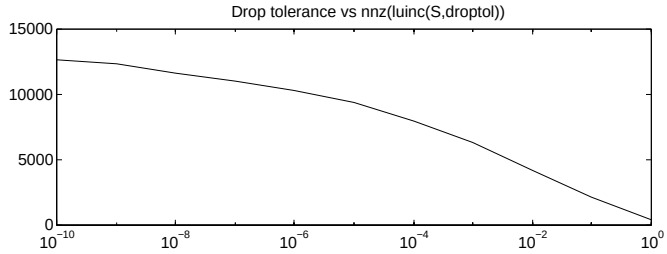


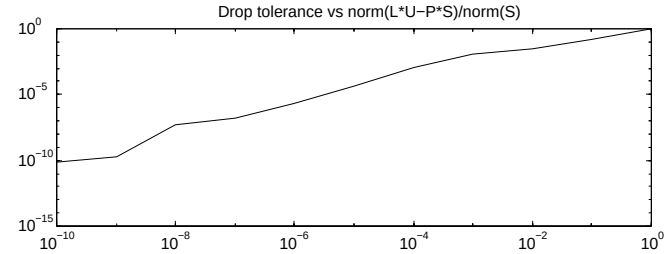

```
[IL0,IU0,IP0] = luinc(S,0);
[IL1,IU1,IP1] = luinc(S,1e-10);
                .
                .
                .
```

A drop tolerance of `0` produces the complete LU factorization. Increasing the drop tolerance increases the sparsity of the factors (decreases the number of

nonzeros) but also increases the error in the factors, as seen in the plot of drop tolerance versus `norm(L*U-P*S,1)/norm(S,1)` in second figure below.







Algorithm

`luinc(X,'0')` is based on the "KJI" variant of the LU factorization with partial pivoting. Updates are made only to positions which are nonzero in `X`.

`luinc(X,droptol)` and `luinc(X,options)` are based on the column-oriented `lu` for sparse matrices.

See Also

`lu`, `cholinc`, `bicg`

References

Saad, Yousef, *Iterative Methods for Sparse Linear Systems*, PWS Publishing Company, 1996, Chapter 10 - Preconditioning Techniques.

Purpose

Magic square

Syntax

```
M = magic(n)
```

Description

`M = magic(n)` returns an `n`-by-`n` matrix constructed from the integers `1` through `n^2` with equal row and column sums. The order `n` must be a scalar greater than or equal to `3`.

Remarks

A magic square, scaled by its magic sum, is doubly stochastic.

Examples

The magic square of order 3 is

```
M = magic(3)

M =

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

This is called a magic square because the sum of the elements in each column is the same.

```
sum(M) =

    15    15    15
```

And the sum of the elements in each row, obtained by transposing twice, is the same.

```
sum(M')' =

    15
    15
    15
```

This is also a special magic square because the diagonal elements have the same sum.

```
sum(diag(M)) =

    15
```

The value of the characteristic sum for a magic square of order n is

```
sum(1:n^2)/n
```

which, when n = 3, is 15.

Algorithm

There are three different algorithms:

- one for odd n
- one for even n not divisible by four
- one for even n divisible by four.

To make this apparent, type:

```
for n = 3:20
    A = magic(n);
    plot(A,'-');
    r(n) = rank(A);
end
r
```

Limitations

If you supply n less than 3, magic returns either a nonmagic square, or else the degenerate magic squares 1 and [].

See Also

ones, rand

Purpose

Convert a matrix into a string

Syntax

```
str = mat2str(A)
str = mat2str(A,n)
```

Description

`str = mat2str(A)` converts matrix `A` into a string, suitable for input to the `eval` function, using full precision.

`str = mat2str(A,n)` converts matrix `A` using `n` digits of precision.

Limitations

The `mat2str` function is intended to operate on scalar, vector, or rectangular array inputs only. An error will result if `A` is a multidimensional array.

Examples

Consider the matrix:

```
A =
     1     2
     3     4
```

The statement

```
b = mat2str(A)
```

produces:

```
b =
[1 2 ;3 4 ]
```

where `b` is a string of 11 characters, including the square brackets, spaces, and a semicolon.

`eval(mat2str(A))` reproduces `A`.

See Also

`int2str`, `sprintf`, `str2num`

matlabrc

Purpose

MATLAB startup M-file

Syntax

```
matlabrc
```

Description

At startup time, MATLAB automatically executes the master M-file `matlabrc.m` and, if it exists, `startup.m`. On multiuser or networked systems, `matlabrc.m` is reserved for use by the system manager. The file `matlabrc.m` invokes the file `startup.m` if it exists on MATLAB's search path.

As an individual user, you can create a startup file in your own MATLAB directory. Use the startup file to define physical constants, engineering conversion factors, graphics defaults, or anything else you want predefined in your workspace.

Algorithm

Only `matlabrc` is actually invoked by MATLAB at startup. However, `matlabrc.m` contains the statements:

```
if exist('startup') == 2
    startup
end
```

that invoke `startup.m`. Extend this process to create additional startup M-files, if required.

Remarks

You can also start MATLAB using options you define at the command line or in your Windows shortcut for MATLAB. See Chapter 2 of *Using MATLAB* for details.

Examples

Example 1 – Specifying the Default Editor for UNIX

For UNIX platforms, you can include the `system_dependent` command in your `startup.m` file, or your `matlabrc.m` file if you have access to it. Then when you use `edit` for M-files, your default UNIX editor, for example Emacs, is used instead of the MATLAB Editor. The sample `matlabrc.m` file, included with MATLAB, already contains this command but it is commented out. If you want

to use your UNIX editor when you use `edit`, copy these lines to your `startup.m` file and remove the comment marks.

```
%% For the 'edit' command, to use an editor defined in the $EDITOR
%% environment variable, the following line should be uncommented
%% (UNIX only)
%% system_dependent('builtinEditor','off')
```

Example 2 – Turning Off the Figure Window Toolbar

If you do not want the toolbar to appear in the figure window, remove the comment marks from the following line in the `matlabrc.m` file, or create a similar line in your own `startup.m` file.

```
%  set(0,'defaultfiguretoolbar','none')
```

See Also

`exist`, `path`, `quit`, `startup`

matlabroot

Purpose

Return root directory of MATLAB installation

Syntax

```
rd = matlabroot
```

Description

`rd = matlabroot` returns the name of the directory in which the MATLAB software is installed.

Examples

```
fullfile(matlabroot,'toolbox','matlab','general','')
```

produces a full path to the `toolbox/matlab/general` directory that is correct for the platform it is executed on.

Purpose

Maximum elements of an array

Syntax

```
C = max(A)
C = max(A,B)
C = max(A,[],dim)
[C,I] = max(...)
```

Description

`C = max(A)` returns the largest elements along different dimensions of an array.

If `A` is a vector, `max(A)` returns the largest element in `A`.

If `A` is a matrix, `max(A)` treats the columns of `A` as vectors, returning a row vector containing the maximum element from each column.

If `A` is a multidimensional array, `max(A)` treats the values along the first non-singleton dimension as vectors, returning the maximum value of each vector.

`C = max(A,B)` returns an array the same size as `A` and `B` with the largest elements taken from `A` or `B`.

`C = max(A,[],dim)` returns the largest elements along the dimension of `A` specified by scalar *dim*. For example, `max(A,[],1)` produces the maximum values along the first dimension (the rows) of `A`.

`[C,I] = max(...)` finds the indices of the maximum values of `A`, and returns them in output vector `I`. If there are several identical maximum values, the index of the first one found is returned.

Remarks

For complex input `A`, `max` returns the complex number with the largest modulus, computed with `max(abs(A))`. The `max` function ignores `NaN`s.

See Also

`isnan`, `mean`, `median`, `min`, `sort`

mean

Purpose

Average or mean value of arrays

Syntax

```
M = mean(A)
M = mean(A,dim)
```

Description

`M = mean(A)` returns the mean values of the elements along different dimensions of an array.

If `A` is a vector, `mean(A)` returns the mean value of `A`.

If `A` is a matrix, `mean(A)` treats the columns of `A` as vectors, returning a row vector of mean values.

If `A` is a multidimensional array, `mean(A)` treats the values along the first non-singleton dimension as vectors, returning an array of mean values.

`M = mean(A,dim)` returns the mean values for elements along the dimension of `A` specified by scalar *dim*.

Examples

```
A = [1 2 4 4; 3 4 6 6; 5 6 8 8; 5 6 8 8];
mean(A)
ans =
    3.5000    4.5000    6.5000    6.5000

mean(A,2)
ans =
    2.7500
    4.7500
    6.7500
    6.7500
```

See Also

`corrcoef`, `cov`, `max`, `median`, `min`, `std`

Purpose

Median value of arrays

Syntax

```
M = median(A)
M = median(A,dim)
```

Description

`M = median(A)` returns the median values of the elements along different dimensions of an array.

If `A` is a vector, `median(A)` returns the median value of `A`.

If `A` is a matrix, `median(A)` treats the columns of `A` as vectors, returning a row vector of median values.

If `A` is a multidimensional array, `median(A)` treats the values along the first nonsingleton dimension as vectors, returning an array of median values.

`M = median(A,dim)` returns the median values for elements along the dimension of `A` specified by scalar *dim*.

Examples

```
A = [1 2 4 4; 3 4 6 6; 5 6 8 8; 5 6 8 8];
median(A)

ans =

     4     5     7     7

median(A,2)

ans =

     3
     5
     7
     7
```

See Also

`corrcoef`, `cov`, `max`, `mean`, `min`, `std`

menu

Purpose

Generate a menu of choices for user input

Syntax

```
k = menu('mtitle','opt1','opt2',...,'optn')
```

Description

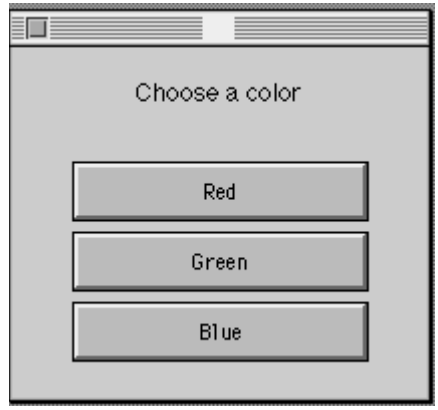
`k = menu('mtitle','opt1','opt2',...,'optn')` displays the menu whose title is in the string variable '*mtitle*' and whose choices are string variables *'opt1'*, *'opt2'*, and so on. `menu` returns the value you entered.

Remarks

To call `menu` from another ui-object, set that object's `Interruptible` property to `'yes'`. For more information, see the *MATLAB Graphics Guide*.

Examples

`k = menu('Choose a color','Red','Green','Blue')` displays



After input is accepted, use `k` to control the color of a graph.

```
color = ['r','g','b']
plot(t,s,color(k))
```

See Also

`input`, `uicontrol`

Purpose

Generate X and Y matrices for three-dimensional plots

Syntax

```
[X,Y] = meshgrid(x,y)
[X,Y] = meshgrid(x)
[X,Y,Z] = meshgrid(x,y,z)
```

Description

`[X,Y] = meshgrid(x,y)` transforms the domain specified by vectors `x` and `y` into arrays `X` and `Y`, which can be used to evaluate functions of two variables and three-dimensional mesh/surface plots. The rows of the output array `X` are copies of the vector `x`; columns of the output array `Y` are copies of the vector `y`.

`[X,Y] = meshgrid(x)` is the same as `[X,Y] = meshgrid(x,x)`.

`[X,Y,Z] = meshgrid(x,y,z)` produces three-dimensional arrays used to evaluate functions of three variables and three-dimensional volumetric plots.

Remarks

The `meshgrid` function is similar to `ndgrid` except that the order of the first two input and output arguments is switched. That is, the statement

```
[X,Y,Z] = meshgrid(x,y,z)
```

produces the same result as

```
[Y,X,Z] = ndgrid(y,x,z)
```

Because of this, `meshgrid` is better suited to problems in two- or three-dimensional Cartesian space, while `ndgrid` is better suited to multidimensional problems that aren't spatially based.

`meshgrid` is limited to two- or three-dimensional Cartesian space.

Examples

```
[X,Y] = meshgrid(1:3,10:14)

X =

     1     2     3
     1     2     3
     1     2     3
     1     2     3
     1     2     3

Y =

    10    10    10
    11    11    11
    12    12    12
    13    13    13
    14    14    14
```

See Also

griddata, mesh, ndgrid, slice, surf

Purpose

Display method names

Syntax

```
methods class_name
n = methods('class_name')
```

Description

`methods class_name` displays the names of the methods for the class with the name *class_name*.

`n = methods('class_name')` returns the method names in a cell array of strings.

See Also

`help`, `what`, `which`

mexext

Purpose Return the MEX-filename extension

Syntax `ext = mexext`

Description `ext = mexext` returns the filename extension for the current platform.

Purpose

The name of the currently running M-file

Syntax

```
mfilename
```

Description

`mfilename` returns a string containing the name of the most recently invoked M-file. When called from within an M-file, it returns the name of that M-file, allowing an M-file to determine its name, even if the filename has been changed.

When called from the command line, `mfilename` returns an empty matrix.

min

Purpose

Minimum elements of an array

Syntax

```
C = min(A)
C = min(A,B)
C = min(A,[],dim)
[C,I] = min(...)
```

Description

`C = min(A)` returns the smallest elements along different dimensions of an array.

If `A` is a vector, `min(A)` returns the smallest element in `A`.

If `A` is a matrix, `min(A)` treats the columns of `A` as vectors, returning a row vector containing the minimum element from each column.

If `A` is a multidimensional array, `min` operates along the first nonsingleton dimension.

`C = min(A,B)` returns an array the same size as `A` and `B` with the smallest elements taken from `A` or `B`.

`C = min(A,[],dim)` returns the smallest elements along the dimension of `A` specified by scalar *dim*. For example, `min(A,[],1)` produces the minimum values along the first dimension (the rows) of `A`.

`[C,I] = min(...)` finds the indices of the minimum values of `A`, and returns them in output vector `I`. If there are several identical minimum values, the index of the first one found is returned.

Remarks

For complex input `A`, `min` returns the complex number with the smallest modulus, computed with `min(abs(A))`. The `min` function ignores `NaN`s.

See Also

`max`, `mean`, `median`, `sort`

Purpose

True if M-file cannot be cleared

Syntax

```
mislocked
mislocked(fun)
```

Description

`mislocked` by itself is 1 if the currently running M-file is locked and 0 otherwise.

`mislocked(`*fun*`)` is 1 if the function named *fun* is locked in memory and 0 otherwise. Locked M-files cannot be removed with the `clear` function.

See Also

`mlock`, `munlock`

mkdir

Purpose

Make directory

Syntax

```
mkdir('dirname')
mkdir('parentdir','newdir')
status = mkdir('parentdir','newdir')
[status,msg] = mkdir('parentdir','newdir')
```

Description

`mkdir('parentdir')` creates the directory `dirname` in the current directory.

`mkdir('parentdir','newdir')` creates the directory `newdir` in the existing directory `parentdir`.

`status = mkdir('parentdir','newdir')` returns `1` if the new directory is created successfully, `2` if it already exists, and `0` otherwise.

`[status,msg] = mkdir('parentdir','newdir')` returns a non-empty error message string when an error occurs.

See Also

`copyfile`

Purpose

Prevent M-file clearing

Syntax

```
mlock
mlock(fun)
```

Description

`mlock` locks the currently running M-file so that subsequent `clear` commands do not remove it.

`mlock(fun)` locks the M-file named `fun` in memory.

Use the command `munlock` or `munlock(fun)` to return the M-file to its normal removable state.

See Also

`munlock`

mod

Purpose

Modulus (signed remainder after division)

Syntax

```
M = mod(X,Y)
```

Definition

`mod(x,y)` is *x* mod *y*.

Description

`M = mod(X,Y)` returns the remainder `X - Y.*floor(X./Y)` for nonzero `Y`, and returns `X` otherwise. `mod(X,Y)` always differs from `X` by a multiple of `Y`.

Remarks

So long as operands `X` and `Y` are of the same sign, the function `mod(X,Y)` returns the same result as does `rem(X,Y)`. However, for positive `X` and `Y`,

```
mod(-x,y) = rem(-x,y)+y
```

The `mod` function is useful for congruence relationships:
x and y are congruent (mod m) if and only if `mod(x,m)` == `mod(y,m)`.

Examples

```
mod(13,5)

ans =
     3

mod([1:5],3)

ans =
     1     2     0     1     2

mod(magic(3),3)

ans =
     2     1     0
     0     2     1
     1     0     2
```

Limitations

Arguments `X` and `Y` should be integers. Due to the inexact representation of floating-point numbers on a computer, real (or complex) inputs may lead to unexpected results.

See Also

`rem`

Purpose

Control paged output for the command window

Syntax

```
more off
more on
more(n)
```

Description

`more off` disables paging of the output in the MATLAB command window.

`more on` enables paging of the output in the MATLAB command window.

`more(n)` displays `n` lines per page.

When you have enabled `more` and are examining output, you can do the following.

Press the...	To...
Return key	Advance to the next line of output.
Space bar	Advance to the next page of output.
q (for quit) key	Terminate display of the text.

By default, `more` is disabled. When enabled, `more` defaults to displaying `23` lines per page.

See Also

`diary`

munlock

Purpose

Allow M-file clearing

Syntax

```
munlock
munlock(fun)
```

Description

`munlock` unlocks the currently running M-file so that subsequent `clear` commands can remove it.

`munlock(fun)` unlocks the M-file named `fun` from memory. By default, M-files are unlocked so that changes to the M-file are picked up. Calls to `munlock` are needed only to unlock M-files that have been locked with `mlock`.

See Also

`mlock`

Purpose

Convert mu-law audio signal to linear

Syntax

```
y = mu2lin(mu)
```

Description

`y = mu2lin(mu)` converts mu-law encoded 8-bit audio signals, stored as "flints" in the range $0 \le mu \le 255$, to linear signal amplitude in the range $-s < Y < s$ where `s = 32124/32768 ~= .9803`. The input `mu` is often obtained using `fread(...,'uchar')` to read byte-encoded audio files. "Flints" are MATLAB's integers – floating-point numbers whose values are integers.

See Also

`auread`, `lin2mu`

NaN

Purpose

Not-a-Number

Syntax

```
NaN
```

Description

`NaN` returns the IEEE arithmetic representation for Not-a-Number (`NaN`). These result from operations which have undefined numerical results.

Examples

These operations produce `NaN`:

- Any arithmetic operation on a `NaN`, such as `sqrt(NaN)`
- Addition or subtraction, such as magnitude subtraction of infinities as `(+Inf)+(-Inf)`
- Multiplication, such as `0*Inf`
- Division, such as `0/0` and `Inf/Inf`
- Remainder, such as `rem(x,y)` where `y` is zero or `x` is infinity

Remarks

Logical operations involving `NaN`s always return false, except ~= (not equal). Consequently, the statement `NaN ~= NaN` is true while the statement `NaN == NaN` is false.

See Also

`Inf`

Purpose

Check number of input arguments

Syntax

```
msg = nargchk(low,high,number)
```

Description

The nargchk function often is used inside an M-file to check that the correct number of arguments have been passed.

`msg = nargchk(`*low*`,`*high*`,number)` returns an error message if number is less than *low* or greater than *high*. If number is between *low* and *high* (inclusive), nargchk returns an empty matrix.

Arguments

low, *high*	The minimum and maximum number of input arguments that should be passed.
number	The number of arguments actually passed, as determined by the nargin function.

Examples

Given the function foo:

```
function f = foo(x,y,z)
error(nargchk(2,3,nargin))
```

Then typing `foo(1)` produces:

```
Not enough input arguments.
```

See Also

nargin, nargout

nargin, nargout

Purpose

Number of function arguments

Syntax

```
n = nargin
n = nargin('fun')
n = nargout
n = nargout('fun')
```

Description

In the body of a function M-file, `nargin` and `nargout` indicate how many input or output arguments, respectively, a user has supplied. Outside the body of a function M-file, `nargin` and `nargout` indicate the number of input or output arguments, respectively, for a given function. The number of arguments is negative if the function has a variable number of arguments.

`nargin` returns the number of input arguments specified for a function.

`nargin('fun')` returns the number of declared inputs for the M-file function *fun* or `-1` if the function has a variable of input arguments.

`nargout` returns the number of output arguments specified for a function.

`nargout('fun')` returns the number of declared outputs for the M-file function *fun*.

Examples

This example shows portions of the code for a function called `myplot`, which accepts an optional number of input and output arguments:

```
function [x0,y0] = myplot(fname,lims,npts,angl,subdiv)
% MYPLOT  Plot a function.
% MYPLOT(fname,lims,npts,angl,subdiv)
%     The first two input arguments are
%     required; the other three have default values.
 ...
if nargin < 5, subdiv = 20; end
if nargin < 4, angl = 10; end
if nargin < 3, npts = 25; end
 ...
if nargout == 0
     plot(x,y)
else
     x0 = x;
     y0 = y;
end
```

See Also

`inputname`, `nargchk`

nchoosek

Purpose

Binomial coefficient or all combinations

Syntax

```
C = nchoosek(n,k)
C = nchoosek(v,k)
```

Description

`C = nchoosek(n,k)` where `n` and `k` are nonnegative integers, returns *n! / ((n–k)! k!)*. This is the number of combinations of *n* things taken *k* at a time.

`C = nchoosek(v,k)`, where `v` is a row vector of length `n`, creates a matrix whose rows consist of all possible combinations of the *n* elements of `v` taken *k* at a time. Matrix `C` contains *n! / ((n–k)! k!)* rows and *k* columns.

Examples

The command `nchoosek(2:2:10,4)` returns the even numbers from two to ten, taken four at a time:

```
     2     4     6     8
     2     4     6    10
     2     4     8    10
     2     6     8    10
     4     6     8    10
```

Limitations

This function is only practical for situations where `n` is less than about 15.

See Also

`perms`

Purpose

Generate arrays for multidimensional functions and interpolation

Syntax

```
[X1,X2,X3,...] = ndgrid(x1,x2,x3,...)
[X1,X2,...] = ndgrid(x)
```

Description

`[X1,X2,X3,...] = ndgrid(x1,x2,x3,...)` transforms the domain specified by vectors `x1,x2,x3...` into arrays `X1,X2,X3...` that can be used for the evaluation of functions of multiple variables and multidimensional interpolation. The `i`th dimension of the output array `X`i are copies of elements of the vector `x`i.

`[X1,X2,...] = ndgrid(x)` is the same as `[X1,X2,...] = ndgrid(x,x,...)`.

Examples

Evaluate the function $x_1 e^{-x_1^2 - x_2^2}$ over the range $-2 < x_1 < 2$; $-2 < x_2 < 2$.

```
[X1,X2] = ndgrid(–2:.2:2, –2:.2:2);
Z = X1 .* exp(–X1.^2 – X2.^2);
mesh(Z)
```

Remarks

The `ndgrid` function is like `meshgrid` except that the order of the first two input arguments are switched. That is, the statement

```
[X1,X2,X3] = ndgrid(x1,x2,x3)
```

produces the same result as

```
[X2,X1,X3] = meshgrid(x2,x1,x3).
```

Because of this, `ndgrid` is better suited to multidimensional problems that aren't spatially based, while `meshgrid` is better suited to problems in two- or three-dimensional Cartesian space.

See Also

`meshgrid`, `interpn`

ndims

Purpose

Number of array dimensions

Syntax

```
n = ndims(A)
```

Description

`n = ndims(A)` returns the number of dimensions in the array `A`. The number of dimensions in an array is always greater than or equal to `2`. Trailing singleton dimensions are ignored. A singleton dimension is any dimension for which `size(A,dim) = 1`.

Algorithm

`ndims(x)` is `length(size(x))`.

See Also

`size`

Purpose

Next power of two

Syntax

```
p = nextpow2(A)
```

Description

`p = nextpow2(A)` returns the smallest power of two that is greater than or equal to the absolute value of `A`. (That is, `p` that satisfies `2^p ≥ abs(A)`).

This function is useful for optimizing FFT operations, which are most efficient when sequence length is an exact power of two.

If `A` is non-scalar, `nextpow2` returns the smallest power of two greater than or equal to `length(A)`.

Examples

For any integer `n` in the range from `513` to `1024`, `nextpow2(n)` is `10`.

For a 1-by-30 vector `A`, `length(A)` is `30` and `nextpow2(A)` is `5`.

See Also

`fft`, `log2`, `pow2`

nnls

Purpose

Nonnegative least squares

NOTE The name of this function has been changed to `lsqnonneg` in Release 11 (MATLAB 5.3). While `nnls` is supported in Release 11, it will be removed in a future release so please begin using `lsqnonneg`.

Syntax

```
x = nnls(A,b)
x = nnls(A,b,tol)
[x,w] = nnls(A,b)
[x,w] = nnls(A,b,tol)
```

Description

`x = nnls(A,b)` solves the system of equations $Ax = b$ in a least squares sense, subject to the constraint that the solution vector `x` has nonnegative elements: $x_j \geq 0, \quad j = 1, 2, \ldots n$. The solution `x` minimizes $\|(Ax = b)\|$ subject to $x \geq 0$.

`x = nnls(A,b,tol)` solves the system of equations, and specifies a tolerance `tol`. By default, `tol` is: `max(size(A))*norm(A,1)*eps`.

`[x,w] = nnls(A,b)` also returns the dual vector `w`, where $w_i \leq 0$ when $x_i = 0$ and $w_i \cong 0$ when $x_i > 0$.

`[x,w] = nnls(A,b,tol)` solves the system of equations, returns the dual vector `w`, and specifies a tolerance `tol`.

Examples

Compare the unconstrained least squares solution to the `nnls` solution for a 4-by-2 problem:

```
A =
    0.0372    0.2869
    0.6861    0.7071
    0.6233    0.6245
    0.6344    0.6170

b =

    0.8587
    0.1781
```

```
    0.0747
    0.8405

[A\b nnls(A,b)] =

    -2.5627        0
     3.1108   0.6929


[norm(A*(a\b)-b) norm(A*nnls(a,b)-b)] =

     0.6674 0.9118
```

The solution from `nnls` does not fit as well, but has no negative components.

Algorithm

The `nnls` function uses the algorithm described in [1], Chapter 23. The algorithm starts with a set of possible basis vectors, computes the associated dual vector `w`, and selects the basis vector corresponding to the maximum value in `w` to swap out of the basis in exchange for another possible candidate, until $w \leq 0$.

See Also

`\` Matrix left division (backslash)

References

[1] Lawson, C. L. and R. J. Hanson, *Solving Least Squares Problems*, Prentice-Hall, 1974, Chapter 23.

nnz

Purpose

Number of nonzero matrix elements

Syntax

```
n = nnz(X)
```

Description

`n = nnz(X)` returns the number of nonzero elements in matrix `X`.

The density of a sparse matrix is `nnz(X)/prod(size(X))`.

Examples

The matrix

```
w = sparse(wilkinson(21));
```

is a tridiagonal matrix with `20` nonzeros on each of three diagonals, so `nnz(w) = 60`.

See Also

`find`, `isa`, `nonzeros`, `nzmax`, `size`, `whos`

Purpose

Nonzero matrix elements

Syntax

```
s = nonzeros(A)
```

Description

`s = nonzeros(A)` returns a full column vector of the nonzero elements in `A`, ordered by columns.

This gives the `s`, but not the `i` and `j`, from `[i,j,s] = find(A)`. Generally,

```
length(s) = nnz(A) ≤ nzmax(A) ≤ prod(size(A))
```

See Also

`find`, `isa`, `nnz`, `nzmax`, `size`, `whos`

norm

Purpose

Vector and matrix norms

Syntax

```
n = norm(A)
n = norm(A,p)
```

Description

The *norm* of a matrix is a scalar that gives some measure of the magnitude of the elements of the matrix. The `norm` function calculates several different types of matrix norms:

`n = norm(A)` returns the largest singular value of `A`, `max(svd(A))`.

`n = norm(A,p)` returns a different kind of norm, depending on the value of *p*:

If *p* is...	**Then `norm` returns...**
`1`	The 1-norm, or largest column sum of `A`, `max(sum(abs((A)))`.
`2`	The largest singular value (same as `norm(A)`).
`inf`	The infinity norm, or largest row sum of `A`, `max(sum(abs(A')))`.
`'fro'`	The Frobenius-norm of matrix `A`, `sqrt(sum(diag(A'*A)))`.

When `A` is a vector, slightly different rules apply:

`norm(A,p)`	Returns `sum(abs(A).^p)^(1/p)`, for any $1 \le p \le \infty$.
`norm(A)`	Returns `norm(A,2)`.
`norm(A,inf)`	Returns `max(abs(A))`.
`norm(A,-inf)`	Returns `min(abs(A))`.

Remarks

To obtain the root-mean-square (RMS) value, use `norm(A)/sqrt(n)`. Note that `norm(A)`, where `A` is an `n`-element vector, is the length of `A`.

See Also

`cond`, `normest`, `svd`

Purpose

2-norm estimate

Syntax

```
nrm = normest(S)
nrm = normest(S,tol)
[nrm,count] = normest(...)
```

Description

This function is intended primarily for sparse matrices, although it works correctly and may be useful for large, full matrices as well.

`nrm = normest(S)` returns an estimate of the 2-norm of the matrix `S`.

`nrm = normest(S,tol)` uses relative error `tol` instead of the default tolerance `1.e-6`. The value of `tol` determines when the estimate is considered acceptable.

`[nrm,count] = normest(...)` returns an estimate of the 2-norm and also gives the number of power iterations used.

Examples

The matrix `W = gallery('wilkinson',101)` is a tridiagonal matrix. Its order, 101, is small enough that `norm(full(W))`, which involves `svd(full(W))`, is feasible. The computation takes 4.13 seconds (on one computer) and produces the exact norm, 50.7462. On the other hand, `normest(sparse(W))` requires only 1.56 seconds and produces the estimated norm, 50.7458.

Algorithm

The power iteration involves repeated multiplication by the matrix `S` and its transpose, `S'`. The iteration is carried out until two successive estimates agree to within the specified relative tolerance.

See Also

cond, condest, norm, svd

now

Purpose

Current date and time

Syntax

```
t = now
```

Description

`t = now` returns the current date and time as a serial date number. To return the time only, use `rem(now,1)`. To return the date only, use `floor(now)`.

Examples

```
t1 = now, t2 = rem(now,1)

t1 =

   7.2908e+05


t2 =

    0.4013
```

See Also

`clock`, `date`, `datenum`

Purpose Null space of a matrix

Syntax `B = null(A)`

Description `B = null(A)` returns an orthonormal basis for the null space of `A`.

Remarks `B'*B = I`, `A*B` has negligible elements, and (if `B` is not equal to the empty matrix) the number of columns of `B` is the nullity of `A`.

See Also `orth`, `qr`, `svd`

num2cell

Purpose

Convert a numeric array into a cell array

Syntax

```
c = num2cell(A)
c = num2cell(A,dims)
```

Description

`c = num2cell(A)` converts the matrix `A` into a cell array by placing each element of `A` into a separate cell. Cell array `c` will be the same size as matrix `A`.

`c = num2cell(A,dims)` converts the matrix `A` into a cell array by placing the dimensions specified by `dims` into separate cells. `C` will be the same size as `A` except that the dimensions matching `dims` will be 1.

Examples

The statement

```
num2cell(A,2)
```

places the rows of `A` into separate cells. Similarly

```
num2cell(A,[1 3])
```

places the column-depth pages of `A` into separate cells.

See Also

`cat`

Purpose

Number to string conversion

Syntax

```
str = num2str(A)
str = num2str(A,precision)
str = num2str(A,format)
```

Description

The `num2str` function converts numbers to their string representations. This function is useful for labeling and titling plots with numeric values.

`str = num2str(a)` converts array `A` into a string representation `str` with roughly four digits of precision and an exponent if required.

`str = num2str(a,`*`precision`*`)` converts the array `A` into a string representation `str` with maximum precision specified by *`precision`*. Argument *`precision`* specifies the number of digits the output string is to contain. The default is four.

`str = num2str(A,`*`format`*`)` converts array `A` using the supplied *`format`*. By default, this is `'%11.4g'`, which signifies four significant digits in exponential or fixed-point notation, whichever is shorter. (See `fprintf` for format string details).

Examples

`num2str(pi)` is `3.142`.

`num2str(eps)` is `2.22e-16`.

`num2str(magic(2))` produces the string matrix

```
  1  3
  4  2
```

See Also

`fprintf`, `int2str`, `sprintf`

nzmax

Purpose

Amount of storage allocated for nonzero matrix elements

Syntax

```
n = nzmax(S)
```

Description

`n = nzmax(S)` returns the amount of storage allocated for nonzero elements.

If `S` is a sparse matrix...	`nzmax(S)` is the number of storage locations allocated for the nonzero elements in `S`.
If `S` is a full matrix...	`nzmax(S) = prod(size(S))`.

Often, `nnz(S)` and `nzmax(S)` are the same. But if `S` is created by an operation which produces fill-in matrix elements, such as sparse matrix multiplication or sparse LU factorization, more storage may be allocated than is actually required, and `nzmax(S)` reflects this. Alternatively, `sparse(i,j,s,m,n,nzmax)` or its simpler form, `spalloc(m,n,nzmax)`, can set `nzmax` in anticipation of later fill-in.

See Also

`find`, `isa`, `nnz`, `nonzeros`, `size`, `whos`

ode45, ode23, ode113, ode15s, ode23s, ode23t, ode23tb

Purpose

Solve differential equations

Syntax

```
[T,Y] = solver('F',tspan,y0)
[T,Y] = solver('F',tspan,y0,options)
[T,Y] = solver('F',tspan,y0,options,p1,p2...)
[T,Y,TE,YE,IE] = solver('F',tspan,y0,options)
```

Arguments

`F`	Name of the ODE file, a MATLAB function of `t` and `y` returning a column vector. All solvers can solve systems of equations in the form $y' = F(t, y)$. `ode15s`, `ode23s`, `ode23t`, and `ode23tb` can solve equations of the form $My' = F(t, y)$. Of these four solvers all but `ode23s` can solve equations in the form $M(t)y' = F(t, y)$. For information about ODE file syntax, see the `odefile` reference page.
`tspan`	A vector specifying the interval of integration `[t0 tfinal]`. To obtain solutions at specific times (all increasing or all decreasing), use `tspan = [t0,t1, ..., tfinal]`.
`y0`	A vector of initial conditions.
`options`	Optional integration argument created using the `odeset` function. See `odeset` for details.
`p1,p2...`	Optional parameters to be passed to `F`.
`T,Y`	Solution matrix `Y`, where each row corresponds to a time returned in column vector `T`.

Description

`[T,Y] = solver('F',tspan,y0)` with `tspan = [t0 tfinal]` integrates the system of differential equations $y' = F(t,y)$ from time `t0` to `tfinal` with initial conditions `y0`. `'F'` is a string containing the name of an ODE file. Function `F(t,y)` must return a column vector. Each row in solution array `y` corresponds to a time returned in column vector `t`. To obtain solutions at the specific times `t0`, `t1`, . . ., `tfinal` (all increasing or all decreasing), use `tspan = [t0 t1 ... tfinal]`.

`[T,Y] = solver('F',tspan,y0,options)` solves as above with default integration parameters replaced by property values specified in `options`, an argument created with the `odeset` function (see `odeset` for details). Commonly

used properties include a scalar relative error tolerance `RelTol` (`1e-3` by default) and a vector of absolute error tolerances `AbsTol` (all components `1e-6` by default).

`[T,Y] = solver('F',tspan,y0,options,p1,p2...)` solves as above, passing the additional parameters `p1,p2...` to the M-file `F`, whenever it is called. Use `options = []` as a place holder if no options are set.

`[T,Y,TE,YE,IE] = solver('F',tspan,y0,options)` with the `Events` property in `options` set to `'on'`, solves as above while also locating zero crossings of an event function defined in the ODE file. The ODE file must be coded so that `F(t,y,'events')` returns appropriate information. See `odefile` for details. Output `TE` is a column vector of times at which events occur, rows of `YE` are the corresponding solutions, and indices in vector `IE` specify which event occurred.

When called with no output arguments, the solvers call the default output function `odeplot` to plot the solution as it is computed. An alternate method is to set the `OutputFcn` property to `'odeplot'`. Set the `OutputFcn` property to `'odephas2'` or `'odephas3'` for two- or three-dimensional phase plane plotting. See `odefile` for details.

The solvers of the ODE suite can solve problems of the form $M(t, y)\, y' = F(t, y)$ with a mass matrix M that is nonsingular and (usually) sparse. Use `odeset` to set `Mass` to `'M'`, `'M(t)'`, or `'M(t,y)'` if the ODE file `F.m` is coded so that `F(t,y,'mass')` returns a constant, time-dependent, or time-and-state-dependent mass matrix, respectively. The default value of `Mass` is `'none'`. The `ode23s` solver can only solve problems with a constant mass matrix M. For examples of mass matrix problems, see `fem1ode`, `fem2ode`, or `batonode`.

For the stiff solvers `ode15s`, `ode23s`, `ode23t`, and `ode23tb` the Jacobian matrix $\partial F/\partial y$ is critical to reliability and efficiency so there are special options. Set `JConstant` to `'on'` if $\partial F/\partial y$ is constant. Set `Vectorized` to `'on'` if the ODE file is coded so that `F(t,[y1 y2 ...])` returns `[F(t,y1) F(t,y2) ...]`. Set `JPattern` to `'on'` if $\partial F/\partial y$ is a sparse matrix and the ODE file is coded so that `F([],[],'jpattern')` returns a sparsity pattern matrix of `1`'s and `0`'s showing the nonzeros of $\partial F/\partial y$. Set `Jacobian` to `'on'` if the ODE file is coded so that `F(t,y,'jacobian')` returns $\partial F/\partial y$.

If *M* is singular, then *M(t) * y' = F(t, y)* is a differential algebraic equation (DAE). DAEs have solutions only when *y0* is consistent, that is, if there is a vector *yp0* such that *M(t0) * y0 = f(t0, y0)*. The `ode15s` and `ode23t` solvers can solve DAEs of index 1 provided that *M* is not state dependent and *y0* is sufficiently close to being consistent. If there is a mass matrix, you can use `odeset` to set the `MassSingular` property to `'yes'`, `'no'`, or `'maybe'`. The default value of `'maybe'` causes the solver to test whether the problem is a DAE. If it is, the solver treats *y0* as a guess, attempts to compute consistent initial conditions that are close to `y0`, and continues to solve the problem. When solving DAEs, it is very advantageous to formulate the problem so that *M* is a diagonal matrix (a semi-explicit DAE). For examples of DAE problems, see `hb1dae` or `amp1dae`.

Solver	Problem Type	Order of Accuracy	When to Use
`ode45`	Nonstiff	Medium	Most of the time. This should be the first solver you try.
`ode23`	Nonstiff	Low	If using crude error tolerances or solving moderately stiff problems.
`ode113`	Nonstiff	Low to high	If using stringent error tolerances or solving a computationally intensive ODE file.
`ode15s`	Stiff	Low to medium	If `ode45` is slow (stiff systems) or there is a mass matrix.
`ode23s`	Stiff	Low	If using crude error tolerances to solve stiff systems or there is a constant mass matrix.
`ode23t`	Moderately Stiff	Low	If the problem is only moderately stiff and you need a solution without numerical damping.
`ode23tb`	Stiff	Low	If using crude error tolerances to solve stiff systems or there is a mass matrix.

The algorithms used in the ODE solvers vary according to order of accuracy [5] and the type of systems (stiff or nonstiff) they are designed to solve. See Algorithms on page 2-547 for more details.

It is possible to specify `tspan`, `y0`, and `options` in the ODE file (see `odefile`). If `tspan` or `y0` is empty, then the solver calls the ODE file

```
[tspan,y0,options] = F([],[],'init')
```

to obtain any values not supplied in the solver's argument list. Empty arguments at the end of the call list may be omitted. This permits you to call the solvers with other syntaxes such as:

```
[T,Y] = solver('F')
[T,Y] = solver('F',[],y0)
[T,Y] = solver('F',tspan,[],options)
[T,Y] = solver('F',[],[],options)
```

Integration parameters (`options`) can be specified both in the ODE file and on the command line. If an option is specified in both places, the command line specification takes precedence. For information about constructing an ODE file, see `odefile`.

Options

Different solvers accept different parameters in the options list. For more information, see `odeset` and *Using MATLAB*.

Parameters	ode45	ode23	ode113	ode15s	ode23s	ode23t	ode23tb
`RelTol`, `AbsTol`	√	√	√	√	√	√	√
`OutputFcn`, `OutputSel`, `Refine`, `Stats`	√	√	√	√	√	√	√
`Events`	√	√	√	√	√	√	√
`MaxStep`, `InitialStep`	√	√	√	√	√	√	√

Parameters	ode45	ode23	ode113	ode15s	ode23s	ode23t	ode23tb
JConstant, Jacobian, JPattern, Vectorized	—	—	—	√	√	√	√
Mass MassSingular	√ —	√ —	√ —	√ √	√ —	√ √	√ —
MaxOrder, BDF	—	—	—	√	—	√	√

Examples

Example 1. An example of a nonstiff system is the system of equations describing the motion of a rigid body without external forces:

$$
\begin{aligned}
y'_1 &= y_2\, y_3 & y_1(0) &= 0\\
y'_2 &= -y_1\, y_3 & y_2(0) &= 1\\
y'_3 &= -0.51\, y_1\, y_2 & y_3(0) &= 1
\end{aligned}
$$

To simulate this system, create a function M-file `rigid` containing the equations:

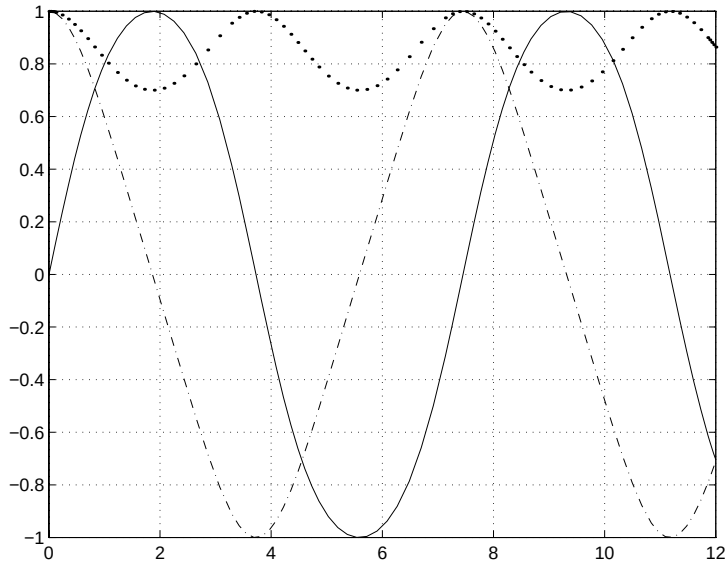
```
function dy = rigid(t,y)
dy = zeros(3,1);    % a column vector
dy(1) = y(2) * y(3);
dy(2) = -y(1) * y(3);
dy(3) = -0.51 * y(1) * y(2);
```

In this example we will change the error tolerances with the `odeset` command and solve on a time interval of `[0 12]` with initial condition vector `[0 1 1]` at time `0`.

```
options = odeset('RelTol',1e-4,'AbsTol',[1e-4 1e-4 1e-5]);
[t,y] = ode45('rigid',[0 12],[0 1 1],options);
```

Plotting the columns of the returned array `Y` versus `T` shows the solution:

```
plot(T,Y(:,1),'-',T,Y(:,2),'-.',T,Y(:,3),'.')
```



Example 2. An example of a stiff system is provided by the van der Pol equations governing relaxation oscillation. The limit cycle has portions where the solution components change slowly and the problem is quite stiff, alternating with regions of very sharp change where it is not stiff.

$$y'_1 = y_2 \qquad y_1(0) = 0$$
$$y'_2 = 1000(1 - y_1^2)y_2 - y_1 \quad y_2(0) = 1$$

To simulate this system, create a function M-file `vdp1000` containing the equations:

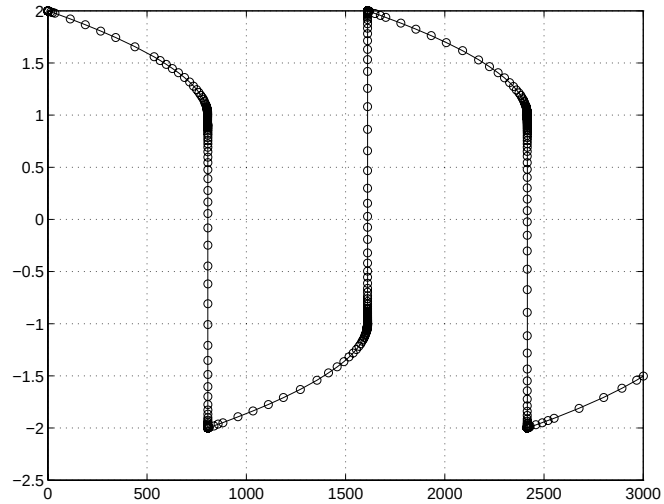
```
function dy = vdp1000(t,y)
dy = zeros(2,1);    % a column vector
dy(1) = y(2);
dy(2) = 1000*(1 - y(1)^2)*y(2) - y(1);
```

For this problem, we will use the default relative and absolute tolerances (`1e-3` and `1e-6`, respectively) and solve on a time interval of `[0 3000]` with initial condition vector `[2 0]` at time `0`.

```
[T,Y] = ode15s('vdp1000',[0 3000],[2 0]);
```

Plotting the first column of the returned matrix `Y` versus `T` shows the solution:

```
plot(T,Y(:,1),'-o'):
```



Algorithms

`ode45` is based on an explicit Runge-Kutta (4,5) formula, the Dormand-Prince pair. It is a *one-step* solver – in computing $y(t_n)$, it needs only the solution at the immediately preceding time point, $y(t_{n-1})$. In general, `ode45` is the best function to apply as a "first try" for most problems. [1]

`ode23` is an implementation of an explicit Runge-Kutta (2,3) pair of Bogacki and Shampine. It may be more efficient than `ode45` at crude tolerances and in the presence of moderate stiffness. Like `ode45`, `ode23` is a one-step solver. [2]

`ode113` is a variable order Adams-Bashforth-Moulton PECE solver. It may be more efficient than `ode45` at stringent tolerances and when the ODE file function is particularly expensive to evaluate. `ode113` is a *multistep* solver – it normally needs the solutions at several preceding time points to compute the current solution. [3]

The above algorithms are intended to solve non-stiff systems. If they appear to be unduly slow, try using one of the stiff solvers below.

`ode15s` is a variable order solver based on the numerical differentiation formulas, NDFs. Optionally, it uses the backward differentiation formulas, BDFs (also known as Gear's method) that are usually less efficient. Like `ode113`, `ode15s` is a multistep solver. If you suspect that a problem is stiff or if `ode45` has failed or was very inefficient, try `ode15s`. [7]

`ode23s` is based on a modified Rosenbrock formula of order 2. Because it is a one-step solver, it may be more efficient than `ode15s` at crude tolerances. It can solve some kinds of stiff problems for which `ode15s` is not effective. [7]

`ode23t` is an implementation of the trapezoidal rule using a "free" interpolant. Use this solver if the problem is only moderately stiff and you need a solution without numerical damping.

`ode23tb` is an implementation of TR-BDF2, an implicit Runge-Kutta formula with a first stage that is a trapezoidal rule step and a second stage that is a backward differentiation formula of order two. By construction, the same iteration matrix is used in evaluating both stages. Like `ode23s`, this solver may be more efficient than `ode15s` at crude tolerances. [8, 9]

See Also

`odeset`, `odeget`, `odefile`

References

[1] Dormand, J. R. and P. J. Prince, "A family of embedded Runge-Kutta formulae," *J. Comp. Appl. Math.*, Vol. 6, 1980, pp 19–26.

[2] Bogacki, P. and L. F. Shampine, "A 3(2) pair of Runge-Kutta formulas," *Appl. Math. Letters*, Vol. 2, 1989, pp 1–9.

[3] Shampine, L. F. and M. K. Gordon, *Computer Solution of Ordinary Differential Equations: the Initial Value Problem*, W. H. Freeman, San Francisco, 1975.

[4] Forsythe, G. , M. Malcolm, and C. Moler, *Computer Methods for Mathematical Computations*, Prentice-Hall, New Jersey, 1977.

[5] Shampine, L. F. , *Numerical Solution of Ordinary Differential Equations*, Chapman & Hall, New York, 1994.

[6] Kahaner, D. , C. Moler, and S. Nash, *Numerical Methods and Software*, Prentice-Hall, New Jersey, 1989.

[7] Shampine, L. F. and M. W. Reichelt, "The MATLAB ODE Suite," (to appear in *SIAM Journal on Scientific Computing*, Vol. 18-1, 1997).

[8] Shampine, L. F. and M. E. Hosea, "Analysis and Implementation of TR-BDF2," *Applied Numerical Mathematics 20*, 1996.

[9] Bank, R. E., W. C. Coughran, Jr., W. Fichtner, E. Grosse, D. Rose, and R. Smith, "Transient Simulation of Silicon Devices and Circuits," *IEEE Trans. CAD*, 4 (1985), pp 436-451

odefile

Purpose

Define a differential equation problem for ODE solvers

Description

`odefile` is not a command or function. It is a help entry that describes how to create an M-file defining the system of equations to be solved. This definition is the first step in using any of MATLAB's ODE solvers. In MATLAB documentation, this M-file is referred to as `odefile`, although you can give your M-file any name you like.

You can use the `odefile` M-file to define a system of differential equations in one of these forms

$$y' = F(t, y)$$
$$M(t, y)\, y' = F(t, y)$$

where

- t is a scalar independent variable, typically representing time.
- y is a vector of dependent variables.
- F is a function of t and y returning a column vector the same length as y.
- $M(t, y)$ is a time-and-state-dependent mass matrix.

The ODE file must accept the arguments `t` and `y`, although it does not have to use them. By default, the ODE file must return a column vector the same length as `y`.

All of the solvers of the ODE Suite can solve $M(t, y)\, y' = F(t, y)$, except `ode23s`, which can only solve problems with constant mass matrices. The `ode15s` and `ode23t` solvers can solve some differential-algebraic equations (DAEs) of the form $M(t)\, y' = F(t, y)$.

Beyond defining a system of differential equations, you can specify an entire initial value problem (IVP) within the ODE M-file, eliminating the need to supply time and initial value vectors at the command line (see Examples on page 2-553).

To Use the ODE File Template:

- Enter the command `help odefile` to display the help entry.
- Cut and paste the ODE file text into a separate file.
- Edit the file to eliminate any cases not applicable to your IVP.

- Insert the appropriate information where indicated. The definition of the ODE system is required information.

```
switch flag
 case ''                  % Return dy/dt = f(t,y).
   varargout{1} = f(t,y,p1,p2);
 case 'init'              % Return default [tspan,y0,options].
   [varargout{1:3}] = init(p1,p2);
 case 'jacobian'          % Return Jacobian matrix df/dy.
   varargout{1} = jacobian(t,y,p1,p2);
 case 'jpattern'          % Return sparsity pattern matrix S.
   varargout{1} = jpattern(t,y,p1,p2);
 case 'mass'              % Return mass matrix.
   varargout{1} = mass(t,y,p1,p2);
 case 'events'            % Return [value,isterminal,direction].
   [varargout{1:3}] = events(t,y,p1,p2);
 otherwise
   error(['Unknown flag ''' flag '''.']);
 end
% --------------------------------------------------------------
function dydt = f(t,y,p1,p2)
 dydt = < Insert a function of t and/or y, p1, and p2 here. >
% --------------------------------------------------------------
function [tspan,y0,options] = init(p1,p2)
 tspan = < Insert tspan here. >;
 y0 = < Insert y0 here. >;
 options = < Insert options = odeset(...) or [] here. >;
% --------------------------------------------------------------
function dfdy = jacobian(t,y,p1,p2)
 dfdy = < Insert Jacobian matrix here. >;
% --------------------------------------------------------------
function S = jpattern(t,y,p1,p2)
 S = < Insert Jacobian matrix sparsity pattern here. >;
% --------------------------------------------------------------

function M = mass(t,y,p1,p2)
 M = < Insert mass matrix here. >;
% --------------------------------------------------------------
function [value,isterminal,direction] = events(t,y,p1,p2)
 value = < Insert event function vector here. >
```

```
isterminal = < Insert logical ISTERMINAL vector here.>;
direction = < Insert DIRECTION vector here.>;
```

Notes

1. The ODE file must accept `t` and `y` vectors from the ODE solvers and must return a column vector the same length as `y`. The optional input argument `flag` determines the type of output (mass matrix, Jacobian, etc.) returned by the ODE file.
2. The solvers repeatedly call the ODE file to evaluate the system of differential equations at various times. *This is required information* – you must define the ODE system to be solved.
3. The `switch` statement determines the type of output required, so that the ODE file can pass the appropriate information to the solver. (See steps 4 - 9.)
4. In the default *initial conditions (*`'init'`*)* case, the ODE file returns basic information (time span, initial conditions, options) to the solver. If you omit this case, you must supply all the basic information on the command line.
5. In the `'jacobian'` case, the ODE file returns a Jacobian matrix to the solver. You need only provide this case when you want to improve the performance of the stiff solvers `ode15s` and `ode23s`.
6. In the `'jpattern'` case, the ODE file returns the Jacobian sparsity pattern matrix to the solver. You need to provide this case only when you want to generate sparse Jacobian matrices numerically for a stiff solver.
7. In the `'mass'` case, the ODE file returns a mass matrix to the solver. You need to provide this case only when you want to solve a system in the form $M(t, y)\, y' = F(t, y)$.
8. In the `'events'` case, the ODE file returns to the solver the values that it needs to perform event location. When the `Events` property is set to `1`, the ODE solvers examine any elements of the `event` vector for transitions to, from, or through zero. If the corresponding element of the logical `isterminal` vector is set to `1`, integration will halt when a zero-crossing is detected. The elements of the `direction` vector are `–1`, `1`, or `0`, specifying that the corresponding event must be decreasing, increasing, or that any crossing is to be detected. See *Using MATLAB* and also the examples `ballode` and `orbitode`.
9. An unrecognized `flag` generates an error.

Examples

The van der Pol equation, $y''_1 - \mu(1 - y_1^2)y'_1 + y_1 = 0$, is equivalent to a system of coupled first-order differential equations:

$$y'_1 = y_2$$
$$y'_2 = \mu(1 - y_1^2)y_2 - y_1$$

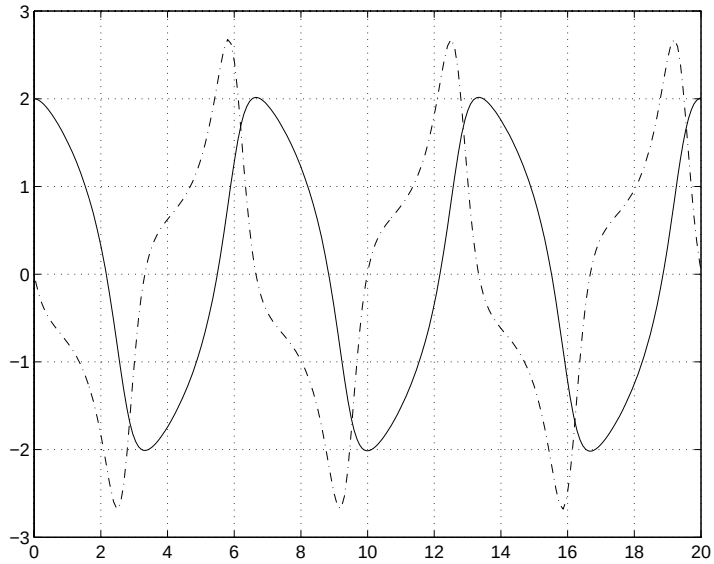
The M-file

```
function out1 = vdp1(t,y)
out1 = [y(2); (1-y(1)^2)*y(2) - y(1)];
```

defines this system of equations (with $\mu = 1$).

To solve the van der Pol system on the time interval `[0 20]` with initial values (at time `0`) of `y(1) = 2` and `y(2) = 0`, use:

```
[t,y] = ode45('vdp1',[0 20],[2; 0]);
plot(t,y(:,1),'-',t,y(:,2),'-.')
```



To specify the entire initial value problem (IVP) within the M-file, rewrite vdp1 as follows:

```
function [out1,out2,out3] = vdp1(t,y,flag)
if nargin < 3 | isempty(flag)
  out1 = [y(1).*(1-y(2).^2)-y(2); y(1)];
else
  switch(flag)
    case 'init'               % Return tspan, y0, and options
      out1 = [0 20];
      out2 = [2; 0];
      out3 = [];
  otherwise
    error(['Unknown request ''' flag '''.']);
  end
end
```

You can now solve the IVP without entering any arguments from the command line:

```
[T,Y] = ode23('vdp1')
```

In this example the ode23 function looks to the vdp1 M-file to supply the missing arguments. Note that, once you've called odeset to define options, the calling syntax

```
[T,Y] = ode23('vdp1',[],[],options)
```

also works, and that any options supplied via the command line override corresponding options specified in the M-file (see odeset).

Some example ODE files we have provided include b5ode, brussode, vdpode, orbitode, and rigidode. Use type *filename* from the MATLAB command line to see the coding for a specific ODE file.

See Also

The *Using MATLAB* and the reference entries for the ODE solvers and their associated functions:

ode23, ode45, ode113, ode15s, ode23s, odeget, odeset

Purpose

Extract properties from options structure created with odeset

Syntax

```
o = odeget(options,'name')
o = odeget(options,'name',default)
```

Description

`o = odeget(options,'name')` extracts the value of the property specified by string 'name' from integrator options structure options, returning an empty matrix if the property value is not specified in options. It is only necessary to type the leading characters that uniquely identify the property name. Case is ignored for property names. The empty matrix `[]` is a valid options argument.

`o = odeget(options,'name',default)` returns `o = default` if the named property is not specified in options.

Example

Having constructed an ODE options structure,

```
options = odeset('RelTol',1e-4,'AbsTol',[1e-3 2e-3 3e-3]);
```

you can view these property settings with odeget:

```
odeget(options,'RelTol')
ans =

       1.0000e-04

odeget(options,'AbsTol')
ans =

    0.0010    0.0020    0.0030
```

See Also

odeset

odeset

Purpose

Create or alter options structure for input to ODE solvers

Syntax

```
options = odeset('name1',value1,'name2',value2,...)
options = odeset(oldopts,'name1',value1,...)
options = odeset(oldopts,newopts)
odeset
```

Description

The odeset function lets you adjust the integration parameters of the ODE solvers. See below for information about the integration parameters.

`options = odeset('name1',value1,'name2',value2,...)` creates an integrator options structure in which the named properties have the specified values. The odeset function sets any unspecified properties to the empty matrix `[]`.

It is sufficient to type only the leading characters that uniquely identify the property name. Case is ignored for property names.

`options = odeset(oldopts,'name1',value1,...)` alters an existing options structure with the values supplied.

`options = odeset(oldopts,newopts)` alters an existing options structure `oldopts` by combining it with a new options structure `newopts`. Any new options not equal to the empty matrix overwrite corresponding options in `oldopts`. For example:

`oldopts`

F	1	[]	4	's'	's'	[]	[]	[]	...

`newopts`

T	3	F	[]	''	[]	[]	[]	[]	...

`odeset(oldopts,newopts)`

T	3	F	4	''	's'	[]	[]	[]	...

odeset by itself displays all property names and their possible values:

```
odeset
      AbsTol: [ positive scalar or vector {1e-6}]
      BDF: [ on | {off} ]
      Events: [ on | {off} ]
      InitialStep: [ positive scalar ]
      Jacobian: [ on | {off} ]
      JConstant: [ on | {off} ]
      JPattern: [ on | {off} ]
      Mass: [ {none} | M | M(t) | M(t,y) ]
      MassSingular: [ yes | no | {maybe} ]
      MaxOrder: [ 1 | 2 | 3 | 4 | {5} ]
      MaxStep: [ positive scalar ]
      OutputFcn: [ string ]
      OutputSel: [ vector of integers ]
      Refine: [ positive integer ]
      RelTol: [ positive scalar {1e-3} ]
      Stats: [ on | {off} ]
      Vectorized: [ on | {off} ]
```

Properties

The available properties depend on the ODE solver used. There are seven principal categories of properties:

- Error tolerance
- Solver output
- Jacobian matrix
- Event location
- Mass matrix
- Step size
- ode15s

Table 2-1: Error Tolerance Properties

Property	Value	Description
`RelTol`	Positive scalar {`1e-3`}	A relative error tolerance that applies to all components of the solution vector.
`AbsTol`	Positive scalar or vector {`1e-6`}	The absolute error tolerance. If scalar, the tolerance applies to all components of the solution vector. Otherwise the tolerances apply to corresponding components.

Table 2-2: Solver Output Properties

Property	Value	Description
`OutputFcn`	String	The name of an installable output function (for example, `odeplot`, `odephas2`, `odephas3`, and `odeprint`). The ODE solvers call `outputfcn(TSPAN,Y0,'init')` before beginning the integration, to initialize the output function. Subsequently, the solver calls `status = outputfcn(T,Y)` after computing each output point `(T,Y)`. The `status` return value should be `1` if integration should be halted (e.g., a **STOP** button has been pressed) and 0 otherwise. When the integration is complete, the solver calls `outputfcn([],[],'done')`.
`OutputSel`	Vector of indices	Specifies which components of the solution vector are to be passed to the output function.

Table 2-2: Solver Output Properties

Property	Value	Description
`Refine`	Positive Integer	Produces smoother output, increasing the number of output points by a factor of `n`. In most solvers, the default value is `1`. However, within `ode45`, `Refine` is `4` by default to compensate for the solver's large step sizes. To override this and see only the time steps chosen by `ode45`, set `Refine` to `1`.
`Stats`	on | {off}	Specifies whether statistics about the computational cost of the integration should be displayed.

Table 2-3: Jacobian Matrix Properties (for ode15s and ode23s)

Property	Value	Description
`Jacobian`	on | {off}	Informs the solver that the ODE file responds to the arguments `(t,y,'jacobian')` by returning $\partial F/\partial y$ (see `odefile`).
`JConstant`	on | {off}	Specifies whether the Jacobian matrix $\partial F/\partial y$ is constant (see `b5ode`).
`JPattern`	on | {off}	Informs the solver that the ODE file responds to the arguments `([],[],'jpattern')` by returning a sparse matrix containing `1`'s showing the nonzeros of $\partial F/\partial y$ (see `brussode`).

Table 2-3: Jacobian Matrix Properties (for ode15s and ode23s)

Property	Value	Description
`Vectorized`	`on | {off}`	Informs the solver that the ODE file `F(t,y)` has been vectorized so that `F(t,[y1 y2 ...])` returns `[F(t,y1) F(t,y2) ...]`. That is, your ODE file can pass to the solver a whole array of column vectors at once. Your ODE file will be called by a stiff solver in a vectorized manner only if generating Jacobians numerically (the default behavior) and `odeset` has been used to set `Vectorized` to `'on'`.

Table 2-4: Event Location Property

Property	Value	Description
`Events`	`on | {off}`	Instructs the solver to locate events. The ODE file must respond to the arguments `(t,y,'events')` by returning the appropriate values. See `odefile`.

Table 2-5: Mass Matrix Properties (for ode15s and ode23s)

Property	Value	Description
`Mass`	`{none} | M | M(t) | M(t,y)`	Indicates whether the ODE file returns a mass matrix.
`MassSingular`	`yes | no | {maybe}`	Indicates whether the mass matrix is singular.

Table 2-6: Step Size Properties

Property	Value	Description
`MaxStep`	Positive scalar	An upper bound on the magnitude of the step size that the solver uses.
`InitialStep`	Positive scalar	Suggested initial step size. The solver tries this first, but if too large an error results, the solver uses a smaller step size.

In addition there are two options that apply only to the `ode15s` solver.

Table 2-7: ode15s Properties

Property	Value	Description
`MaxOrder`	`1 | 2 | 3 | 4 | {5}`	The maximum order formula used.
`BDF`	`on | {off}`	Specifies whether the backward differentiation formulas (BDFs) are to be used instead of the default numerical differentiation formulas (NDFs).

See Also

`odefile`, `odeget`, `ode45`, `ode23`, `ode23t`, `ode23tb`, `ode113`, `ode15s`,`ode23s`

ones

Purpose

Create an array of all ones

Syntax

```
Y = ones(n)
Y = ones(m,n)
Y = ones([m n])
Y = ones(d1,d2,d3...)
Y = ones([d1 d2 d3...])
Y = ones(size(A))
```

Description

`Y = ones(n)` returns an `n`-by-`n` matrix of `1`s. An error message appears if `n` is not a scalar.

`Y = ones(m,n)` or `Y = ones([m n])` returns an `m`-by-`n` matrix of ones.

`Y = ones(d1,d2,d3...)` or `Y = ones([d1 d2 d3...])` returns an array of `1`s with dimensions `d1`-by-`d2`-by-`d3`-by-`...`.

`Y = ones(size(A))` returns an array of `1`s that is the same size as `A`.

See Also

`eye`, `rand`, `randn`, `zeros`

Purpose

Open files based on extension

Syntax

```
open('name')
```

Description

`open('name')` opens the file `name`, where the specific action upon opening depends on the type of file that `name` is.

name	Action
variable	open array `name` in the Array Editor (the array must be numeric); `open` calls `openvar`
figure file (`*.fig`)	open figure in a figure window
M-file (`name.m`)	open M-file `name` in Editor
model (`name.mdl`)	open model `name` in Simulink
p-file (`name.p`)	open the corresponding M-file, `name.m`, if it exists, in the Editor
other extensions (`name.custom`)	open `name.custom` by calling the helper function `opencustom`, where `opencustom` is a user-defined function.

Remarks

Behavior When name Does Not Have an Extension

If `name` does not contain a file extension, `open` opens the object returned by `which(name)`, where `name` is a variable, function, or model. If there is no matching helper function found, `open` uses the default editor.

If `name` does not contain a file extension and there is a matching filename without an extension, `open` opens the file in the editor. If it does not find a matching file without an extension, `open` looks for an M-file with the same name on the path, and if found, opens it in the editor.

To handle a variable, `open` calls the function `openvar`.

Create Custom open

Create your own opencustom functions to change the way standard file types are handled or to set up handlers for new file types. open calls the opencustom function it finds on the path.

Examples

Example 1 – No File Extension Specified

If testdata exists on the path,

```
open('testdata')
```

opens testdata in the editor.

If testdata does not exist, but testdata.m is on the path,

```
open('testdata')
```

opens testdata.m in the editor.

Example 2 – No File Extension Specified, M-file and Model Files Present

If testdata.m and testdata.mdl are both present on the search path, and you type

```
open('testdata')
```

testdata.mdl opens in Simulink. This is because model files take precedence over M-files, which you can see by typing

```
which('testdata')
```

It returns the file that takes precedence, in this case

```
testdata.mdl
```

Example 3 – Customized open

open('mychart.cht') calls opencht('myfigure.cht'), where opencht is a user-created function that uses .cht files.

See Also

load, openvar, save, saveas

Purpose

Open workspace variable in Array Editor, for graphical editing

Syntax

```
openvar('name')
```

Description

`openvar('name')` opens the workspace variable name in the Array Editor for graphical debugging. The array must be numeric. For more information about the Array Editor, see Chapter 2 in *Using MATLAB*.

See Also

open, save

optimget

Purpose

Get optimization options structure parameter values

Syntax

```
val = optimget(options,'param')
val = optimget(options,'param',default)
```

Description

`val = optimget(options,'param')` returns the value of the specified parameter in the optimization options structure `options`. You need to type only enough leading characters to define the parameter name uniquely. Case is ignored for parameter names.

`val = optimget(options,'param',default)` returns `default` if the specified parameter is not defined in the optimization options structure `options`. Note that this form of the function is used primarily by other optimization functions.

Examples

This statement returns the value of the `Display` optimization options parameter in the structure called `my_options`.

```
val = optimget(my_options,'Display')
```

This statement returns the value of the `Display` optimization options parameter in the structure called `my_options` (as in the previous example) except that if the `Display` parameter is not defined, it returns the value `'final'`.

```
optnew = optimget(my_options,'Display','final');
```

See Also

`optimset`, `fminbnd`, `fminsearch`, `fzero`, `lsqnonneg`

Purpose

Create or edit optimization options parameter structure

Syntax

```
options = optimset('param1',value1,'param2',value2,...)
optimset
options = optimset
options = optimset(optimfun)
options = optimset(oldopts,'param1',value1,...)
options = optimset(oldopts,newopts)
```

Description

`options = optimset('param1',value1,'param2',value2,...)` creates an optimization options structure called `options`, in which the specified parameters (`param`) have specified values. Any unspecified parameters are set to `[]` (parameters with value `[]` indicate to use the default value for that parameter when `options` is passed to the optimization function). It is sufficient to type only enough leading characters to define the parameter name uniquely. Case is ignored for parameter names.

`optimset` with no input or output arguments displays a complete list of parameters with their valid values.

`options = optimset` (with no input arguments) creates an options structure `options` where all fields are set to `[]`.

`options = optimset(optimfun)` creates an options structure `options` with all parameter names and default values relevant to the optimization function `optimfun`.

`options = optimset(oldopts,'param1',value1,...)` creates a copy of `oldopts`, modifying the specified parameters with the specified values.

`options = optimset(oldopts,newopts)` combines an existing options structure `oldopts` with a new options structure `newopts`. Any parameters in `newopts` with nonempty values overwrite the corresponding old parameters in `oldopts`.

Parameters

Optimization parameters used by MATLAB functions and Optimization Toolbox functions:

`Display` `[ off | iter | {final} ]`

Level of display. `none` displays no output; `iter` displays output at each iteration; `final` displays just the final output.

`MaxFunEvals` `[ positive integer ]`

Maximum number of function evaluations allowed.

`MaxIter` `[ positive integer ]`

Maximum number of iterations allowed.

`TolFun` `[ positive scalar ]`

Termination tolerance on the function value.

`TolX` `[ positive scalar ]`

Termination tolerance on *x*.

Optimization parameters used by Optimization Toolbox functions (for more information about individual parameters, see the optimization functions that use these parameters):

```
DerivativeCheck     [ on | {off} ]
Diagnostics         [ on | {off} ]
DiffMaxChange       [ positive scalar | {1e-1} ]
DiffMinChange       [ positive scalar | {1e-8} ]
GoalsExactAchieve   [ positive scalar integer | {0} ]
GradConstr          [ on | {off} ]
GradObj             [ on | {off} ]
Hessian             [ on | {off} ]
HessPattern         [ sparse matrix ]
HessUpdate          [ {bfgs} | dfp | gillmurray | steepdesc ]
JacobPattern        [ sparse matrix ]
Jacobian            [ on | {off} ]
LargeScale          [ {on} | off ]
LevenbergMarquardt  [ on | off ]
LineSearchType      [ cubicpoly | {quadcubic} ]
MaxPCGIter          [ positive integer ]
MeritFunction       [ singleobj | {multiobj} ]

MinAbsMax           [ positive scalar integer | {0} ]
PrecondBandWidth    [ positive integer | Inf ]
TolCon              [ positive scalar ]
TolPCG              [ positive scalar | {0.1} ]
TypicalX            [ vector ]
```

Examples

This statement creates an optimization options structure called `options` in which the `Display` parameter is set to `'iter'` and the `TolFun` parameter is set to `1e-8`.

```
options = optimset('Display','iter','TolFun',1e-8)
```

This statement makes a copy of the options structure called `options`, changing the value of the `TolX` parameter and storing new values in `optnew`.

```
optnew = optimset(options,'TolX',1e-4);
```

This statement returns an optimization options structure that contains all the parameter names and default values relevant to the function `fminbnd`.

```
optimset('fminbnd')
```

See Also

`optimget`, `fminbnd`, `fminsearch`, `fzero`, `lsqnnoneg`

Purpose

Range space of a matrix

Syntax

```
B = orth(A)
```

Description

`B = orth(A)` returns an orthonormal basis for the range of `A`. The columns of `B` span the same space as the columns of `A`, and the columns of `B` are orthogonal, so that `B'*B = eye(rank(A))`. The number of columns of `B` is the rank of `A`.

See Also

`null`, `svd`, `rank`

otherwise

Purpose

Default part of switch statement

Description

`otherwise` is part of the `switch` statement syntax, which allows for conditional execution. The statements following `otherwise` are executed only if none of the preceding case expressions (`case_expr`) match the switch expression (`sw_expr`).

Examples

The general form of the `switch` statement is:

```
switch sw_expr
    case case_expr
       statement
       statement
    case {case_expr1,case_expr2,case_expr3}
       statement
       statement
   otherwise
       statement
       statement
end
```

See `switch` for more details.

See Also

`switch`

Purpose

Consolidate workspace memory

Syntax

```
pack
pack filename
```

Description

`pack` frees up needed space by compressing information into the minimum memory required. You must run `pack` from a directory for which you have write permission.

`pack filename` accepts an optional `filename` for the temporary file used to hold the variables. Otherwise it uses the file named `pack.tmp`. You must run `pack` from a directory for which you have write permission.

Remarks

The `pack` command does not affect the amount of memory allocated to the MATLAB process.You must quit MATLAB to free up this memory.

Since MATLAB uses a heap method of memory management, extended MATLAB sessions may cause memory to become fragmented. When memory is fragmented, there may be plenty of free space, but not enough contiguous memory to store a new large variable.

If you get the `Out of memory` message from MATLAB, the `pack` command may find you some free memory without forcing you to delete variables.

The `pack` command frees space by:

- Saving all variables on disk in a temporary file called `pack.tmp`.
- Clearing all variables and functions from memory.
- Reloading the variables back from `pack.tmp`.
- Deleting the temporary file `pack.tmp`.

If you use `pack` and there is still not enough free memory to proceed, you must clear some variables. If you run out of memory often, you can allocate larger matrices earlier in the MATLAB session and use these system-specific tips:

- UNIX: Ask your system manager to increase your swap space.
- VAX/VMS: Ask your system manager to increase your working set and/or pagefile quota.
- Windows: Increase virtual memory by using **System Properties** for **Performance**, which you can access from the **Control Panel**.

Examples

Change the current directory to one that is writeable, run pack, and return to the previous directory.

```
cwd = pwd;
cd(tempdir);
pack
cd(cwd)
```

See Also

clear

Purpose

Partial pathname

Description

A partial pathname is a `MATLABPATH` relative pathname used to locate private and method files, which are usually hidden, or to restrict the search for files when more than one file with the given name exists.

A partial pathname contains the last component, or last several components, of the full pathname separated by `/`. For example, `matfun/trace`, `private/children`, `inline/formula`, and `demos/clown.mat` are valid partial pathnames. Specifying the `@` in method directory names is optional, so `funfun/inline/formula` is also a valid partial pathname.

Partial pathnames make it easy to find toolbox or MATLAB relative files on your path in a portable way, independent of the location where MATLAB is installed.

See Also

`path`

pascal

Purpose

Pascal matrix

Syntax

```
A = pascal(n)
A = pascal(n,1)
A = pascal(n,2)
```

Description

`A = pascal(n)` returns the Pascal matrix of order `n`: a symmetric positive definite matrix with integer entries taken from Pascal's triangle. The inverse of `A` has integer entries.

`A = pascal(n,1)` returns the lower triangular Cholesky factor (up to the signs of the columns) of the Pascal matrix. It is *involutary*, that is, it is its own inverse.

`A = pascal(n,2)` returns a transposed and permuted version of `pascal(n,1)`. `A` is a cube root of the identity matrix.

Examples

`pascal(4)` returns

```
   1     1     1     1
   1     2     3     4
   1     3     6    10
   1     4    10    20
```

`A = pascal(3,2)` produces

```
   A =
        0     0    -1
        0    -1     2
       -1    -1     1
```

See Also

`chol`

Purpose

Control MATLAB's directory search path

Syntax

```
path
p = path
path('newpath')
path(path,'newpath')
path('newpath',path)
```

Description

`path` prints out the current setting of MATLAB's search path. The path resides in `pathdef.m` (in `toolbox/local`).

`p = path` returns the current search path in string variable `p`.

`path('newpath')` changes the path to the string `'newpath'`.

`path(path,'newpath')` appends a new directory to the current path.

`path('newpath',path)` prepends a new directory to the current path.

Remarks

MATLAB has a *search path*. If you enter a name, such as `fox`, the MATLAB interpreter:

1. Looks for `fox` as a variable.
2. Checks for `fox` as a built-in function.
3. Looks in the current directory for `fox.mex` and `fox.m`.
4. Searches the directories specified by `path` for `fox.mex` and `fox.m`.

Note Save any M-files you create or any MATLAB-supplied M-files that you edit in a directory that is not in the `MATLAB` directory tree. If you keep your files in the `MATLAB` directory tree, they might be overwritten when you install a new version of MATLAB. Another consideration is that files in the `MATLAB/toolbox` directory tree are loaded and cached into memory at the beginning of each MATLAB session to improve performance. This cache is not updated until MATLAB is restarted. If you add any files or make changes to any files in the `toolbox` directory, you will not be able to see the changes until you restart MATLAB.

---

path

Examples

Add a new directory to the search path on various operating systems.

UNIX	`path(path,'/home/myfriend/goodstuff')`
VMS	`path(path,'DISKS1:[MYFRIEND.GOODSTUFF]')`
Windows	`path(path,'TOOLS\GOODSTUFF')`

See Also

`addpath`, `cd`, `dir`, `partialpath`, `rmpath`, `what`

Purpose

Start the Path Browser, a GUI for viewing and modifying MATLAB's path

Syntax

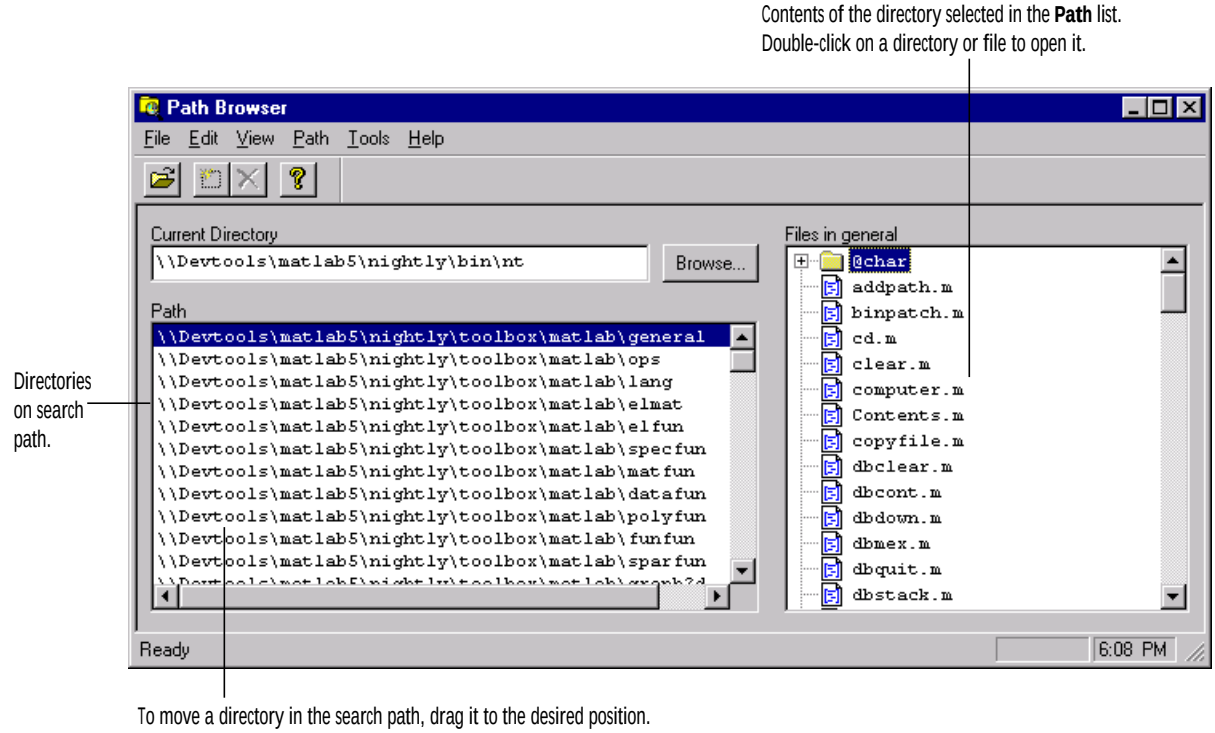
```
pathtool
```

Description

`pathtool` opens the Path Browser, which is a graphical interface you use to view and modify the MATLAB search path, as well as see all of the files on the path.

Remarks

On Windows platforms, you can also open the Path Browser by selecting the Path Browser button on the toolbar, or by selecting **Set Path** from the **File** menu. From the Editor/Debugger, to open the Path Browser, select **Path Browser** from the **View** menu.



Use the menus in the Path Browser to:

- Add a directory to the front of the path.
- Remove a selected directory from the path.
- Save settings to the `pathdef.m` file.
- Restore default settings.

See Also

`addpath`, `edit`, `path`, `rmpath`, `workspace`

Purpose

Halt execution temporarily

Syntax

```
pause
pause(n)
pause on
pause off
```

Description

pause, by itself, causes M-files to stop and wait for you to press any key before continuing.

`pause(n)` pauses execution for `n` seconds before continuing, where `n` can be any real number. The resolution of the clock is platform specific. A fractional pause of 0.01 seconds should be supported on most platforms.

`pause on` allows subsequent pause commands to pause execution.

`pause off` ensures that any subsequent `pause` or `pause(n)` statements do not pause execution. This allows normally interactive scripts to run unattended.

See Also

`drawnow`

pcg

Purpose

Preconditioned Conjugate Gradients method

Syntax

```
x = pcg(A,b)
pcg(A,b,tol)
pcg(A,b,tol,maxit)
pcg(A,b,tol,maxit,M)
pcg(A,b,tol,maxit,M1,M2)
pcg(A,b,tol,maxit,M1,M2,x0)
x = pcg(A,b,tol,maxit,M1,M2,x0)
[x,flag] = pcg(A,b,tol,maxit,M1,M2,x0)
[x,flag,relres] = pcg(A,b,tol,maxit,M1,M2,x0)
[x,flag,relres,iter] = pcg(A,b,tol,maxit,M1,M2,x0)
[x,flag,relres,iter,resvec] = pcg(A,b,tol,maxit,M1,M2,x0)
```

Description

`x = pcg(A,b)` attempts to solve the system of linear equations `A*x = b` for `x`. The coefficient matrix `A` must be symmetric and positive definite and the column vector `b` must have length `n`, where `A` is `n`-by-`n`. When `A` is not explicitly available as a matrix, you can express `A` as an operator `afun` that returns the matrix-vector product `A*x` for `afun(x)`. This operator can be the name of an M-file, a string expression, or an inline object. In this case `n` is taken to be the length of the column vector `b`.

`pcg` will start iterating from an initial estimate that, by default, is an all zero vector of length `n`. Iterates are produced until the method either converges, fails, or has computed the maximum number of iterations. Convergence is achieved when an iterate `x` has relative residual `norm(b-A*x)/norm(b)` less than or equal to the tolerance of the method.The default tolerance is `1e-6`. The default maximum number of iterations is the minimum of `n` and 20. No preconditioning is used.

`pcg(A,b,tol)` specifies the tolerance of the method, `tol`.

`pcg(A,b,tol,maxit)` additionally specifies the maximum number of iterations, `maxit`.

`pcg(A,b,tol,maxit,M)` and `pcg(A,b,tol,maxit,M1,M2)` use left preconditioner `M` or `M = M1*M2` and effectively solve the system `inv(M)*A*x = inv(M)*b` for `x`. You can replace the matrix `M` with a function `mfun` such that `mfun(x)` returns `M\x`. If `M1` or `M2` is given as the empty matrix

([]), it is considered to be the identity matrix, equivalent to no preconditioning at all. Since systems of equations of the form `M*y = r` are solved using backslash within `pcg`, it is wise to factor preconditioners into their Cholesky factors first. For example, replace `pcg(A,b,tol,maxit,M)` with:

```
R = chol(M);
pcg(A,b,tol,maxit,R',R).
```

The preconditioner `M` must be symmetric and positive definite.

`pcg(A,b,tol,maxit,M1,M2,x0)` specifies the initial estimate `x0`. If `x0` is given as the empty matrix (`[]`), the default all zero vector is used.

`x = pcg(A,b,tol,maxit,M1,M2,x0)` returns a solution `x`. If `pcg` converged, a message to that effect is displayed. If `pcg` failed to converge after the maximum number of iterations or halted for any reason, a warning message is printed displaying the relative residual `norm(b–A*x)/norm(b)` and the iteration number at which the method stopped or failed.

`[x,flag] = pcg(A,b,tol,maxit,M1,M2,x0)` returns a solution `x` and a flag that describes the convergence of `pcg`.

Flag	Convergence
`0`	`pcg` converged to the desired tolerance `tol` within `maxit` iterations without failing for any reason.
`1`	`pcg` iterated `maxit` times but did not converge.
`2`	One of the systems of equations of the form `M*y = r` involving the preconditioner was ill-conditioned and did not return a useable result when solved by \ (backslash).
`3`	The method stagnated. (Two consecutive iterates were the same.)
`4`	One of the scalar quantities calculated during `pcg` became too small or too large to continue computing

Whenever `flag` is not `0`, the solution `x` returned is that with minimal norm residual computed over all the iterations. No messages are displayed if the `flag` output is specified.

`[x,flag,relres] = pcg(A,b,tol,maxit,M1,M2,x0)` also returns the relative residual `norm(b-A*x)/norm(b)`. If `flag` is `0`, then `relres` ≤ `tol`.

`[x,flag,relres,iter] = pcg(A,b,tol,maxit,M1,M2,x0)` also returns the iteration number at which `x` was computed. This always satisfies `0` ≤ `iter` ≤ `maxit`.

`[x,flag,relres,iter,resvec] = pcg(A,b,tol,maxit,M1,M2,x0)` also returns a vector of the residual norms at each iteration, starting from `resvec(1) = norm(b-A*x0)`. If `flag` is `0`, `resvec` is of length `iter+1` and `resvec(end)` ≤ `tol*norm(b)`.

Examples

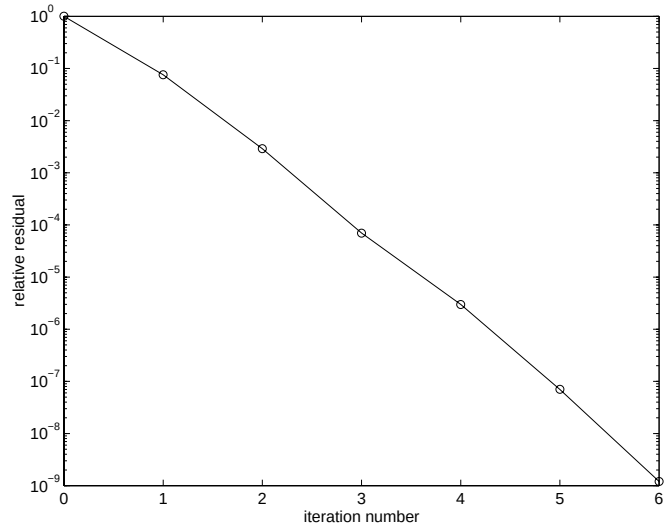
```
A = delsq(numgrid('C',25))
b = ones(length(A),1)
[x,flag] = pcg(A,b)
```

`flag` is `1` since `pcg` will not converge to the default tolerance of `1e-6` within the default 20 iterations.

```
R = cholinc(A,1e-3)
[x2,flag2,relres2,iter2,resvec2] = pcg(A,b,1e-8,10,R',R)
```

`flag2` is `0` since `pcg` will converge to the tolerance of `1.2e-9` (the value of `relres2`) at the sixth iteration (the value of `iter2`) when preconditioned by the incomplete Cholesky factorization with a drop tolerance of `1e-3`. `resvec2(1) = norm(b)` and `resvec2(7) = norm(b-A*x2)`.You can follow the progress of `pcg` by plotting the relative residuals at each iteration starting from

the initial estimate (iterate number 0) with `semilogy(0:iter2,resvec2/norm(b),'-o')`.



See Also

`bicg`, `bicgstab`, `cgs`, `cholinc`, `gmres`, `qmr`

The arithmetic operator \

References

"Templates for the Solution of Linear Systems: Building Blocks for Iterative Methods", *SIAM*, Philadelphia, 1994.

pcode

Purpose

Create preparsed pseudocode file (P-file)

Syntax

```
pcode fun
pcode *.m
pcode fun1 fun2 ...
pcode... -inplace
```

Description

`pcode` *`fun`* parses the M-file `fun.m` into the P-file `fun.p` and puts it into the current directory. The original M-file can be anywhere on the search path.

`pcode *.m` creates P-files for all the M-files in the current directory.

`pcode` *`fun1 fun2`* `...` creates P-files for the listed functions.

`pcode... -inplace` creates P-files in the same directory as the M-files. An error occurs if the files can't be created.

Purpose

All possible permutations

Syntax

```
P = perms(v)
```

Description

`P = perms(v)`, where `v` is a row vector of length `n`, creates a matrix whose rows consist of all possible permutations of the `n` elements of `v`. Matrix `P` contains `n!` rows and `n` columns.

Examples

The command `perms(2:2:6)` returns *all* the permutations of the numbers 2, 4, and 6:

```
6     4     2
4     6     2
6     2     4
2     6     4
4     2     6
2     4     6
```

Limitations

This function is only practical for situations where `n` is less than about 15.

See Also

`nchoosek`, `permute`, `randperm`

permute

Purpose

Rearrange the dimensions of a multidimensional array

Syntax

```
B = permute(A,order)
```

Description

`B = permute(A,order)` rearranges the dimensions of `A` so that they are in the order specified by the vector *order*. `B` has the same values of `A` but the order of the subscripts needed to access any particular element is rearranged as specified by *order*. All the elements of `order` must be unique.

Remarks

`permute` and `ipermute` are a generalization of transpose (`.'`) for multidimensional arrays.

Examples

Given any matrix `A`, the statement

```
permute(A,[2 1])
```

is the same as `A'`.

For example:

```
A = [1 2; 3 4]; permute(A,[2 1])
ans =
     1     3
     2     4
```

The following code permutes a three-dimensional array:

```
X = rand(12,13,14);
Y = permute(X,[2 3 1]);
size(Y)
ans =
    13    14    12
```

See Also

`ipermute`

Purpose

Define persistent variable

Syntax

```
persistent X Y Z
```

Description

`persistent X Y Z` defines `X`, `Y`, and `Z` as persistent in scope, so that `X`, `Y`, and `Z` maintain their values from one call to the next. `persistent` can be used within a function only.

Persistent variables are cleared when the M-file is cleared from memory or when the M-file is changed. To keep an M-file in memory until MATLAB quits, use `mlock`. If the persistent variable does not exist the first time you issue the `persistent` statement, it is initializied to the empty matrix.

It is an error to declare a variable persistent if a variable with the same name exists in the current workspace.

By convention, persistent variable names are often long with all capital letters (not required).

See Also

`clear`, `global`, `mislocked`, `mlock`, `munlock`

pi

Purpose

Ratio of a circle's circumference to its diameter, π

Syntax

```
pi
```

Description

`pi` returns the floating-point number nearest the value of π. The expressions `4*atan(1)` and `imag(log(-1))` provide the same value.

Examples

The expression `sin(pi)` is not exactly zero because `pi` is not exactly π:

```
sin(pi)

ans =

   1.2246e-16
```

See Also

`ans`, `eps`, `i`, `Inf`, `j`, `NaN`

Purpose

Moore-Penrose pseudoinverse of a matrix

Syntax

```
B = pinv(A)
B = pinv(A,tol)
```

Definition

The Moore-Penrose pseudoinverse is a matrix `B` of the same dimensions as `A'` satisfying four conditions:

```
A*B*A = A
B*A*B = B
A*B is Hermitian
B*A is Hermitian
```

The computation is based on `svd(A)` and any singular values less than `tol` are treated as zero.

Description

`B = pinv(A)` returns the Moore-Penrose pseudoinverse of `A`.

`B = pinv(A,tol)` returns the Moore-Penrose pseudoinverse and overrides the default tolerance, `max(size(A))*norm(A)*eps`.

Examples

If `A` is square and not singular, then `pinv(A)` is an expensive way to compute `inv(A)`. If `A` is not square, or is square and singular, then `inv(A)` does not exist. In these cases, `pinv(A)` has some of, but not all, the properties of `inv(A)`.

If `A` has more rows than columns and is not of full rank, then the overdetermined least squares problem

```
minimize norm(A*x-b)
```

does not have a unique solution. Two of the infinitely many solutions are

```
x = pinv(A)*b
```

and

```
y = A\b
```

These two are distinguished by the facts that `norm(x)` is smaller than the norm of any other solution and that `y` has the fewest possible nonzero components.

For example, the matrix generated by

```
A = magic(8); A = A(:,1:6)
```

is an 8-by-6 matrix that happens to have `rank(A) = 3`.

```
A =
    64     2     3    61    60     6
     9    55    54    12    13    51
    17    47    46    20    21    43
    40    26    27    37    36    30
    32    34    35    29    28    38
    41    23    22    44    45    19
    49    15    14    52    53    11
     8    58    59     5     4    62
```

The right-hand side is `b = 260*ones(8,1)`,

```
b =
     260
     260
     260
     260
     260
     260
     260
     260
```

The scale factor 260 is the 8-by-8 magic sum. With all eight columns, one solution to `A*x = b` would be a vector of all `1`'s. With only six columns, the equations are still consistent, so a solution exists, but it is not all `1`'s. Since the matrix is rank deficient, there are infinitely many solutions. Two of them are

```
x = pinv(A)*b
```

which is

```
x =
     1.1538
     1.4615
     1.3846
     1.3846
     1.4615
     1.1538
```

and

```
y = A\b
```

which is

```
y =
     3.0000
     4.0000
          0
          0
     1.0000
          0
```

Both of these are exact solutions in the sense that `norm(A*x-b)` and `norm(A*y-b)` are on the order of roundoff error. The solution `x` is special because

```
norm(x) = 3.2817
```

is smaller than the norm of any other solution, including

```
norm(y) = 5.0990
```

On the other hand, the solution `y` is special because it has only three nonzero components.

See Also

`inv`, `qr`, `rank`, `svd`

plotedit

Purpose

Start plot edit mode to allow editing and annotation of plots

Syntax

```
plotedit on
plotedit off
plotedit
plotedit(h)
plotedit(h,'state')
```

Description

`plotedit on` starts plot edit mode for the current figure, allowing you to use a graphical interface to annotate and edit plots easily. The Plot Editor interface provides an intuitive way to perform functions such as labeling axes, changing line styles, and adding text, line, and arrow annotations.

`plotedit off` ends plot mode for the current figure.

`plotedit` toggles the plot edit mode for the current figure.

`plotedit(h)` toggles the plot edit mode for the figure specified by figure handle `h`.

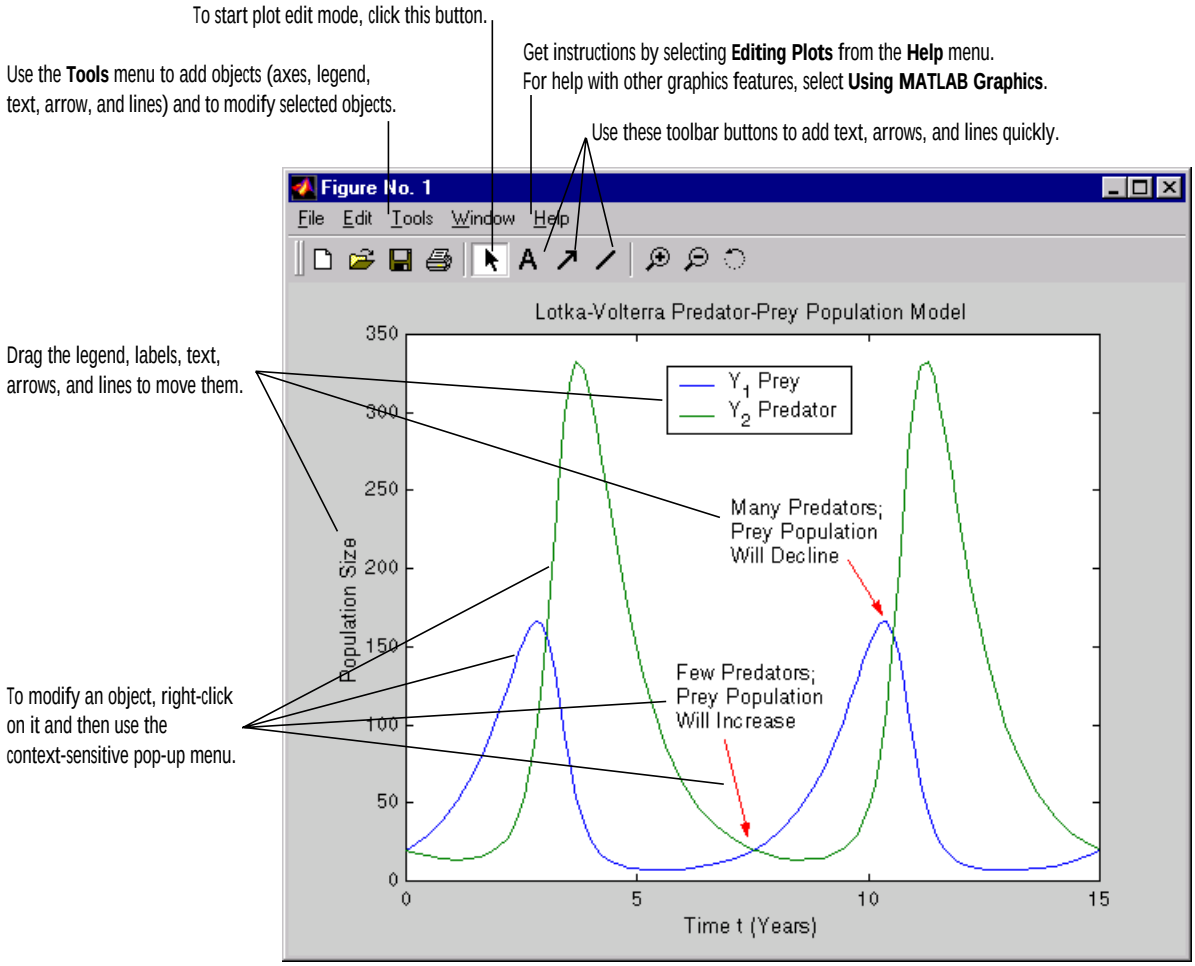
`plotedit(h,'state')` specifies the `plotedit` `state` for figure handle `h`. Values for `state` can be as shown.

Value for state	Description
`on`	starts plot edit mode
`off`	ends plot edit mode
`showtoolsmenu`	displays the **Tools** menu in the menu bar
`hidetoolsmenu`	does not display the **Tools** menu in the menu bar

`hidetoolsmenu` is intended for GUI developers who do not want the **Tools** menu to appear in applications that use the figure window.

Remarks

Main Features of the Plot Editor



Help

For more information about using the Plot Editor, select **Editing Plots** from the Plot Editor **Help** menu. For help with other graphics features, select **Using MATLAB Graphics**.

Examples

Start plot edit mode for the current figure, if the mode is not currently on for that figure:

```
plotedit
```

End plot edit mode for the current figure:

```
plotedit off
```

End plot edit mode for the current figure if it is currently on for that figure:

```
plotedit
```

Start plot edit mode for figure 2:

```
plotedit(2)
```

End plot edit mode for figure 2:

```
plotedit(2, 'off')
```

Hide the **Tools** menu for the current figure:

```
plotedit('hidetoolsmenu')
```

See Also

`axes`, `line`, `open`, `plot`, `print`, `saveas`, `text`

Purpose

Transform polar or cylindrical coordinates to Cartesian

Syntax

```
[X,Y] = pol2cart(THETA,RHO)
[X,Y,Z] = pol2cart(THETA,RHO,Z)
```

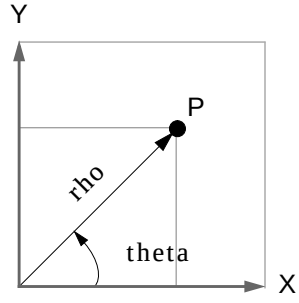
Description

`[X,Y] = pol2cart(THETA,RHO)` transforms the polar coordinate data stored in corresponding elements of `THETA` and `RHO` to two-dimensional Cartesian, or *xy*, coordinates. The arrays `THETA` and `RHO` must be the same size (or either can be scalar). The values in `THETA` must be in radians.

`[X,Y,Z] = pol2cart(THETA,RHO,Z)` transforms the cylindrical coordinate data stored in corresponding elements of `THETA`, `RHO`, and `Z` to three-dimensional Cartesian, or *xyz*, coordinates. The arrays `THETA` , `RHO`, and `Z` must be the same size (or any can be scalar). The values in `THETA` must be in radians.

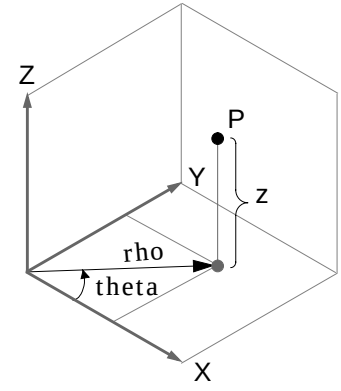
Algorithm

The mapping from polar and cylindrical coordinates to Cartesian coordinates is:



Polar to Cartesian Mapping

```
  theta = atan2(y,x)
rho = sqrt(x.^2 + y.^2)
```



Cylindrical to Cartesian Mapping

```
  theta = atan2(y,x)
rho = sqrt(x.^2 + y.^2)
      z = z
```

See Also

`cart2pol`, `cart2sph`, `sph2cart`

poly

Purpose

Polynomial with specified roots

Syntax

```
p = poly(A)
p = poly(r)
```

Description

`p = poly(A)` where `A` is an `n`-by-`n` matrix returns an `n+1` element row vector whose elements are the coefficients of the characteristic polynomial, $det(sI - A)$. The coefficients are ordered in descending powers: if a vector `c` has `n+1` components, the polynomial it represents is $c_1 s^n + \ldots + c_n s + c_{n+1}$

`p = poly(r)` where `r` is a vector returns a row vector whose elements are the coefficients of the polynomial whose roots are the elements of `r`.

Remarks

Note the relationship of this command to

```
r = roots(p)
```

which returns a column vector whose elements are the roots of the polynomial specified by the coefficients row vector `p`. For vectors, `roots` and `poly` are inverse functions of each other, up to ordering, scaling, and roundoff error.

Examples

MATLAB displays polynomials as row vectors containing the coefficients ordered by descending powers. The characteristic equation of the matrix

```
A =

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

is returned in a row vector by `poly`:

```
p = poly(A)

p =

     1    -6    -72    -27
```

The roots of this polynomial (eigenvalues of matrix A) are returned in a column vector by roots:

```
r = roots(p)

r =

    12.1229
    -5.7345
    -0.3884
```

Algorithm

The algorithms employed for poly and roots illustrate an interesting aspect of the modern approach to eigenvalue computation. poly(A) generates the characteristic polynomial of A, and roots(poly(A)) finds the roots of that polynomial, which are the eigenvalues of A. But both poly and roots use EISPACK eigenvalue subroutines, which are based on similarity transformations. The classical approach, which characterizes eigenvalues as roots of the characteristic polynomial, is actually reversed.

If A is an n-by-n matrix, poly(A) produces the coefficients c(1) through c(n+1), with c(1) = 1, in

$$det(\lambda I - A) = c_1\lambda^n + \ldots + c_n\lambda + c_{n+1}$$

The algorithm is expressed in an M-file:

```
z = eig(A);
c = zeros(n+1,1); c(1) = 1;
for j = 1:n
    c(2:j+1) = c(2:j+1)-z(j)*c(1:j);
end
```

This recursion is easily derived by expanding the product.

$$(\lambda - \lambda_1)(\lambda - \lambda_2)\ldots(\lambda - \lambda_n)$$

It is possible to prove that poly(A) produces the coefficients in the characteristic polynomial of a matrix within roundoff error of A. This is true even if the eigenvalues of A are badly conditioned. The traditional algorithms for obtaining the characteristic polynomial, which do not use the eigenvalues, do not have such satisfactory numerical properties.

See Also conv, polyval, residue, roots

Purpose

Area of polygon

Syntax

```
A = polyarea(X,Y)
A = polyarea(X,Y,dim)
```

Description

`A = polyarea(X,Y)` returns the area of the polygon specified by the vertices in the vectors `X` and `Y`.

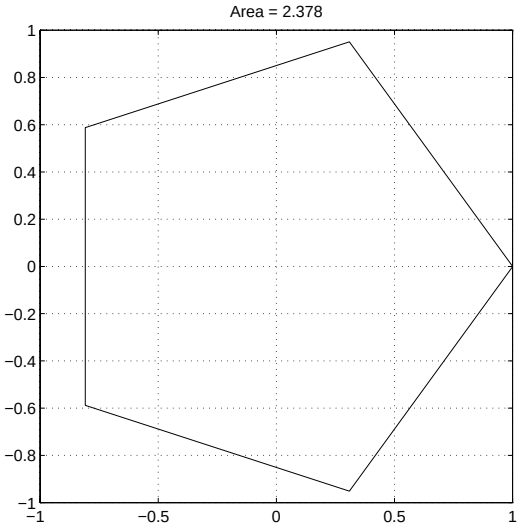
If `X` and `Y` are matrices of the same size, then `polyarea` returns the area of polygons defined by the columns `X` and `Y`.

If `X` and `Y` are multidimensional arrays, `polyarea` returns the area of the polygons in the first nonsingleton dimension of `X` and `Y`.

`A = polyarea(X,Y,dim)` operates along the dimension specified by scalar `dim`.

Examples

```
L = linspace(0,2.*pi,6); xv = cos(L)';yv = sin(L)';
xv = [xv ; xv(1)]; yv = [yv ; yv(1)];
A = polyarea(xv,yv);
plot(xv,yv); title(['Area = ' num2str(A)]); axis image
```



See Also

`convhull`, `inpolygon`

polyder

Purpose

Polynomial derivative

Syntax

```
k = polyder(p)
k = polyder(a,b)
[q,d] = polyder(b,a)
```

Description

The `polyder` function calculates the derivative of polynomials, polynomial products, and polynomial quotients. The operands `a`, `b`, and `p` are vectors whose elements are the coefficients of a polynomial in descending powers.

`k = polyder(p)` returns the derivative of the polynomial `p`.

`k = polyder(a,b)` returns the derivative of the product of the polynomials `a` and `b`.

`[q,d] = polyder(b,a)` returns the numerator `q` and denominator `d` of the derivative of the polynomial quotient `b/a`.

Examples

The derivative of the product

$$(3x^2 + 6x + 9)(x^2 + 2x)$$

is obtained with

```
a = [3 6 9];
b = [1 2 0];
k = polyder(a,b)
k =
    12    36    42    18
```

This result represents the polynomial

$$12x^3 + 36x^2 + 42x + 18$$

See Also

conv, deconv

Purpose

Polynomial eigenvalue problem

Syntax

```
[X,e] = polyeig(A0,A1,...Ap)
```

Description

`[X,e] = polyeig(A0,A1,...Ap)` solves the polynomial eigenvalue problem of degree `p`:

$$(A_0 + \lambda A_1 + \ldots + \lambda^P A_p)x = 0$$

where polynomial degree `p` is a non-negative integer, and `A0,A1,...Ap` are input matrices of order `n`. Output matrix `X`, of size `n`-by-`n`∗`p`, contains eigenvectors in its columns. Output vector `e`, of length `n*p`, contains eigenvalues.

Remarks

Based on the values of `p` and `n`, `polyeig` handles several special cases:

- `p = 0`, or `polyeig(A)` is the standard eigenvalue problem: `eig(A)`.
- `p = 1`, or `polyeig(A,B)` is the generalized eigenvalue problem: `eig(A,-B)`.
- `n = 1`, or `polyeig(a0,a1,...ap)` for scalars `a0`, `a1` ..., `ap` is the standard polynomial problem: `roots([ap ... a1 a0])`.

Algorithm

If both `A0` and `Ap` are singular, the problem is potentially ill posed; solutions might not exist or they might not be unique. In this case, the computed solutions may be inaccurate. `polyeig` attempts to detect this situation and display an appropriate warning message. If either one, but not both, of `A0` and `Ap` is singular, the problem is well posed but some of the eigenvalues may be zero or infinite (`Inf`).

The `polyeig` function uses the QZ factorization to find intermediate results in the computation of generalized eigenvalues. It uses these intermediate results to determine if the eigenvalues are well-determined. See the descriptions of `eig` and `qz` for more on this, as well as the *EISPACK Guide*.

See Also

`eig`, `qz`

polyfit

Purpose

Polynomial curve fitting

Syntax

```
p = polyfit(x,y,n)
[p,s] = polyfit(x,y,n)
```

Description

`p = polyfit(x,y,n)` finds the coefficients of a polynomial `p(x)` of degree `n` that fits the data, `p(x(i))` to `y(i)`, in a least squares sense. The result `p` is a row vector of length `n+1` containing the polynomial coefficients in descending powers:

$$p(x) = p_1 x^n + p_2 x^{n-1} + \ldots + p_n x + p_{n+1}$$

`[p,s] = polyfit(x,y,n)` returns the polynomial coefficients `p` and a structure `S` for use with `polyval` to obtain error estimates or predictions. If the errors in the data `Y` are independent normal with constant variance; `polyval` will produce error bounds that contain at least 50% of the predictions.

Examples

This example involves fitting the error function, `erf(x)`, by a polynomial in `x`. This is a risky project because `erf(x)` is a bounded function, while polynomials are unbounded, so the fit might not be very good.

First generate a vector of `x`-points, equally spaced in the interval [0, 2.5]; then evaluate `erf(x)` at those points.

```
x = (0: 0.1: 2.5)';
y = erf(x);
```

The coefficients in the approximating polynomial of degree 6 are

```
p = polyfit(x,y,6)

p =

  0.0084  -0.0983   0.4217   -0.7435  0.1471   1.1064  0.0004
```

There are seven coefficients and the polynomial is

$$0.0084x^6 - 0.0983x^5 + 0.4217x^4 - 0.7435x^3 + 0.1471x^2 + 1.1064x + 0.0004$$

To see how good the fit is, evaluate the polynomial at the data points with

```
f = polyval(p,x);
```

A table showing the data, fit, and error is

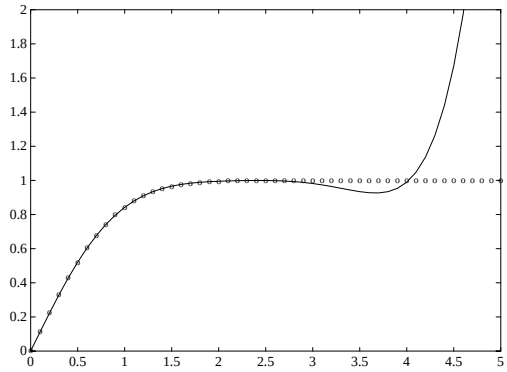
```
table = [x y f y-f]

table =

   0          0          0.0004    -0.0004
   0.1000     0.1125     0.1119     0.0006
   0.2000     0.2227     0.2223     0.0004
   0.3000     0.3286     0.3287    -0.0001
   0.4000     0.4284     0.4288    -0.0004
   ...
   2.1000     0.9970     0.9969     0.0001
   2.2000     0.9981     0.9982    -0.0001
   2.3000     0.9989     0.9991    -0.0003
   2.4000     0.9993     0.9995    -0.0002
   2.5000     0.9996     0.9994     0.0002
```

So, on this interval, the fit is good to between three and four digits. Beyond this interval the graph shows that the polynomial behavior takes over and the approximation quickly deteriorates.

```
x = (0: 0.1: 5)';
y = erf(x);
f = polyval(p,x);
plot(x,y,'o',x,f,'-')
axis([0  5  0  2])
```



Algorithm

The M-file forms the Vandermonde matrix, *V*, whose elements are powers of *x*.

$$v_{i,j} = x_i^{n-j}$$

It then uses the backslash operator, \, to solve the least squares problem

$$V_p \cong y$$

The M-file can be modified to use other functions of *x* as the basis functions.

See Also

`polyval`, `roots`

polyval

Purpose

Polynomial evaluation

Syntax

```
y = polyval(p,x)
[y,delta] = polyval(p,x,S)
```

Description

`y = polyval(p,x)` returns the value of the polynomial `p` evaluated at `x`. Polynomial `p` is a vector whose elements are the coefficients of a polynomial in descending powers.

`x` can be a matrix or a vector. In either case, `polyval` evaluates `p` at each element of `x`.

`[y,delta] = polyval(p,x,S)` uses the optional output structure `S` generated by `polyfit` to generate error estimates, `y±delta`. If the errors in the data input to `polyfit` are independent normal with constant variance, `y±delta` contains at least 50% of the predictions.

Remarks

The `polyvalm(p,x)` function, with `x` a matrix, evaluates the polynomial in a matrix sense. See `polyvalm` for more information.

Examples

The polynomial $p(x) = 3x^2 + 2x + 1$ is evaluated at $x = 5$, 7, and 9 with

```
p = [3 2 1];
polyval(p,[5 7 9])
```

which results in

```
ans =

     86   162   262
```

For another example, see `polyfit`.

See Also

`polyfit`, `polyvalm`

Purpose

Matrix polynomial evaluation

Syntax

```
Y = polyvalm(p,X)
```

Description

`Y = polyvalm(p,X)` evaluates a polynomial in a matrix sense. This is the same as substituting matrix `X` in the polynomial `p`.

Polynomial `p` is a vector whose elements are the coefficients of a polynomial in descending powers, and `X` must be a square matrix.

Examples

The Pascal matrices are formed from Pascal's triangle of binomial coefficients. Here is the Pascal matrix of order 4.

```
X = pascal(4)
X =
    1    1    1    1
    1    2    3    4
    1    3    6   10
    1    4   10   20
```

Its characteristic polynomial can be generated with the `poly` function.

```
p = poly(X)
p =
   1    -29    72    -29    1
```

This represents the polynomial $x^4 - 29x^3 + 72x^2 - 29x + 1$.

Pascal matrices have the curious property that the vector of coefficients of the characteristic polynomial is palindromic; it is the same forward and backward.

Evaluating this polynomial at each element is not very interesting.

```
polyval(p,X)
ans =
   16      16      16      16
   16      15    -140    -563
   16    -140   -2549  -12089
   16    -563  -12089  -43779
```

But evaluating it in a matrix sense is interesting.

```
polyvalm(p,X)
ans =
   0    0    0    0
   0    0    0    0
   0    0    0    0
   0    0    0    0
```

The result is the zero matrix. This is an instance of the Cayley-Hamilton theorem: a matrix satisfies its own characteristic equation.

See Also

`polyfit`, `polyval`

Purpose

Base 2 power and scale floating-point numbers

Syntax

```
X = pow2(Y)
X = pow2(F,E)
```

Description

`X = pow2(Y)` returns an array `X` whose elements are 2 raised to the power `Y`.

`X = pow2(F,E)` computes $x = f \cdot 2^e$ for corresponding elements of `F` and `E`. The result is computed quickly by simply adding `E` to the floating-point exponent of `F`. Arguments `F` and `E` are real and integer arrays, respectively.

Remarks

This function corresponds to the ANSI C function `ldexp()` and the IEEE floating-point standard function `scalbn()`.

Examples

For IEEE arithmetic, the statement `X = pow2(F,E)` yields the values:

```
F          E         X
1/2        1         1
pi/4       2         pi
-3/4       2         -3
1/2        -51       eps
1-eps/2    1024      realmax
1/2        -1021     realmin
```

See Also

`log2`, `exp`, `hex2num`, `realmax`, `realmin`

The arithmetic operators `^` and `.^`

primes

Purpose

Generate list of prime numbers

Syntax

```
p = primes(n)
```

Description

`p = primes(n)` returns a row vector of the prime numbers less than or equal to `n`. A prime number is one that has no factors other than `1` and itself.

Examples

```
p = primes(37)

p =

     2     3     5     7    11    13    17    19    23    29    31    37
```

See Also

`factor`

Purpose

Product of array elements

Syntax

```
B = prod(A)
B = prod(A,dim)
```

Description

`B = prod(A)` returns the products along different dimensions of an array.

If `A` is a vector, `prod(A)` returns the product of the elements.

If `A` is a matrix, `prod(A)` treats the columns of `A` as vectors, returning a row vector of the products of each column.

If `A` is a multidimensional array, `prod(A)` treats the values along the first non-singleton dimension as vectors, returning an array of row vectors.

`B = prod(A,dim)` takes the products along the dimension of `A` specified by scalar *dim*.

Examples

The magic square of order 3 is

```
M = magic(3)

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

The product of the elements in each column is

```
prod(M) =

    96    45    84
```

The product of the elements in each row can be obtained by:

```
prod(M,2) =

     48
    105
     72
```

See Also

`cumprod`, `diff`, `sum`

profile

Purpose

Start the M-file profiler, a utility for debugging and optimizing M-file code

Syntax

```
profile on
profile on -detail level
profile on -history
profile off
profile resume
profile clear
profile report
profile report basename
profile plot
profile status
stats = profile('info')
```

Description

The profiler utility helps you debug and optimize M-files by tracking their execution time. For each function, the profiler records information about execution time, number of calls, parent functions, child functions, code line hit count, and code line execution time.

`profile on` starts the profiler, clearing previously recorded profile statistics.

`profile on -detail level` starts the profiler for the set of functions specified by `level`, clearing previously recorded profile statistics.

Value for level	Functions Profiler Gathers Information About
`mmex`	M-functions, M-subfunctions, and MEX-functions; `mmex` is the default value
`builtin`	Same functions as for `mmex` plus built-in functions such as `eig`
operator	Same functions as for `builtin` plus built-in operators such as `+`

`profile on -history` starts the profiler, clearing previously recorded profile statistics, and recording the exact sequence of function calls. The profiler records up to 10,000 function entry and exit events. For more than 10,000

events, the profiler continues to record other profile statistics, but not the sequence of calls.

`profile off` suspends the profiler.

`profile resume` restarts the profiler without clearing previously recorded statistics.

`profile clear` clears the statistics recorded by the profiler.

`profile report` suspends the profiler, generates a profile report in HTML format, and displays the report in your Web browser.

`profile report basename` suspends the profiler, generates a profile report in HTML format, saves the report in the file `basename` in the current directory, and displays the report in your Web browser. Because the report consists of several files, do not provide an extension for `basename`.

`profile plot` suspends the profiler and displays in a figure window a bar graph of the functions using the most execution time.

`profile status` displays a structure containing the current profiler status. The structure's fields are shown below.

Field	Values
`ProfilerStatus`	`'on'` or `'off'`
`DetailLevel`	`'mmex'`, `'builtin'`, or `'operator'`
`HistoryTracking`	`'on'` or `'off'`

`stats = profile('info')` suspends the profiler and displays a structure containing profiler results.Use this command to access the data generated by the profiler. The structure's fields are

`FunctionTable`	Array containing list of all functions called.
`FunctionHistory`	Array containing function call history.
`ClockPrecision`	Precision of profiler's time measurement.

Remarks

To see an example of a profile report and profile plot, as well as to learn more about the results and how to use profiling, see Chapter 3 of *Using MATLAB*.

Examples

Example

1. Run the profiler for code that computes the Lotka-Volterra predator-prey population model.

   ```
   profile on -detail builtin -history
   [t,y] = ode23('lotka',[0 2],[20;20]);
   profile report
   ```

   The profile report appears in a Web browser, providing information for all M-functions, M-subfunctions, MEX-functions, and built-in functions. The report includes the function call history.

2. Generate the profile plot.

   ```
   profile plot
   ```

   The profile plot appears in a figure window.

3. Because the report and plot features suspend the profiler, resume its operation without clearing the statistics already gathered.

   ```
   profile resume
   ```

   The profiler will continue gathering statistics when you execute the next M-file.

See Also

`profreport`

Purpose

Generate a profile report

Syntax

```
profreport
profreport(basename)
profreport(stats)
profreport(basename,stats)
```

Description

`profreport` suspends the profiler, generates a profile report in HTML format using the current profiler results, and displays the report in your Web browser.

`profreport(basename)` suspends the profiler, generates a profile report in HTML format using the current profiler results, saves the report using the `basename` you supply, and displays the report in your Web browser. Because the report consists of several files, do not provide an extension for `basename`.

`profreport(stats)` suspends the profiler, generates a profile report in HTML format using the profiler results `info`, and displays the report in your Web browser. `stats` is the profiler information structure returned by `stats = profile('info')`.

`profreport(basename,stats)` suspends the profiler, generates a profile report in HTML format using the profiler results `stats`, saves the report using the `basename` you supply, and displays the report in your Web browser. `stats` is the profiler information structure returned by `stats = profile('info')`. Because the report consists of several files, do not provide an extension for `basename`.

Examples

1 Run the profiler for code that computes the Lotka-Volterra predator-prey population model.

```
profile on -detail builtin -history
[t,y] = ode23('lotka',[0 2],[20;20]);
```

2 View the structure containing the profile results.

```
stats = profile('info')
```

MATLAB returns

```
stats =
FunctionTable: [28x1 struct]
    FunctionHistory: [2x774 double]
     ClockPrecision: 0.01000000000022
```

3 View the contents of the second element in the `FunctionTable` structure.

```
stats.FunctionTable(2)
```

MATLAB returns

```
ans =
          FunctionName: 'ode23'
             MfileName: [1x56 char]
                  Type: 'M-function'
              NumCalls: 1
             TotalTime: 0.42100000000028
    TotalRecursiveTime: 0.42100000000028
              Children: [21x1 struct]
               Parents: [0x1 struct]
         ExecutedLines: [159x3 double]
```

4 Display the profile report from the structure.

```
profreport(stats)
```

MATLAB displays the profile report in your Web browser.

See Also

`profile`

Purpose Display current directory

Syntax

```
s = pwd
```

Description `s = pwd` returns the current directory to the variable `s`.

See Also `cd`, `dir`, `path`, `what`

quit

Purpose

Terminate MATLAB

Syntax

```
quit
quit cancel
quit force
```

Description

`quit` terminates MATLAB after running `finish.m`, if `finish.m` exists. The workspace is not automatically saved by `quit`. To save the workspace or perform other actions when quitting, create a `finish.m` file to perform those actions. If an error occurs while `finish.m` is running, `quit` is canceled so that you can correct your `finish.m` file without losing your workspace.

`quit cancel` is for use in `finish.m` and cancels quitting. It has no effect anywhere else.

`quit force` bypasses `finish.m` and terminates MATLAB. Use this to override `finish.m`, for example, if an errant `finish.m` will not let you quit.

Remarks

When using Handle Graphics in `finish.m`, use `uiwait`, `waitfor`, or `drawnow` so that figures are visible. See the reference pages for these commands for more information.

Examples

Two sample `finish.m` files are included with MATLAB. Use them to help you create your own `finish.m`, or rename one of the files to `finish.m` to use it.

- `finishsav.m` – saves the workspace to a MAT-file when MATLAB quits
- `finishdlg.m` – displays a dialog allowing you to cancel quitting; it uses `quit cancel` and contains the following code.

```
button = questdlg('Ready to quit?', ...
                            'Exit Dialog','Yes','No','No');
switch button
            case 'Yes',
              disp('Exiting MATLAB');
              %Save variables to matlab.mat
              save
            case 'No',
              quit cancel;
end
```

See Also save, startup

qmr

Purpose

Quasi-Minimal Residual method

Syntax

```
x = qmr(A,b)
qmr(A,b,tol)
qmr(A,b,tol,maxit)
qmr(A,b,tol,maxit,M1)
qmr(A,b,tol,maxit,M1,M2)
qmr(A,b,tol,maxit,M1,M2,x0)
x = qmr(A,b,tol,maxit,M1,M2,x0)
[x,flag] = qmr(A,b,tol,maxit,M1,M2,x0)
[x,flag,relres] = qmr(A,b,tol,maxit,M1,M2,x0)
[x,flag,relres,iter] = qmr(A,b,tol,maxit,M1,M2,x0)
[x,flag,relres,iter,resvec] = qmr(A,b,tol,maxit,M1,M2,x0)
```

Description

`x = qmr(A,b)` attempts to solve the system of linear equations `A*x=b` for `x`. The coefficient matrix `A` must be square and the column vector `b` must have length `n`, where `A` is `n`-by-`n`. When `A` is not explicitly available as a matrix, you can express `A` as an operator `afun` where `afun(x)` returns the matrix-vector product `A*x` and `afun(x,'transp')` returns `A'*x`. This operator can be the name of an M-file or an inline object. In this case `n` is taken to be the length of the column vector `b`.

`qmr` will start iterating from an initial estimate that, by default, is an all zero vector of length `n`. Iterates are produced until the method either converges, fails, or has computed the maximum number of iterations. Convergence is achieved when an iterate `x` has a relative residual `norm(b-A*x)/norm(b)` less than or equal to the tolerance of the method. The default tolerance is `1e-6`. The default maximum number of iterations is the minimum of `n` and 20. No preconditioning is used.

`qmr(A,b,tol)` specifies the tolerance of the method, `tol`.

`qmr(A,b,tol,maxit)` additionally specifies the maximum number of iterations, `maxit`.

`qmr(A,b,tol,maxit,M1)` and `qmr(A,b,tol,maxit,M1,M2)` use left and right preconditioners `M1` and `M2` and effectively solve the system `inv(M1)*A*inv(M2)*y = inv(M1)*b` for `y`, where `x = inv(M2)*y`. You can replace the matrix `M` with a function `mfun` such that `mfun(x)` returns either `M\x`

or `M'\x`, depending upon the last argument. If `M1` or `M2` is given as the empty matrix (`[]`), it is considered to be the identity matrix, equivalent to no preconditioning at all. Since systems of equations of the form `M1*y = r` are solved using backslash within `qmr`, it is wise to factor preconditioners into their LU factorizations first. For example, replace `qmr(A,b,tol,maxit,M,[]) or qmr(A,b,tol,maxit,[],M)` with:

```
[M1,M2] = lu(M);
qmr(A,b,tol,maxit,M1,M2).
```

`qmr(A,b,tol,maxit,M1,M2,x0)` specifies the initial estimate `x0`. If `x0` is given as the empty matrix (`[]`), the default all zero vector is used.

`x = qmr(A,b,tol,maxit,M1,M2,x0)` returns a solution `x`. If `qmr` converged, a message to that effect is displayed. If `qmr` failed to converge after the maximum number of iterations or halted for any reason, a warning message is printed displaying the relative residual `norm(b-A*x)/norm(b)` and the iteration number at which the method stopped or failed.

`[x,flag] = qmr(A,b,tol,maxit,M1,M2,x0)` returns a solution `x` and a flag that describes the convergence of `qmr`:

Flag	Convergence
`0`	`qmr` converged to the desired tolerance `tol` within `maxit` iterations without failing for any reason.
`1`	`qmr` iterated `maxit` times but did not converge.
`2`	One of the systems of equations of the form `M*y = r` involving one of the preconditioners was ill-conditioned and did not return a useable result when solved by `\` (backslash).
`3`	The method stagnated. (Two consecutive iterates were the same.)
`4`	One of the scalar quantities calculated during `qmr` became too small or too large to continue computing.

Whenever `flag` is not `0`, the solution `x` returned is that with minimal norm residual computed over all the iterations. No messages are displayed if the `flag` output is specified.

`[x,flag,relres] = qmr(A,b,tol,maxit,M1,M2,x0)` also returns the relative residual `norm(b-A*x)/norm(b)`. If `flag` is `0`, then `relres` $\leq$ `tol`.

`[x,flag,relres,iter] = qmr(A,b,tol,maxit,M1,M2,x0)` also returns the iteration number at which `x` was computed. This always satisfies `0` $\leq$ `iter` $\leq$ `maxit`.

`[x,flag,relres,iter,resvec] = qmr(A,b,tol,maxit,M1,M2,x0)` also returns a vector of the residual norms at each iteration, starting from `resvec(1) = norm(b-A*x0)`. If `flag` is `0`, `resvec` is of length `iter+1` and `resvec(end)` $\leq$ `tol*norm(b)`.

Examples

```
load west0479
A = west0479
b = sum(A,2)
[x,flag] = qmr(A,b)
```

`flag` is `1` since `qmr` will not converge to the default tolerance `1e-6` within the default 20 iterations.

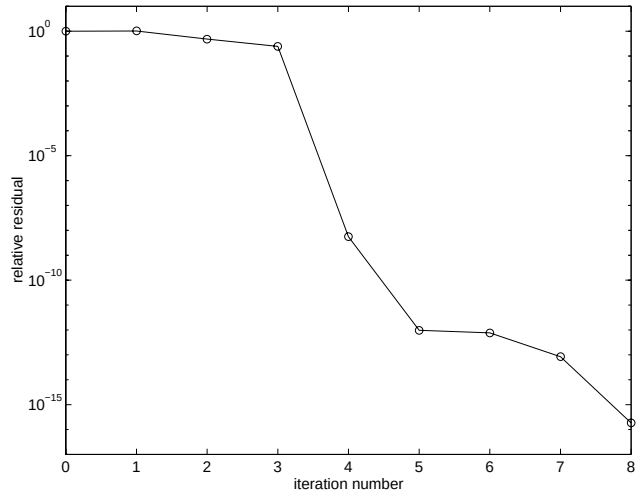
```
[L1,U1] = luinc(A,1e-5)
[x1,flag1] = qmr(A,b,1e-6,20,L1,U1)
```

`flag1` is `2` since the upper triangular `U1` has a zero on its diagonal so `qmr` fails in the first iteration when it tries to solve a system such as `U1*y = r` for `y` with backslash.

```
[L2,U2] = luinc(A,1e-6)
[x2,flag2,relres2,iter2,resvec2] = qmr(A,b,1e-15,10,L2,U2)
```

`flag2` is `0` since `qmr` will converge to the tolerance of `1.9e-16` (the value of `relres2`) at the eighth iteration (the value of `iter2`) when preconditioned by the incomplete LU factorization with a drop tolerance of `1e-6`. `resvec2(1) = norm(b)` and `resvec2(9) = norm(b-A*x2)`. You can follow the progress of `qmr`

by plotting the relative residuals at each iteration starting from the initial estimate (iterate number 0) with `semilogy(0:iter2,resvec2/norm(b),'-o')`.



See Also

`bicg`, `bicgstab`, `cgs`, `gmres`, `luinc`, `pcg`

The arithmetic operator \

References

Freund, Roland W. and Nöel M. Nachtigal, "QMR: A quasi-minimal residual method for non-Hermitian linear systems", *Journal: Numer. Math.* 60, 1991, pp. 315-339

"Templates for the Solution of Linear Systems: Building Blocks for Iterative Methods", *SIAM*, Philadelphia, 1994.

qr

Purpose

Orthogonal-triangular decomposition

Syntax

```
[Q,R] = qr(X)
[Q,R,E] = qr(X)
[Q,R] = qr(X,0)
[Q,R,E] = qr(X,0)
A = qr(X)
```

Description

The `qr` function performs the orthogonal-triangular decomposition of a matrix. This factorization is useful for both square and rectangular matrices. It expresses the matrix as the product of a real orthonormal or complex unitary matrix and an upper triangular matrix.

`[Q,R] = qr(X)` produces an upper triangular matrix `R` of the same dimension as `X` and a unitary matrix `Q` so that `X = Q*R`.

`[Q,R,E] = qr(X)` produces a permutation matrix `E`, an upper triangular matrix `R` with decreasing diagonal elements, and a unitary matrix `Q` so that `X*E = Q*R`. The column permutation `E` is chosen so that `abs(diag(R))` is decreasing.

`[Q,R] = qr(X,0)` and `[Q,R,E] = qr(X,0)` produce "economy-size" decompositions in which `E` is a permutation vector, so that `Q*R = X(:,E)`. The column permutation `E` is chosen so that `abs(diag(R))` is decreasing.

`A = qr(X)` returns the output of the LINPACK subroutine `ZQRDC`. `triu(qr(X))` is `R`.

Examples

Start with

```
A =
     1     2     3
     4     5     6
     7     8     9
    10    11    12
```

This is a rank-deficient matrix; the middle column is the average of the other two columns. The rank deficiency is revealed by the factorization:

```
[Q,R] = qr(A)

Q =

    -0.0776    -0.8331     0.5444     0.0605
    -0.3105    -0.4512    -0.7709     0.3251
    -0.5433    -0.0694    -0.0913    -0.8317
    -0.7762     0.3124     0.3178     0.4461

R =

    -12.8841    -14.5916    -16.2992
           0     -1.0413     -2.0826
           0           0      0.0000
           0           0           0
```

The triangular structure of `R` gives it zeros below the diagonal; the zero on the diagonal in `R(3,3)` implies that `R`, and consequently `A`, does not have full rank.

The QR factorization is used to solve linear systems with more equations than unknowns. For example

```
b =

    1
    3
    5
    7
```

The linear system $Ax = b$ represents four equations in only three unknowns. The best solution in a least squares sense is computed by

```
x = A\b
```

which produces

```
Warning: Rank deficient, rank = 2, tol = 1.4594E-014
x =
    0.5000
         0
    0.1667
```

The quantity `tol` is a tolerance used to decide if a diagonal element of `R` is negligible. If `[Q,R,E] = qr(A)`, then

```
tol = max(size(A))*eps*abs(R(1,1))
```

The solution `x` was computed using the factorization and the two steps

```
y = Q'*b;
x = R\y
```

The computed solution can be checked by forming *Ax*. This equals *b* to within roundoff error, which indicates that even though the simultaneous equations *Ax* = *b* are overdetermined and rank deficient, they happen to be consistent. There are infinitely many solution vectors `x`; the QR factorization has found just one of them.

Algorithm

The `qr` function uses the LINPACK routines `ZQRDC` and `ZQRSL`. `ZQRDC` computes the QR decomposition, while `ZQRSL` applies the decomposition.

See Also

`lu`, `null`, `orth`, `qrdelete`, `qrinsert`

The arithmetic operators `\` and `/`

References

Dongarra, J.J., J.R. Bunch, C.B. Moler, and G.W. Stewart, *LINPACK Users' Guide*, SIAM, Philadelphia, 1979.

Purpose

Delete column from QR factorization

Syntax

```
[Q,R] = qrdelete(Q,R,j)
```

Description

`[Q,R] = qrdelete(Q,R,j)` changes `Q` and `R` to be the factorization of the matrix `A` with its jth column, `A(:,j)`, removed.

Inputs `Q` and `R` represent the original QR factorization of matrix `A`, as returned by the statement `[Q,R] = qr(A)`. Argument `j` specifies the column to be removed from matrix `A`.

Algorithm

The `qrdelete` function uses a series of Givens rotations to zero out the appropriate elements of the factorization.

See Also

`qr`, `qrinsert`

qrinsert

Purpose

Insert column in QR factorization

Syntax

```
[Q,R] = qrinsert(Q,R,j,x)
```

Description

`[Q,R] = qrinsert(Q,R,j,x)` changes `Q` and `R` to be the factorization of the matrix obtained by inserting an extra column, `x`, before `A(:,j)`. If `A` has `n` columns and `j = n+1`, then `qrinsert` inserts `x` after the last column of `A`.

Inputs `Q` and `R` represent the original QR factorization of matrix `A`, as returned by the statement `[Q,R] = qr(A)`. Argument `x` is the column vector to be inserted into matrix `A`. Argument `j` specifies the column before which `x` is inserted.

Algorithm

The `qrinsert` function inserts the values of `x` into the jth column of `R`. It then uses a series of Givens rotations to zero out the nonzero elements of `R` on and below the diagonal in the jth column.

See Also

`qr`, `qrdelete`

Description

Rank 1 update to QR factorization

Syntax

```
[Q1,R1] = qrupdate(Q,R,u,v)
```

Description

`[Q1,R1] = qrupdate(Q,R,u,v)` when `[Q,R] = qr(A)` is the original QR factorization of `A`, returns the QR factorization of `A + u*v'`, where `u` and `v` are column vectors of appropriate lengths.

Remarks

`qrupdate` works only for full matrices.

Examples

The matrix

```
mu = sqrt(eps)

mu =

   1.4901e-08

A = [ones(1,4); mu*eye(4)];
```

is a well-known example in least squares that indicates the dangers of forming `A'*A`. Instead, we work with the QR factorization – orthonormal Q and upper triangular R.

```
[Q,R] = qr(A);
```

As we expect, `R` is upper triangular.

```
R =

   -1.0000   -1.0000   -1.0000   -1.0000
         0    0.0000    0.0000    0.0000
         0         0    0.0000    0.0000
         0         0         0    0.0000
         0         0         0         0
```

In this case, the upper triangular entries of `R`, excluding the first row, are on the order of `sqrt(eps)`.

Consider the update vectors

```
u = [-1 0 0 0 0]'; v = ones(4,1);
```

Instead of computing the rather trivial QR factorization of this rank one update to A from scratch with

```
[QT,RT] = qr(A + u*v')

QT =

     0     0     0     0     1
    -1     0     0     0     0
     0    -1     0     0     0
     0     0    -1     0     0
     0     0     0    -1     0

RT =

   1.0e-07 *
   -0.1490         0         0         0
         0   -0.1490         0         0
         0         0   -0.1490         0
         0         0         0   -0.1490
         0         0         0         0
```

we may use qrupdate.

```
[Q1,R1] = qrupdate(Q,R,u,v)

Q1 =

   -0.0000   -0.0000   -0.0000   -0.0000    1.0000
    1.0000   -0.0000   -0.0000   -0.0000    0.0000
   -0.0000    1.0000   -0.0000   -0.0000    0.0000
   -0.0000   -0.0000    1.0000   -0.0000    0.0000
         0         0         0    1.0000    0.0000

R1 =

   1.0e-07 *
    0.1490    0.0000    0.0000    0.0000
         0    0.1490   -0.0000   -0.0000
         0         0    0.1490   -0.0000
         0         0         0    0.1490
         0         0         0         0
```

Note that both factorizations are correct, even though they are different.

Algorithm

qrupdate uses the algorithm in section 12.5.1 of the third edition of *Matrix Computations* by Golub and van Loan. qrupdate is useful since, if we take N = max(m,n), then computing the new QR factorization from scratch is roughly an $O(N^3)$ algorithm, while simply updating the existing factors in this way is an $O(N^2)$ algorithm.

References

Golub, Gene H. and Charles Van Loan, *Matrix Computations*, Third Edition, Johns Hopkins University Press, Baltimore, 1996

See Also

cholupdate, qr

quad, quad8

Purpose

Numerical evaluation of integrals

Syntax

```
q = quad('fun',a,b)
q = quad('fun',a,b,tol)
q = quad('fun',a,b,tol,trace)
q = quad('fun',a,b,tol,trace,P1,P2,...)
q = quad8(...)
```

Description

Quadrature is a numerical method of finding the area under the graph of a function, that is, computing a definite integral.

$$q = \int_a^b f(x)dx$$

`q = quad('fun',a,b)` returns the result of numerically integrating `'fun'` between the limits `a` and `b`. `'fun'` must return a vector of output values when given a vector of input values.

`q = quad('fun',a,b,tol)` iterates until the relative error is less than `tol`. The default value for `tol` is `1.e-3`. Use a two element tolerance vector, `tol = [rel_tol abs_tol]`, to specify a combination of relative and absolute error.

`q = quad('fun',a,b,tol,trace)` integrates to a relative error of `tol`, and for non-zero `trace`, plots a graph showing the progress of the integration.

`q = quad('fun',a,b,tol,trace,P1,P2,...)` allows coefficients `P1`, `P2`, ... to be passed directly to the specified function: `G = fun(X,P1,P2,...)`. To use default values for `tol` or `trace`, pass in the empty matrix, for example: `quad('fun',a,b,[],[],P1)`.

Remarks

`quad8`, a higher-order method, has the same calling sequence as `quad`.

Examples

Integrate the sine function from 0 to π:

```
a = quad('sin',0,pi)

a =

    2.0000
```

Algorithm

quad and quad8 implement two different quadrature algorithms. quad implements a low order method using an adaptive recursive Simpson's rule. quad8 implements a higher order method using an adaptive recursive Newton-Cotes 8 panel rule. quad8 is better than quad at handling functions with soft singularities, for example:

$$\int_0^1 \sqrt{x}\ dx$$

Diagnostics

quad and quad8 have recursion level limits of 10 to prevent infinite recursion for a singular integral. Reaching this limit in one of the integration intervals produces the warning message:

```
Recursion level limit reached in quad. Singularity likely.
```

and sets `q = inf`.

Limitations

Neither quad nor quad8 is set up to handle integrable singularities, such as:

$$\int_0^1 \frac{1}{\sqrt{x}}\ dx$$

If you need to evaluate an integral with such a singularity, recast the problem by transforming the problem into one in which you can explicitly evaluate the integrable singularities and let quad or quad8 take care of the remainder.

References

[1] Forsythe, G.E., M.A. Malcolm and C.B. Moler, *Computer Methods for Mathematical Computations*, Prentice-Hall, 1977.

qz

Purpose

QZ factorization for generalized eigenvalues

Syntax

```
[AA,BB,Q,Z,V] = qz(A,B)
```

Description

The qz function gives access to what are normally only intermediate results in the computation of generalized eigenvalues.

`[AA,BB,Q,Z,V] = qz(A,B)` produces upper triangular matrices `AA` and `BB`, and matrices `Q` and `Z` containing the products of the left and right transformations, such that

```
Q*A*Z = AA
Q*B*Z = BB
```

The qz function also returns the generalized eigenvector matrix `V`.

The generalized eigenvalues are the diagonal elements of `AA` and `BB` so that

```
A*V*diag(BB) = B*V*diag(AA)
```

Arguments

`A,B`	Square matrices.
`AA,BB`	Upper triangular matrices.
`Q,Z`	Transformation matrices.
`V`	Matrix whose columns are eigenvectors.

Algorithm

Complex generalizations of the EISPACK routines `QZHES`, `QZIT`, `QZVAL`, and `QZVEC` implement the QZ algorithm.

See Also

`eig`

References

[1] Moler, C. B. and G.W. Stewart, “An Algorithm for Generalized Matrix Eigenvalue Problems”, *SIAM J. Numer. Anal.*, Vol. 10, No. 2, April 1973.

Purpose

Uniformly distributed random numbers and arrays

Syntax

```
Y = rand(n)
Y = rand(m,n)
Y = rand([m n])
Y = rand(m,n,p,...)
Y = rand([m n p...])
Y = rand(size(A))
rand
s = rand('state')
```

Description

The rand function generates arrays of random numbers whose elements are uniformly distributed in the interval (0,1).

`Y = rand(n)` returns an n-by-n matrix of random entries. An error message appears if n is not a scalar.

`Y = rand(m,n)` or `Y = rand([m n])` returns an m-by-n matrix of random entries.

`Y = rand(m,n,p,...)` or `Y = rand([m n p...])` generates random arrays.

`Y = rand(size(A))` returns an array of random entries that is the same size as A.

rand, by itself, returns a scalar whose value changes each time it's referenced.

`s = rand('state')` returns a 35-element vector containing the current state of the uniform generator. To change the state of the generator:

`rand('state',s)`	Resets the state to s.
`rand('state',0)`	Resets the generator to its initial state.
`rand('state',j)`	For integer j, resets the generator to its j-th state.
`rand('state',sum(100*clock))`	Resets it to a different state each time.

Remarks

MATLAB 5 uses a new multiseed random number generator that can generate all the floating-point numbers in the closed interval $[2^{-53}, 1 - 2^{-53}]$. Theoretically, it can generate over 2^{1492} values before repeating itself. MATLAB 4 used random number generators with a single seed.
`rand('seed',0)`and `rand('seed',j)` use the MATLAB 4 generator.
`rand('seed')` returns the current seed of the MATLAB 4 uniform generator.
`rand('state',j)` and `rand('state',s)` use the MATLAB 5 generator.

Examples

`R = rand(3,4)` may produce

```
R =
   0.2190    0.6793    0.5194    0.0535
   0.0470    0.9347    0.8310    0.5297
   0.6789    0.3835    0.0346    0.6711
```

This code makes a random choice between two equally probable alternatives.

```
if rand < .5
   'heads'
else
   'tails'
end
```

See Also

`randn`, `randperm`, `sprand`, `sprandn`

Purpose

Normally distributed random numbers and arrays

Syntax

```
Y = randn(n)
Y = randn(m,n)
Y = randn([m n])
Y = randn(m,n,p,...)
Y = randn([m n p...])
Y = randn(size(A))
randn
s = randn('state')
```

Description

The randn function generates arrays of random numbers whose elements are normally distributed with mean 0 and variance 1.

`Y = randn(n)` returns an n-by-n matrix of random entries. An error message appears if n is not a scalar.

`Y = randn(m,n)` or `Y = randn([m n])` returns an m-by-n matrix of random entries.

`Y = randn(m,n,p,...)` or `Y = randn([m n p...])` generates random arrays.

`Y = randn(size(A))` returns an array of random entries that is the same size as A.

randn, by itself, returns a scalar whose value changes each time it's referenced.

`s = randn('state')` returns a 2-element vector containing the current state of the normal generator. To change the state of the generator:

`randn('state',s)`	Resets the state to s.
`randn('state',0)`	Resets the generator to its initial state.
`randn('state',j)`	For integer j, resets the generator to its jth state.
`randn('state',sum(100*clock))`	Resets it to a different state each time.

Remarks

MATLAB 5 uses a new multiseed random number generator that can generate all the floating-point numbers in the closed interval $[2^{-53}, 1 - 2^{-53}]$. Theoretically, it can generate over 2^{1492} values before repeating itself. MATLAB 4 used random number generators with a single seed.
`randn('seed',0)`and `randn('seed',j)` use the MATLAB 4 generator.
`randn('seed')` returns the current seed of the MATLAB 4 normal generator.
`randn('state',j)` and `randn('state',s)` use the MATLAB 5 generator.

Examples

`R = randn(3,4)` may produce

```
R =
   1.1650    0.3516    0.0591    0.8717
   0.6268   -0.6965    1.7971   -1.4462
   0.0751    1.6961    0.2641   -0.7012
```

For a histogram of the `randn` distribution, see `hist`.

See Also

`rand`, `randperm`, `sprand`, `sprandn`

Purpose Random permutation

Syntax

```
p = randperm(n)
```

Description `p = randperm(n)` returns a random permutation of the integers `1:n`.

Remarks The `randperm` function calls `rand` and therefore changes `rand`'s seed value.

Examples `randperm(6)` might be the vector

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

or it might be some other permutation of `1:6`.

See Also `permute`

Purpose

Rank of a matrix

Syntax

```
k = rank(A)
k = rank(A,tol)
```

Description

The `rank` function provides an estimate of the number of linearly independent rows or columns of a matrix.

`k = rank(A)` returns the number of singular values of `A` that are larger than the default tolerance, `max(size(A))*norm(A)*eps`.

`k = rank(A,tol)` returns the number of singular values of `A` that are larger than `tol`.

Algorithm

There are a number of ways to compute the rank of a matrix. MATLAB uses the method based on the singular value decomposition, or SVD, described in Chapter 11 of the *LINPACK Users' Guide*. The SVD algorithm is the most time consuming, but also the most reliable.

The `rank` algorithm is

```
s = svd(A);
tol = max(size(A))*s(1)*eps;
r = sum(s > tol);
```

References

[1] Dongarra, J.J., J.R. Bunch, C.B. Moler, and G.W. Stewart, *LINPACK Users' Guide*, SIAM, Philadelphia, 1979.

Purpose

Rational fraction approximation

Syntax

```
[N,D] = rat(X)
[N,D] = rat(X,tol)
rat(...)
S = rats(X,strlen)
S = rats(X)
```

Description

Even though all floating-point numbers are rational numbers, it is sometimes desirable to approximate them by simple rational numbers, which are fractions whose numerator and denominator are small integers. The `rat` function attempts to do this. Rational approximations are generated by truncating continued fraction expansions. The `rats` function calls `rat`, and returns strings.

`[N,D] = rat(X)` returns arrays `N` and `D` so that `N./D` approximates `X` to within the default tolerance, `1.e-6*norm(X(:),1)`.

`[N,D] = rat(X,tol)` returns `N./D` approximating `X` to within `tol`.

`rat(X)`, with no output arguments, simply displays the continued fraction.

`S = rats(X,strlen)` returns a string containing simple rational approximations to the elements of `X`. Asterisks are used for elements that cannot be printed in the allotted space, but are not negligible compared to the other elements in `X`. `strlen` is the length of each string element returned by the `rats` function. The default is `strlen = 13`, which allows 6 elements in 78 spaces.

`S = rats(X)` returns the same results as those printed by MATLAB with `format rat`.

Examples

Ordinarily, the statement

```
s = 1 - 1/2 + 1/3 - 1/4 + 1/5 - 1/6 + 1/7
```

produces

```
s =
   0.7595
```

However, with

```
format rat
```

or with

```
rats(s)
```

the printed result is

```
s =
   319/420
```

This is a simple rational number. Its denominator is 420, the least common multiple of the denominators of the terms involved in the original expression. Even though the quantity `s` is stored internally as a binary floating-point number, the desired rational form can be reconstructed.

To see how the rational approximation is generated, the statement `rat(s)`

produces

```
1 + 1/(-4 + 1/(-6 + 1/(-3 + 1/(-5))))
```

And the statement

```
[n,d] = rat(s)
```

produces

```
n = 319, d = 420
```

The mathematical quantity π is certainly not a rational number, but the MATLAB quantity `pi` that approximates it is a rational number. With IEEE floating-point arithmetic, `pi` is the ratio of a large integer and 2^{52}:

```
14148475504056880/4503599627370496
```

However, this is not a simple rational number. The value printed for `pi` with `format rat`, or with `rats(pi)`, is

```
355/113
```

This approximation was known in Euclid's time. Its decimal representation is

```
3.14159292035398
```

and so it agrees with `pi` to seven significant figures. The statement

```
rat(pi)
```

produces

```
3 + 1/(7 + 1/(16))
```

This shows how the `355/113` was obtained. The less accurate, but more familiar approximation `22/7` is obtained from the first two terms of this continued fraction.

Algorithm

The `rat(X)` function approximates each element of `X` by a continued fraction of the form:

$$\frac{n}{d} = d_1 + \cfrac{1}{d_2 + \cfrac{1}{\left(d_3 + \ldots + \cfrac{1}{d_k}\right)}}$$

The *d*'s are obtained by repeatedly picking off the integer part and then taking the reciprocal of the fractional part. The accuracy of the approximation increases exponentially with the number of terms and is worst when `X = sqrt(2)`. For `x = sqrt(2)`, the error with `k` terms is about `2.68*(.173)^k`, so each additional term increases the accuracy by less than one decimal digit. It takes 21 terms to get full floating-point accuracy.

See Also

`format`

rcond

Purpose Matrix reciprocal condition number estimate

Syntax

```
c = rcond(A)
```

Description **`c = rcond(A)`** returns an estimate for the reciprocal of the condition of `A` in 1-norm using the LINPACK condition estimator. If `A` is well conditioned, `rcond(A)` is near 1.0. If `A` is badly conditioned, `rcond(A)` is near 0.0. Compared to `cond`, `rcond` is a more efficient, but less reliable, method of estimating the condition of a matrix.

Algorithm The `rcond` function uses the condition estimator from the LINPACK routine `ZGECO`.

See Also `cond`, `condest`, `norm`, `normest`, `rank`, `svd`

References [1] Dongarra, J.J., J.R. Bunch, C.B. Moler, and G.W. Stewart, *LINPACK Users' Guide*, SIAM, Philadelphia, 1979.

Purpose Real part of complex number

Syntax `X = real(Z)`

Description `X = real(Z)` returns the real part of the elements of the complex array `Z`.

Examples `real(2+3*i)` is 2.

See Also `abs`, `angle`, `conj`, `i`, `j`, `imag`

realmax

Purpose

Largest positive floating-point number

Syntax

```
n = realmax
```

Description

`n = realmax` returns the largest floating-point number representable on a particular computer. Anything larger overflows.

Examples

On machines with IEEE floating-point format, `realmax` is one bit less than 2^{1024} or about `1.7977e+308`.

Algorithm

The `realmax` function is equivalent to `pow2(2-eps,maxexp)`, where `maxexp` is the largest possible floating-point exponent.

Execute `type realmax` to see `maxexp` for various computers.

See Also

`eps`, `realmin`

Purpose

Smallest positive floating-point number

Syntax

```
n = realmin
```

Description

`n = realmin` returns the smallest positive normalized floating-point number on a particular computer. Anything smaller underflows or is an IEEE "denormal."

Examples

On machines with IEEE floating-point format, `realmin` is `2^(-1022)` or about `2.2251e-308`.

Algorithm

The `realmin` function is equivalent to `pow2(1,minexp)` where `minexp` is the smallest possible floating-point exponent.

Execute `type realmin` to see `minexp` for various computers.

See Also

`eps`, `realmax`

rem

Purpose

Remainder after division

Syntax

```
R = rem(X,Y)
```

Description

`R = rem(X,Y)` returns `X - fix(X./Y).*Y`, where `fix(X./Y)` is the integer part of the quotient, `X./Y`.

Remarks

So long as operands `X` and `Y` are of the same sign, the statement `rem(X,Y)` returns the same result as does `mod(X,Y)`. However, for positive `X` and `Y`,

```
rem(-x,y) = mod(-x,y)-y
```

The `rem` function returns a result that is between 0 and `sign(X)*abs(Y)`. If `Y` is zero, `rem` returns `NaN`.

Limitations

Arguments `X` and `Y` should be integers. Due to the inexact representation of floating-point numbers on a computer, real (or complex) inputs may lead to unexpected results.

See Also

`mod`

Purpose

Replicate and tile an array

Syntax

```
B = repmat(A,m,n)
B = repmat(A,[m n])
B = repmat(A,[m n p...])
repmat(A,m,n)
```

Description

`B = repmat(A,m,n)` creates a large matrix `B` consisting of an `m`-by-`n` tiling of copies of `A`. The statement `repmat(A,n)` creates an `n`-by-`n` tiling.

`B = repmat(A,[m n])` accomplishes the same result as `repmat(A,m,n)`.

`B = repmat(A,[m n p...])` produces a multidimensional (`m`-by-`n`-by-`p`-by-...) array composed of copies of `A`. `A` may be multidimensional.

`repmat(A,m,n)` when `A` is a scalar, produces an `m`-by-`n` matrix filled with `A`'s value. This can be much faster than `a*ones(m,n)` when `m` or `n` is large.

Examples

In this example, `repmat` replicates 12 copies of the second-order identity matrix, resulting in a "checkerboard" pattern.

```
B = repmat(eye(2),3,4)

B =
     1     0     1     0     1     0     1     0
     0     1     0     1     0     1     0     1
     1     0     1     0     1     0     1     0
     0     1     0     1     0     1     0     1
     1     0     1     0     1     0     1     0
     0     1     0     1     0     1     0     1
```

The statement `N = repmat(NaN,[2 3])` creates a 2-by-3 matrix of `NaN`s.

reshape

Purpose

Reshape array

Syntax

```
B = reshape(A,m,n)
B = reshape(A,m,n,p,...)
B = reshape(A,[m n p...])
B = reshape(A,siz)
```

Description

`B = reshape(A,m,n)` returns the `m`-by-`n` matrix `B` whose elements are taken column-wise from `A`. An error results if `A` does not have `m*n` elements.

`B = reshape(A,m,n,p,...)` or `B = reshape(A,[m n p...])` returns an N-D array with the same elements as `X` but reshaped to have the size `m`-by-`n`-by-`p`-by-... . `m*n*p*...` must be the same as `prod(size(x))`.

`B = reshape(A,siz)` returns an N-D array with the same elements as `A`, but reshaped to `siz`, a vector representing the dimensions of the reshaped array. The quantity `prod(siz)` must be the same as `prod(size(A))`.

Examples

Reshape a 3-by-4 matrix into a 2-by-6 matrix:

```
A =
    1    4    7    10
    2    5    8    11
    3    6    9    12

B = reshape(A,2,6)

B =
    1    3    5    7    9   11
    2    4    6    8   10   12
```

See Also

`shiftdim`, `squeeze`

The colon operator `:`

Purpose

Convert between partial fraction expansion and polynomial coefficients

Syntax

```
[r,p,k] = residue(b,a)
[b,a] = residue(r,p,k)
```

Description

The `residue` function converts a quotient of polynomials to pole-residue representation, and back again.

`[r,p,k] = residue(b,a)` finds the residues, poles, and direct term of a partial fraction expansion of the ratio of two polynomials, *b(s)* and *a(s)*, of the form:

$$\frac{b(s)}{a(s)} = \frac{b_1 + b_2 s^{-1} + b_3 s^{-2} + \ldots + b_{m+1} s^{-m}}{a_1 + a_2 s^{-1} + a_3 s^{-2} + \ldots + a_{n+1} s^{-n}}$$

`[b,a] = residue(r,p,k)` converts the partial fraction expansion back to the polynomials with coefficients in `b` and `a`.

Definition

If there are no multiple roots, then:

$$\frac{b(s)}{a(s)} = \frac{r_1}{s - p_1} + \frac{r_2}{s - p_2} + \ldots + \frac{r_n}{s - p_n} + k(s)$$

The number of poles `n` is

```
n = length(a)-1 = length(r) = length(p)
```

The direct term coefficient vector is empty if `length(b) < length(a)`; otherwise

```
length(k) = length(b)-length(a)+1
```

If `p(j) = ... = p(j+m-1)` is a pole of multiplicity `m`, then the expansion includes terms of the form

$$\frac{r_j}{s - p_j} + \frac{r_{j+1}}{(s - p_j)^2} + \ldots + \frac{r_{j+m-1}}{(s - p_j)^m}$$

Arguments

`b,a`	Vectors that specify the coefficients of the polynomials in descending powers of *s*
`r`	Column vector of residues
`p`	Column vector of poles
`k`	Row vector of direct terms

Algorithm

The `residue` function is an M-file. It first obtains the poles with `roots`. Next, if the fraction is nonproper, the direct term `k` is found using `deconv`, which performs polynomial long division. Finally, the residues are determined by evaluating the polynomial with individual roots removed. For repeated roots, the M-file `resi2` computes the residues at the repeated root locations.

Limitations

Numerically, the partial fraction expansion of a ratio of polynomials represents an ill-posed problem. If the denominator polynomial, *a(s)*, is near a polynomial with multiple roots, then small changes in the data, including roundoff errors, can make arbitrarily large changes in the resulting poles and residues. Problem formulations making use of state-space or zero-pole representations are preferable.

See Also

`deconv`, `poly`, `roots`

References

[1] Oppenheim, A.V. and R.W. Schafer, *Digital Signal Processing*, Prentice-Hall, 1975, p. 56.

Purpose

Return to the invoking function

Syntax

```
return
```

Description

`return` causes a normal return to the invoking function or to the keyboard. It also terminates keyboard mode.

Examples

If the determinant function were an M-file, it might use a `return` statement in handling the special case of an empty matrix as follows:

```
function d = det(A)
%DET det(A) is the determinant of A.
if isempty(A)
    d = 1;
    return
else
    ...
end
```

See Also

`break`, `disp`, `end`, `error`, `for`, `if`, `keyboard`, `switch`, `while`

rmfield

Purpose

Remove structure fields

Syntax

```
s = rmfield(s,'field')
s = rmfield(s,FIELDS)
```

Description

`s = rmfield(s,'field')` removes the specified field from the structure array `s`.

`s = rmfield(s,FIELDS)` removes more than one field at a time when `FIELDS` is a character array of field names or cell array of strings.

See Also

`getfield`, `setfield`, `strvcat`

Purpose

Remove directories from MATLAB's search path

Syntax

```
rmpath directory
```

Description

`rmpath directory` removes the specified directory from MATLAB's current search path.

The function syntax form is also acceptable

```
rmpath('directory')
```

Examples

```
rmpath /usr/local/matlab/mytools
```

See Also

`addpath`, `path`

roots

Purpose

Polynomial roots

Syntax

```
r = roots(c)
```

Description

`r = roots(c)` returns a column vector whose elements are the roots of the polynomial `c`.

Row vector `c` contains the coefficients of a polynomial, ordered in descending powers. If `c` has `n+1` components, the polynomial it represents is $c_1 s^n + \ldots + c_n s + c_{n+1}$.

Remarks

Note the relationship of this function to `p = poly(r)`, which returns a row vector whose elements are the coefficients of the polynomial. For vectors, `roots` and `poly` are inverse functions of each other, up to ordering, scaling, and roundoff error.

Examples

The polynomial $s^3 - 6s^2 - 72s - 27$ is represented in MATLAB as

```
p = [1 -6 -72 -27]
```

The roots of this polynomial are returned in a column vector by

```
r = roots(p)
r =
    12.1229
    -5.7345
    -0.3884
```

Algorithm

The algorithm simply involves computing the eigenvalues of the companion matrix:

```
A = diag(ones(n-2,1),-1);
A(1,:) = -c(2:n-1)./c(1);
eig(A)
```

It is possible to prove that the results produced are the exact eigenvalues of a matrix within roundoff error of the companion matrix `A`, but this does not mean that they are the exact roots of a polynomial with coefficients within roundoff error of those in `c`.

See Also `fzero`, `poly`, `residue`

rot90

Purpose

Rotate matrix 90˚

Syntax

```
B = rot90(A)
B = rot90(A,k)
```

Description

`B = rot90(A)` rotates matrix `A` counterclockwise by 90 degrees.

`B = rot90(A,k)` rotates matrix `A` counterclockwise by `k*90` degrees, where `k` is an integer.

Examples

The matrix

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

rotated by 90 degrees is

```
Y = rot90(X)
Y =
     3     6     9
     2     5     8
     1     4     7
```

See Also

`flipdim`, `fliplr`, `flipud`

Purpose

Round to nearest integer

Syntax

```
Y = round(X)
```

Description

`Y = round(X)` rounds the elements of `X` to the nearest integers. For complex `X`, the imaginary and real parts are rounded independently.

Examples

```
a =
  Columns 1 through 4
  -1.9000           -0.2000            3.4000            5.6000
  Columns 5 through 6
   7.0000             2.4000 + 3.6000i

round(a)

ans =
  Columns 1 through 4
  -2.0000                 0            3.0000            6.0000
  Columns 5 through 6
   7.0000             2.0000 + 4.0000i
```

See Also

`ceil`, `fix`, `floor`

rref, rrefmovie

Purpose

Reduced row echelon form

Syntax

```
R = rref(A)
[R,jb] = rref(A)
[R,jb] = rref(A,tol)
rrefmovie(A)
```

Description

`R = rref(A)` produces the reduced row echelon form of `A` using Gauss Jordan elimination with partial pivoting. A default tolerance of `(max(size(A))*eps *norm(A,inf))` tests for negligible column elements.

`[R,jb] = rref(A)` also returns a vector `jb` so that:

- `r = length(jb)` is this algorithm's idea of the rank of `A`,
- `x(jb)` are the bound variables in a linear system `Ax = b`,
- `A(:,jb)` is a basis for the range of `A`,
- `R(1:r,jb)` is the `r`-by-`r` identity matrix.

`[R,jb] = rref(A,tol)` uses the given tolerance in the rank tests.

Roundoff errors may cause this algorithm to compute a different value for the rank than `rank`, `orth` and `null`.

`rrefmovie(A)` shows a movie of the algorithm working.

Examples

Use `rref` on a rank-deficient magic square:

```
A = magic(4), R = rref(A)
A =
   16    2    3   13
    5   11   10    8
    9    7    6   12
    4   14   15    1
R =
    1    0    0    1
    0    1    0    3
    0    0    1   -3
    0    0    0    0
```

See Also `inv`, `lu`, `rank`

rsf2csf

Purpose

Convert real Schur form to complex Schur form

Syntax

```
[U,T] = rsf2csf(U,T)
```

Description

The *complex Schur form* of a matrix is upper triangular with the eigenvalues of the matrix on the diagonal. The *real Schur form* has the real eigenvalues on the diagonal and the complex eigenvalues in 2-by-2 blocks on the diagonal.

`[U,T] = rsf2csf(U,T)` converts the real Schur form to the complex form.

Arguments `U` and `T` represent the unitary and Schur forms of a matrix `A`, respectively, that satisfy the relationships: `A = U*T*U'` and `U'*U = eye(size(A))`. See `schur` for details.

Examples

Given matrix `A`,

```
 1     1     1     3
 1     2     1     1
 1     1     3     1
-2     1     1     4
```

with the eigenvalues

```
1.9202 - 1.4742i   1.9202 + 1.4742i   4.8121    1.3474
```

Generating the Schur form of `A` and converting to the complex Schur form

```
[u,t] = schur(A);
[U,T] = rsf2csf(u,t)
```

yields a triangular matrix `T` whose diagonal consists of the eigenvalues of `A`.

```
U =

-0.4576 + 0.3044i   0.5802 - 0.4934i   -0.0197   -0.3428
 0.1616 + 0.3556i   0.4235 + 0.0051i    0.1666    0.8001
 0.3963 + 0.2333i   0.1718 + 0.2458i    0.7191   -0.4260
-0.4759 - 0.3278i  -0.2709 - 0.2778i    0.6743    0.2466
```

```
T =
1.9202 + 1.4742i   0.7691 - 1.0772i  -1.5895 - 0.9940i  -1.3798 + 0.1864i
0                  1.9202 - 1.4742i   1.9296 + 1.6909i   0.2511 + 1.0844i
0                  0                  4.8121             1.1314
0                  0                  0                  1.3474
```

See Also

schur

save

Purpose

Save workspace variables on disk

Syntax

```
save
save filename
save filename variables
save filename options
save filename variables options
```

Description

save stores all workspace variables in a binary format in the file named matlab.mat. The data can be retrieved with load.

save filename stores all workspace variables in filename.mat instead of the default matlab.mat. If filename is the special string stdio, the save command sends the data as standard output.

save filename variables saves only the workspace variables you list after the filename. For example, save myfile x y z saves only the variables x, y, and z to myfile.mat.

The function form of the syntax, save('filename'), is also permitted. So, for example, to save variables x and y to the filename myfile, use

```
save ('myfile', 'x', 'y')
```

These forms of the save command use options:

```
save filename options
```

```
save filename variables options
```

Valid option combinations are shown in the table below.

With these options:	Data is:
-ascii	stored in 8-digit ASCII format
-ascii -double	stored in 16-digit ASCII format
-ascii -tabs	stored in 8-digit ASCII format, tab-separated

With these options:	Data is:
`-ascii -double -tabs`	stored in 16-digit ASCII format, tab-separated
`-V4`	stored in a format that MATLAB version 4 can load
`-append`	added to an existing specified MAT-file

Limitations

Saving complex data with the `-ascii` option causes the imaginary part of the data to be lost, as MATLAB cannot load nonnumeric data (`'i'`).

Remarks

The `save` and `load` commands retrieve and store MATLAB variables on disk. They can also import and export numeric matrices as ASCII data files.

MAT-files are double-precision binary MATLAB format files created by the `save` command and readable by the `load` command. They can be created on one machine and later read by MATLAB on another machine with a different floating-point format, retaining as much accuracy and range as the disparate formats allow. They can also be manipulated by other programs, external to MATLAB.

Notes on Options

Variables saved in ASCII format merge into a single variable that takes the name of the ASCII file. Therefore, loading the file `filename` shown above results in a single workspace variable named `filename`. Use the colon operator to access individual variables.

If you save MATLAB version 5 data with the `-V4` option, you must use a filename that MATLAB version 4 supports. In addition, you can only save data constructs that are compatible with MATLAB version 4; therefore, you cannot save structures, cell arrays, multidimensional arrays, or objects.

Algorithm

The binary formats used by `save` depend on the size and type of each array. Arrays with any noninteger entries and arrays with 10,000 or fewer elements are saved in floating-point formats requiring eight bytes per real element.

Arrays with all integer entries and more than 10,000 elements are saved in the formats shown, requiring fewer bytes per element.

Element Range	Bytes per Element
0 to 255	1
0 to 65535	2
–32767 to 32767	2
$-2^{31}+1$ to $2^{31}-1$	4
other	8

The Application Program Interface Libraries contain C and Fortran routines to read and write MAT-files from external programs. It is important to use recommended access methods, rather than rely upon the specific file format, which is likely to change in the future.

See Also

`fprintf`, `fwrite`, `load`, `quit`

Purpose

Save figure or model using specified format

Syntax

```
saveas(h,'filename.ext')
saveas(h,'filename','format')
```

Description

`saveas(h,'filename.ext')` saves the figure or model with the handle `h` to the file `filename.ext`. The format of the file is determined by the extension, `ext`. Allowable values for `ext` are listed in this table.

ext Values	Format
`ai`	Adobe Illustrator '88
`bmp`	Windows bitmap
`emf`	Enhanced metafile
`eps`	EPS Level 1
`fig`	MATLAB figure (invalid for MATLAB models)
`jpg`	JPEG image (invalid for MATLAB models)
`m`	MATLAB M-file (invalid for MATLAB models)
`pbm`	Portable bitmap
`pcx`	Paintbrush 24-bit
`pgm`	Portable Graymap
`png`	Portable Network Graphics
`ppm`	Portable Pixmap
`tif`	TIFF image, compressed

`saveas(h,'filename','format')` saves the figure or model with the handle `h` to the file called `filename` using the specified `format`. The filename can have an extension but the extension is not used to define the file format. If no extension is specified, the standard extension corresponding to the specified format is automatically appended to the filename.

Allowable values for `format` are the extensions in the table above and the device types supported by `print`. The `print` device types include the formats listed in the table of extensions above as well as additional file formats. Use an extension from the table above or from the list of device types supported by `print`. When using the `print` device type to specify `format` for `saveas`, do not use the prepended `-d`.

Remarks

You can use `open` to open files saved using `saveas` with an `m` or `fig` extension. Other formats are not supported by `open`. The **Save As** dialog box you access from the figure window's **File** menu uses `saveas`, limiting the file extensions to `m` and `fig`. The **Export** dialog box you access from the figure window's **File** menu uses `saveas` with the `format` argument.

Examples

Example 1 – Specify File Extension

Save the current figure that you annotated using the Plot Editor to a file named `pred_prey` using the MATLAB `fig` format. This allows you to open the file `pred_prey.fig` at a later time and continue editing it with the Plot Editor.

```
saveas(gcf,'pred_prey.fig')
```

Example 2 – Specify File Format but No Extension

Save the current figure, using Adobe Illustrator format, to the file `logo`. Use the `ai` extension from the above table to specify the format. The file created is `logo.ai`.

```
saveas(gcf,'logo', 'ai')
```

This is the same as using the Adobe Illustrator format from the print devices table, which is `-dill`; use `doc print` or `help print` to see the table for print device types. The file created is `logo.ai`. MATLAB automatically appends the `ai` extension, for an Illustrator format file, because no extension was specified.

```
saveas(gcf,'logo', 'ill')
```

Example 3 – Specify File Format and Extension

Save the current figure to the file `star.eps` using the Level 2 Color PostScript format. If you use `doc print` or `help print`, you can see from the table for print

device types that the device type for this format is `-dpsc2`. The file created is `star.eps`.

```
saveas(gcf,'star.eps', 'psc2')
```

In another example, save the current model to the file `trans.tiff` using the TIFF format with no compression. From the table for print device types, you can see the device type for this format is `-dtiffn`. The file created is `trans.tiff`.

```
saveas(gcf,'trans.tiff', 'tiffn')
```

See Also

`open`, `print`

saveobj

Purpose

User-defined extension of the save function for user objects

Syntax

```
b = saveobj(a)
```

Description

`b = saveobj(a)` extends the save function for user objects. When an object is saved to a MAT file, the save function calls the `saveobj` method for the object's class if it is defined. The `saveobj` method must have the calling sequence shown; the input argument `a` is the object in the workspace and the output argument `b` is the object that the save function saves to the MAT file.

These steps describe how an object is saved from the workspace to a MAT file:

1. The save function detects the object `a` in the workspace.
2. If there is no `saveobj` method defined for the object's class, the object `a` is saved directly to the MAT file.
3. If there is a `saveobj` method defined for the object's class, the save function calls the method passing the workspace object `a` as an input argument. The save function saves the return object, `b`, to the MAT file.

Remarks

`saveobj` can be overloaded only for user objects. `save` will not call `saveobj` for built-in datatypes (such as `double`).

`saveobj` is invoked separately for each object in the MAT file. The save function recursively descends cell arrays and structures applying the `saveobj` method to each object encountered.

See Also

`load`, `loadobj`, `save`

Purpose

Schur decomposition

Syntax

```
[U,T] = schur(A)
T = schur(A)
```

Description

The schur command computes the Schur form of a matrix.

`[U,T] = schur(A)` produces a Schur matrix `T`, and a unitary matrix `U` so that `A = U*T*U'` and `U'*U = eye(size(A))`. `A` must be square.

`T = schur(A)` returns just the Schur matrix `T`.

Remarks

The *complex Schur form* of a matrix is upper triangular with the eigenvalues of the matrix on the diagonal. The *real Schur form* has the real eigenvalues on the diagonal and the complex eigenvalues in 2-by-2 blocks on the diagonal.

If the matrix `A` is real, `schur` returns the real Schur form. If `A` is complex, `schur` returns the complex Schur form. The function `rsf2csf` converts the real form to the complex form.

Examples

`H` is a 3-by-3 eigenvalue test matrix:

```
H =
   -149    -50   -154
    537    180    546
    -27     -9    -25
```

Its Schur form is

```
schur(H) =
   1.0000    7.1119   815.8706
        0    2.0000   -55.0236
        0         0     3.0000
```

The eigenvalues, which in this case are `1`, `2`, and `3`, are on the diagonal. The fact that the off-diagonal elements are so large indicates that this matrix has poorly conditioned eigenvalues; small changes in the matrix elements produce relatively large changes in its eigenvalues.

Algorithm

For real matrices, `schur` uses the EISPACK routines `ORTRAN`, `ORTHES`, and `HQR2`. `ORTHES` converts a real general matrix to Hessenberg form using orthogonal

similarity transformations. ORTRAN accumulates the transformations used by ORTHES. HQR2 finds the eigenvalues of a real upper Hessenberg matrix by the QR method.

The EISPACK subroutine HQR2 has been modified to allow access to the Schur form, ordinarily just an intermediate result, and to make the computation of eigenvectors optional.

When schur is used with a complex argument, the solution is computed using the QZ algorithm by the EISPACK routines QZHES, QZIT, QZVAL, and QZVEC. They have been modified for complex problems and to handle the special case $B = I$.

For detailed descriptions of these algorithms, see the *EISPACK Guide*.

See Also

eig, hess, qz, rsf2csf

References

[1] Garbow, B. S., J. M. Boyle, J. J. Dongarra, and C. B. Moler, *Matrix Eigensystem Routines – EISPACK Guide Extension*, Lecture Notes in Computer Science, Vol. 51, Springer-Verlag, 1977.

[2] Moler, C.B. and G. W. Stewart, "An Algorithm for Generalized Matrix Eigenvalue Problems," *SIAM J. Numer. Anal.*, Vol. 10, No. 2, April 1973.

[3] Smith, B. T., J. M. Boyle, J. J. Dongarra, B. S. Garbow, Y. Ikebe, V. C. Klema, and C. B. Moler, *Matrix Eigensystem Routines – EISPACK Guide*, Lecture Notes in Computer Science, Vol. 6, second edition, Springer-Verlag, 1976.

Purpose

Script M-files

Description

A script file is an external file that contains a sequence of MATLAB statements. By typing the filename, subsequent MATLAB input is obtained from the file. Script files have a filename extension of `.m` and are often called M-files.

Scripts are the simplest kind of M-file. They are useful for automating blocks of MATLAB commands, such as computations you have to perform repeatedly from the command line. Scripts can operate on existing data in the workspace, or they can create new data on which to operate. Although scripts do not return output arguments, any variables that they create remain in the workspace so you can use them in further computations. In addition, scripts can produce graphical output using commands like `plot`.

Scripts can contain any series of MATLAB statements. They require no declarations or begin/end delimiters.

Like any M-file, scripts can contain comments. Any text following a percent sign (%) on a given line is comment text. Comments can appear on lines by themselves, or you can append them to the end of any executable line.

See Also

`echo`, `function`, `type`

sec, sech

Purpose

Secant and hyperbolic secant

Syntax

```
Y = sec(X)
Y = sech(X)
```

Description

The sec and sech commands operate element-wise on arrays. The functions' domains and ranges include complex values. All angles are in radians.

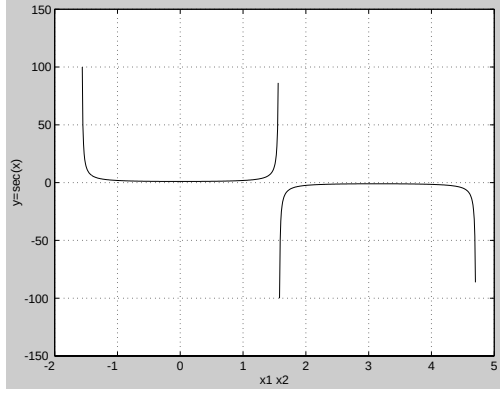
`Y = sec(X)` returns an array the same size as `X` containing the secant of the elements of `X`.

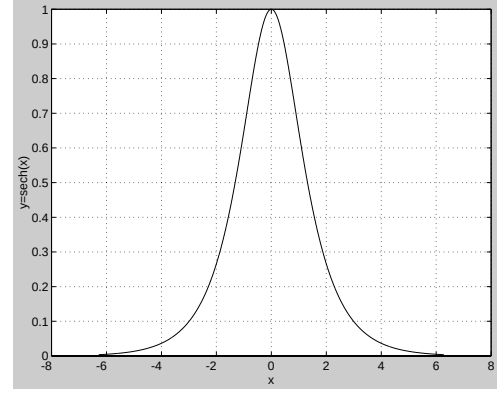
`Y = sech(X)` returns an array the same size as `X` containing the hyperbolic secant of the elements of `X`.

Examples

Graph the secant over the domains $-\pi/2 < x < \pi/2$ and $\pi/2 < x < 3\pi/2$, and the hyperbolic secant over the domain $-2\pi \le x \le 2\pi$.

```
x1 = -pi/2+0.01:0.01:pi/2-0.01;
x2 = pi/2+0.01:0.01:(3*pi/2)-0.01;
plot(x1,sec(x1),x2,sec(x2))
x = -2*pi:0.01:2*pi; plot(x,sech(x))
```





The expression `sec(pi/2)` does not evaluate as infinite but as the reciprocal of the floating-point accuracy `eps`, because `pi` is a floating-point approximation to the exact value of π.

Algorithm

$$\sec(z) = \frac{1}{\cos(z)} \qquad \operatorname{sech}(z) = \frac{1}{\cosh(z)}$$

See Also

asec, asech

setdiff

Purpose

Return the set difference of two vectors

Syntax

```
c = setdiff(a,b)
c = setdiff(A,B,'rows')
[c,i] = setdiff(...)
```

Description

`c = setdiff(a,b)` returns the values in `a` that are not in `b`. The resulting vector is sorted is ascending order. In set theoretic terms, `c = a - b`. `a` and `b` can be cell arrays of strings.

`c = (A,B,'rows')` when `A` and `B` are matrices with the same number of columns returns the rows from `A` that are not in `B`.

`[c,i] = setdiff(...)` also returns an index vector `index` such that `c = a(i)` or `c = a(i,:)`.

Examples

```
A = magic(5);
B = magic(4);
[c,i] = setdiff(A,B);
c' =    17    18    19    20    21    22    23    24    25
i' =     1    10    14    18    19    23     2     6    15
```

See Also

`intersect`, `ismember`, `setxor`, `union`, `unique`

Purpose

Set field of structure array

Syntax

```
s = setfield(s,'field',v)
s = setfield(s,{i,j},'field',{k},v)
```

Description

`s = setfield(s,'field',v)`, where `s` is a 1-by-1 structure, sets the contents of the specified field to the value `v`. This is equivalent to the syntax `s.field = v`.

`s = setfield(s,{i,j},'field',{k},v)` sets the contents of the specified field to the value `v`. This is equivalent to the syntax `s(i,j).field(k) = v`. All subscripts must be passed as cell arrays—that is, they must be enclosed in curly braces (similar to`{i,j}` and `{k}` above). Pass field references as strings.

Examples

Given the structure:

```
mystr(1,1).name = 'alice';
mystr(1,1).ID = 0;
mystr(2,1).name = 'gertrude';
mystr(2,1).ID = 1
```

Then the command `mystr = setfield(mystr,{2,1},'name','ted')` yields

```
mystr =

2x1 struct array with fields:
    name
    ID
```

See Also

`getfield`

setstr

Purpose Set string flag

Description This MATLAB 4 function has been renamed `char` in MATLAB 5.

See Also `char`

Purpose

Set exclusive-or of two vectors

Syntax

```
c = setxor(a,b)
c = setxor(A,B,'rows')
[c,ia,ib] = setxor(...)
```

Description

`c = setxor(a,b)` returns the values that are not in the intersection of `a` and `b`. The resulting vector is sorted. `a` and `b` can be cell arrays of strings.

`c = setxor(A,B,'rows')` when `A` and `B` are matrices with the same number of columns returns the rows that are not in the intersection of `A` and `B`.

`[c,ia,ib] = setxor(...)` also returns index vectors `ia` and `ib` such that `c` is a sorted combination of the elements `c = a(ia)` and `c = b(ib)` or, for row combinations, `c = a(ia,:)` and `c = b(ib,:)`.

Examples

```
a = [-1 0 1 Inf -Inf NaN];
b = [-2 pi 0 Inf];
c = setxor(a,b)

c =
      -Inf   -2.0000   -1.0000    1.0000    3.1416       NaN
```

See Also

`intersect`, `ismember`, `setdiff`, `union`, `unique`

shiftdim

Purpose

Shift dimensions

Syntax

```
B = shiftdim(X,n)
[B,nshifts] = shiftdim(X)
```

Description

`B = shiftdim(X,n)` shifts the dimensions of `X` by `n`. When `n` is positive, `shiftdim` shifts the dimensions to the left and wraps the `n` leading dimensions to the end. When `n` is negative, `shiftdim` shifts the dimensions to the right and pads with singletons.

`[B,nshifts] = shiftdim(X)` returns the array `B` with the same number of elements as `X` but with any leading singleton dimensions removed. A singleton dimension is any dimension for which `size(A,dim) = 1`. `nshifts` is the number of dimensions that are removed.

If `X` is a scalar, `shiftdim` has no effect.

Examples

The `shiftdim` command is handy for creating functions that, like `sum` or `diff`, work along the first nonsingleton dimension.

```
a = rand(1,1,3,1,2);
[b,n]  = shiftdim(a); % b is 3-by-1-by-2 and n is 2.
c = shiftdim(b,-n);   % c == a.
d = shiftdim(a,3);    % d is 1-by-2-by-1-by-1-by-3.
```

See Also

`reshape`, `squeeze`

Purpose

Signum function

Syntax

```
Y = sign(X)
```

Description

`Y = sign(X)` returns an array `Y` the same size as `X`, where each element of `Y` is:

- `1` if the corresponding element of `X` is greater than zero
- `0` if the corresponding element of `X` equals zero
- `-1` if the corresponding element of `X` is less than zero

For nonzero complex `X`, `sign(X) = X./abs(X)`.

See Also

`abs`, `conj`, `imag`, `real`

sin, sinh

Purpose

Sine and hyperbolic sine

Syntax

```
Y = sin(X)
Y = sinh(X)
```

Description

The `sin` and `sinh` commands operate element-wise on arrays. The functions' domains and ranges include complex values. All angles are in radians.

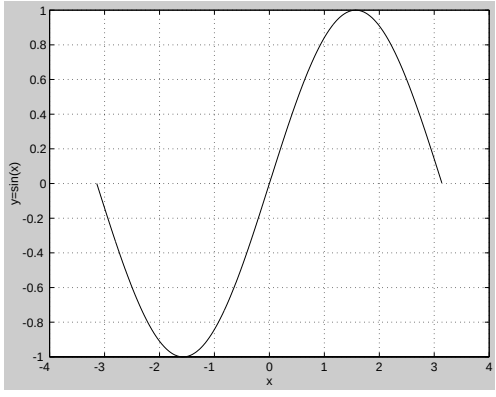
`Y = sin(X)` returns the circular sine of the elements of `X`.

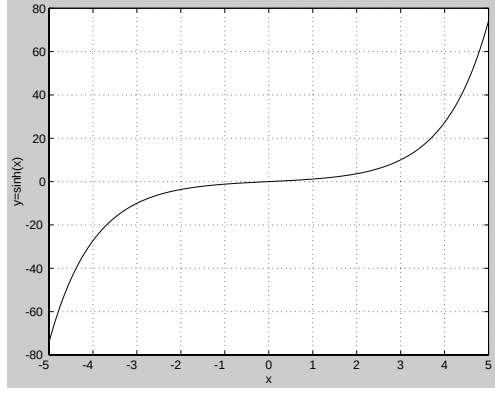
`Y = sinh(X)` returns the hyperbolic sine of the elements of `X`.

Examples

Graph the sine function over the domain $-\pi \le x \le \pi$, and the hyperbolic sine function over the domain $-5 \le x \le 5$.

```
x = -pi:0.01:pi; plot(x,sin(x))
x = -5:0.01:5; plot(x,sinh(x))
```





The expression `sin(pi)` is not exactly zero, but rather a value the size of the floating-point accuracy `eps`, because `pi` is only a floating-point approximation to the exact value of π.

Algorithm

$$\sin(x + iy) = \sin(x)\cos(y) + i\cos(x)\sin(y)$$

$$\sin(z) = \frac{e^{iz} - e^{-iz}}{2i}$$

$$\sinh(z) = \frac{e^{z} - e^{-z}}{2}$$

See Also

`asin`, `asinh`

single

Purpose

Convert to single precision

Syntax

```
Y = single(X)
```

Description

`Y = single(X)` converts the vector `X` to single precision. `X` can be any numeric object (such as a `double`). If `X` is already single precision, `single` has no effect. Single precison quantities require less storage than double precision quantities but have less precision and a smaller range.

The `single` class is primarily meant for storing single-precision values. Most operations that manipulate arrays without changing their elements are defined (e.g., `reshape`, `size`, the relational operators, subscripted assignment and subscripted reference). No math operations are defined for the `single`.

You can define your own methods for the `single` (as you can for any object) by placing the appropriately named method in an `@single` directory within a directory on your path.

See Also

`double`,`int8`,`int16`,`int32`, `uint8`,`uint16`,`uint32`

Purpose

Array dimensions

Syntax

```
d = size(X)
[m,n] = size(X)
m = size(X,dim)
[d1,d2,d3,...,dn] = size(X)
```

Description

`d = size(X)` returns the sizes of each dimension of array `X` in a vector `d` with `ndims(X)` elements.

`[m,n] = size(X)` returns the size of matrix `X` in variables `m` and `n`.

`m = size(X,dim)` returns the size of the dimension of `X` specified by scalar `dim`.

`[d1,d2,d3,...,dn] = size(X)` returns the sizes of the various dimensions of array `X` in separate variables.

If the number of output arguments `n` does not equal `ndims(X)`, then:

If `n > ndims(X)`	Ones are returned in the "extra" variables `dndims(X)+1` through `dn`.
If `n < ndims(X)`	The final variable `dn` contains the product of the sizes of all the "remaining" dimensions of `X`, that is, dimensions `n+1` through `ndims(X)`.

Examples

The size of the second dimension of `rand(2,3,4)` is 3.

```
m = size(rand(2,3,4),2)

m =
     3
```

Here the size is output as a single vector.

```
d = size(rand(2,3,4))

d =
     2     3     4
```

Here the size of each dimension is assigned to a separate variable.

```
[m,n,p] = size(rand(2,3,4))
m =
     2

n =
     3

p =
     4
```

If `X = ones(3,4,5)`, then

```
[d1,d2,d3] = size(X)

d1 =       d2 =    d3 =
   3            4      5
```

but when the number of output variables is less than `ndims(X)`:

```
[d1,d2] = size(X)

d1 =       d2 =
   3            20
```

The “extra” dimensions are collapsed into a single product.

If `n > ndims(X)`, the “extra” variables all represent singleton dimensions:

```
[d1,d2,d3,d4,d5,d6] = size(X)

d1 =       d2 =        d3 =
   3            4          5

d4 =       d5 =        d6 =
    1           1          1
```

See Also `exist`, `length`, `whos`

Purpose

Sort elements in ascending order

Syntax

```
B = sort(A)
[B,INDEX] = sort(A)
B = sort(A,dim)
```

Description

`B = sort(A)` sorts the elements along different dimensions of an array, and arranges those elements in ascending order. a can be a cell array of strings.

Real, complex, and string elements are permitted. For identical values in `A`, the location in the input array determines location in the sorted list. When `A` is complex, the elements are sorted by magnitude, and where magnitudes are equal, further sorted by phase angle on the interval $[-\pi, \pi]$. If `A` includes any `NaN` elements, `sort` places these at the end.

If `A` is a vector, `sort(A)` arranges those elements in ascending order.

If `A` is a matrix, `sort(A)` treats the columns of `A` as vectors, returning sorted columns.

If `A` is a multidimensional array, `sort(A)` treats the values along the first non-singleton dimension as vectors, returning an array of sorted vectors.

`[B,INDEX] = sort(A)` also returns an array of indices. `INDEX` is an array of `size(A)`, each column of which is a permutation vector of the corresponding column of `A`. If `A` has repeated elements of equal value, indices are returned that preserve the original relative ordering.

`B = sort(A,dim)` sorts the elements along the dimension of `A` specified by scalar `dim`.

If `dim` is a vector, `sort` works iteratively on the specified dimensions. Thus, `sort(A,[1 2])` is equivalent to `sort(sort(A,2),1)`.

See Also

`max`, `mean`, `median`, `min`, `sortrows`

sortrows

Purpose

Sort rows in ascending order

Syntax

```
B = sortrows(A)
B = sortrows(A,column)
[B,index] = sortrows(A)
```

Description

`B = sortrows(A)` sorts the rows of `A` as a group in ascending order. Argument `A` must be either a matrix or a column vector.

For strings, this is the familiar dictionary sort. When `A` is complex, the elements are sorted by magnitude, and, where magnitudes are equal, further sorted by phase angle on the interval $[-\pi, \pi]$.

`B = sortrows(A,column)` sorts the matrix based on the columns specified in the vector `column`. For example, `sortrows(A,[2 3])` sorts the rows of `A` by the second column, and where these are equal, further sorts by the third column.

`[B,index] = sortrows(A)` also returns an index vector `index`.

If `A` is a column vector, then `B = A(index)`.

If `A` is an `m`-by-`n` matrix, then `B = A(index,:)`.

Examples

Given the 5-by-5 string matrix,

```
A = ['one  ';'two  ';'three';'four ';'five '];
```

The commands `B = sortrows(A)` and `C = sortrows(A,1)` yield

```
B =            C =
five           four
four           five
one            one
three          two
two            three
```

See Also

`sort`

Purpose

Convert vector into sound

Syntax

```
sound(y,Fs)
sound(y)
sound(y,Fs,bits)
```

Description

`sound(y,Fs)`, sends the signal in vector `y` (with sample frequency `Fs`) to the speaker on the PC and most UNIX platforms. Values in `y` are assumed to be in the range $-1.0 \le y \le 1.0$. Values outside that range are clipped. Stereo sound is played on platforms that support it when `y` is an `n`-by-2 matrix.

`sound(y)` plays the sound at the default sample rate or 8192 Hz.

`sound(y,Fs,bits)` plays the sound using `bits` bits/sample if possible. Most platforms support `bits = 8` or `bits = 16`.

Remarks

MATLAB supports all Windows-compatible sound devices.

See Also

`auread`, `auwrite`, `soundsc`, `wavread`, `wavwrite`

soundsc

Purpose

Scale data and play as sound

Syntax

```
soundsc(y,Fs)
soundsc(y)
soundsc(y,Fs,bits)
soundsc(y,...,slim)
```

Description

`soundsc(y,Fs)` sends the signal in vector `y` (with sample frequency `Fs`) to the speaker on the PC and most UNIX platforms. The signal `y` is scaled to the range $-1.0 \le y \le 1.0$ before it is played, resulting in a sound that is played as loud as possible without clipping.

`soundsc(y)` plays the sound at the default sample rate or 8192 Hz.

`soundsc(y,Fs,bits)` plays the sound using `bits` bits/sample if possible. Most platforms support `bits = 8` or `bits = 16`.

`soundsc(y,...,slim)` where `slim = [slow shigh]` maps the values in `y` between `slow` and `shigh` to the full sound range. The default value is `slim = [min(y) max(y)]`.

Remarks

MATLAB supports all Windows-compatible sound devices.

See Also

`auread`, `auwrite`, `sound`, `wavread`, `wavwrite`

Purpose

Allocate space for sparse matrix

Syntax

```
S = spalloc(m,n,nzmax)
```

Description

`S = spalloc(m,n,nzmax)` creates an all zero sparse matrix `S` of size `m`-by-`n` with room to hold `nzmax` nonzeros. The matrix can then be generated column by column without requiring repeated storage allocation as the number of nonzeros grows.

`spalloc(m,n,nzmax)` is shorthand for

```
sparse([],[],[],m,n,nzmax)
```

Examples

To generate efficiently a sparse matrix that has an average of at most three nonzero elements per column

```
S = spalloc(n,n,3*n);
for j = 1:n
    S(:,j) = [zeros(n-3,1)' round(rand(3,1))']';
end
```

See Also

`sparse`

sparse

Purpose

Create sparse matrix

Syntax

```
S = sparse(A)
S = sparse(i,j,s,m,n,nzmax)
S = sparse(i,j,s,m,n)
S = sparse(i,j,s)
S = sparse(m,n)
```

Description

The sparse function generates matrices in MATLAB's sparse storage organization.

`S = sparse(A)` converts a full matrix to sparse form by squeezing out any zero elements. If `S` is already sparse, `sparse(S)` returns `S`.

`S = sparse(i,j,s,m,n,nzmax)` uses vectors `i`, `j`, and `s` to generate an `m`-by-`n` sparse matrix with space allocated for `nzmax` nonzeros. Any elements of `s` that are zero are ignored, along with the corresponding values of `i` and `j`. Vectors `i`, `j`, and `s` are all the same length. Any elements of `s` that have duplicate values of `i` and `j` are added together.

To simplify this six-argument call, you can pass scalars for the argument `s` and one of the arguments `i` or `j`—in which case they are expanded so that `i`, `j`, and `s` all have the same length.

`S = sparse(i,j,s,m,n)` uses `nzmax = length(s)`.

`S = sparse(i,j,s)` uses `m = max(i)` and `n = max(j)`. The maxima are computed before any zeros in `s` are removed, so one of the rows of `[i j s]` might be `[m n 0]`.

`S = sparse(m,n)` abbreviates `sparse([],[],[],m,n,0)`. This generates the ultimate sparse matrix, an `m`-by-`n` all zero matrix.

Remarks

All of MATLAB's built-in arithmetic, logical, and indexing operations can be applied to sparse matrices, or to mixtures of sparse and full matrices. Operations on sparse matrices return sparse matrices and operations on full matrices return full matrices.

In most cases, operations on mixtures of sparse and full matrices return full matrices. The exceptions include situations where the result of a mixed operation is structurally sparse, for example, `A.*S` is at least as sparse as `S`.

Examples

`S = sparse(1:n,1:n,1)` generates a sparse representation of the n-by-n identity matrix. The same `S` results from `S = sparse(eye(n,n))`, but this would also temporarily generate a full n-by-n matrix with most of its elements equal to zero.

`B = sparse(10000,10000,pi)` is probably not very useful, but is legal and works; it sets up a `10000`-by-`10000` matrix with only one nonzero element. Don't try `full(B);` it requires 800 megabytes of storage.

This dissects and then reassembles a sparse matrix:

```
[i,j,s] = find(S);
[m,n] = size(S);
S = sparse(i,j,s,m,n);
```

So does this, if the last row and column have nonzero entries:

```
[i,j,s] = find(S);
S = sparse(i,j,s);
```

See Also

The sparfun directory, and:

`diag`, `find`, `full`, `nnz`, `nonzeros`, `nzmax`, `spalloc`, `spones`, `sprandn`, `sprandsym`, `spy`

spconvert

Purpose

Import matrix from sparse matrix external format

Syntax

```
S = spconvert(D)
```

Description

`spconvert` is used to create sparse matrices from a simple sparse format easily produced by non-MATLAB sparse programs. `spconvert` is the second step in the process:

1. Load an ASCII data file containing `[i,j,v]` or `[i,j,re,im]` as rows into a MATLAB variable.
2. Convert that variable into a MATLAB sparse matrix.

`S = spconvert(D)` converts a matrix `D` with rows containing `[i,j,s]` or `[i,j,r,s]` to the corresponding sparse matrix. `D` must have an `nnz` or `nnz+1` row and three or four columns. Three elements per row generate a real matrix and four elements per row generate a complex matrix. A row of the form `[m n 0]` or `[m n 0 0]` anywhere in `D` can be used to specify `size(S)`. If `D` is already sparse, no conversion is done, so `spconvert` can be used after `D` is loaded from either a MAT-file or an ASCII file.

Examples

Suppose the ASCII file `uphill.dat` contains

```
1    1    1.000000000000000
1    2    0.500000000000000
2    2    0.333333333333333
1    3    0.333333333333333
2    3    0.250000000000000
3    3    0.200000000000000
1    4    0.250000000000000
2    4    0.200000000000000
3    4    0.166666666666667
4    4    0.142857142857143
4    4    0.000000000000000
```

Then the statements

```
load uphill.dat
H = spconvert(uphill)
```

recreate `sparse(triu(hilb(4)))`, possibly with roundoff errors. In this case, the last line of the input file is not necessary because the earlier lines already specify that the matrix is at least 4-by-4.

spdiags

Purpose

Extract and create sparse band and diagonal matrices

Syntax

```
[B,d] = spdiags(A)
B = spdiags(A,d)
A = spdiags(B,d,A)
A = spdiags(B,d,m,n)
```

Description

The `spdiags` function generalizes the function `diag`. Four different operations, distinguished by the number of input arguments, are possible:

`[B,d] = spdiags(A)` extracts all nonzero diagonals from the `m`-by-`n` matrix `A`. `B` is a `min(m,n)`-by-`p` matrix whose columns are the `p` nonzero diagonals of `A`. `d` is a vector of length `p` whose integer components specify the diagonals in `A`.

`B = spdiags(A,d)` extracts the diagonals specified by `d`.

`A = spdiags(B,d,A)` replaces the diagonals specified by `d` with the columns of `B`. The output is sparse.

`A = spdiags(B,d,m,n)` creates an `m`-by-`n` sparse matrix by taking the columns of `B` and placing them along the diagonals specified by `d`.

Remarks

If a column of `B` is longer than the diagonal it's replacing, `spdiags` takes elements from `B`'s tail.

Arguments

The `spdiags` function deals with three matrices, in various combinations, as both input and output:

- `A` An `m`-by-`n` matrix, usually (but not necessarily) sparse, with its nonzero or specified elements located on `p` diagonals.
- `B` A `min(m,n)`-by-`p` matrix, usually (but not necessarily) full, whose columns are the diagonals of `A`.
- `d` A vector of length `p` whose integer components specify the diagonals in `A`.

Roughly, A, B, and d are related by

```
for k = 1:p
    B(:,k) = diag(A,d(k))
end
```

Some elements of B, corresponding to positions outside of A, are not defined by these loops. They are not referenced when B is input and are set to zero when B is output.

Examples

This example generates a sparse tridiagonal representation of the classic second difference operator on n points.

```
e = ones(n,1);
A = spdiags([e -2*e e], -1:1, n, n)
```

Turn it into Wilkinson's test matrix (see gallery):

```
A = spdiags(abs(-(n-1)/2:(n-1)/2)',0,A)
```

Finally, recover the three diagonals:

```
B = spdiags(A)
```

The second example is not square.

```
A = [11    0   13    0
       0   22    0   24
       0    0   33    0
      41    0    0   44
       0   52    0    0
       0    0   63    0
       0    0    0   74]
```

Here m = 7, n = 4, and p = 3.

The statement [B,d] = spdiags(A) produces d = [-3 0 2]' and

```
B = [41   11    0
     52   22    0
     63   33   13
     74   44   24]
```

Conversely, with the above `B` and `d`, the expression `spdiags(B,d,7,4)` reproduces the original `A`.

See Also

`diag`

Purpose

Sparse identity matrix

Syntax

```
S = speye(m,n)
S = speye(n)
```

Description

`S = speye(m,n)` forms an `m`-by-`n` sparse matrix with `1`s on the main diagonal.

`S = speye(n)` abbreviates `speye(n,n)`.

Examples

`I = speye(1000)` forms the sparse representation of the 1000-by-1000 identity matrix, which requires only about 16 kilobytes of storage. This is the same final result as `I = sparse(eye(1000,1000))`, but the latter requires eight megabytes for temporary storage for the full representation.

See Also

`spalloc`, `spdiags`, `spones`, `sprand`, `sprandn`

spfun

Purpose

Apply function to nonzero sparse matrix elements

Syntax

```
f = spfun('function',S)
```

Description

The spfun function selectively applies a function to only the *nonzero* elements of a sparse matrix, preserving the sparsity pattern of the original matrix (except for underflow).

`f = spfun('function',S)` evaluates *function*(S) on the nonzero elements of S. *function* must be the name of a function, usually defined in an M-file, which can accept a matrix argument, S, and evaluate the function at each element of S.

Remarks

Functions that operate element-by-element, like those in the elfun directory, are the most appropriate functions to use with spfun.

Examples

Given the 4-by-4 sparse diagonal matrix

```
S =
   (1,1)        1
   (2,2)        2
   (3,3)        3
   (4,4)        4
```

`f = spfun('exp',S)` has the same sparsity pattern as S:

```
f =
   (1,1)       2.7183
   (2,2)       7.3891
   (3,3)      20.0855
   (4,4)      54.5982
```

whereas exp(S) has 1s where S has 0s.

```
full(exp(S))

ans =
    2.7183    1.0000    1.0000    1.0000
    1.0000    7.3891    1.0000    1.0000
    1.0000    1.0000   20.0855    1.0000
    1.0000    1.0000    1.0000   54.5982
```

Purpose

Transform spherical coordinates to Cartesian

Syntax

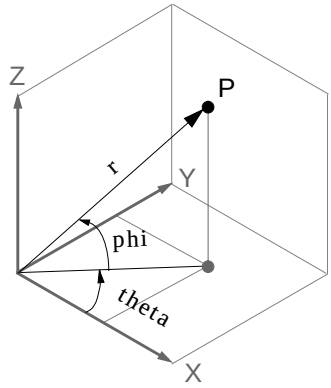
```
[x,y,z] = sph2cart(THETA,PHI,R)
```

Description

`[x,y,z] = sph2cart(THETA,PHI,R)` transforms the corresponding elements of spherical coordinate arrays to Cartesian, or *xyz*, coordinates. `THETA`, `PHI`, and `R` must all be the same size. `THETA` and `PHI` are angular displacements in radians from the positive *x*-axis and from the *x-y* plane, respectively.

Algorithm

The mapping from spherical coordinates to three-dimensional Cartesian coordinates is:




```
x = r .* cos(phi) .* cos(theta)
y = r .* cos(phi) .* sin(theta)
       z = r .* sin(phi)
```

See Also

`cart2pol`, `cart2sph`, `pol2cart`

spline

Purpose

Cubic spline interpolation

Syntax

```
yy = spline(x,y,xx)
pp = spline(x,y)
```

Description

The `spline` function constructs a spline function which takes the value `y(:,j)` at the point `x(j)`, all `j`. In particular, the given values may be vectors, in which case the spline function describes a curve that passes through the point sequence `y(:,1),y(:,2), ....`

`yy = spline(x,y,xx)` returns the value at `xx` of the interpolating cubic spline. If `xx` is a refinement of the mesh `x`, then `yy` provides a corresponding refinement of `y`.

`pp = spline(x,y)` returns the pp-form of the cubic spline interpolant, for later use with `ppval` (and with functions available in the Spline Toolbox).

Ordinarily, the 'not-a-knot' end conditions are used. However, if `y` contains exactly two more values than `x` has entries, then `y(:,1)` and `y(:,end)` are used as the endslopes for the cubic spline.

Examples

The two vectors

```
t = 1900:10:1990;
p = [ 75.995  91.972  105.711  123.203  131.669 ...
     150.697 179.323  203.212  226.505  249.633 ];
```

represent the census years from 1900 to 1990 and the corresponding United States population in millions of people. The expression

```
spline(t,p,2000)
```

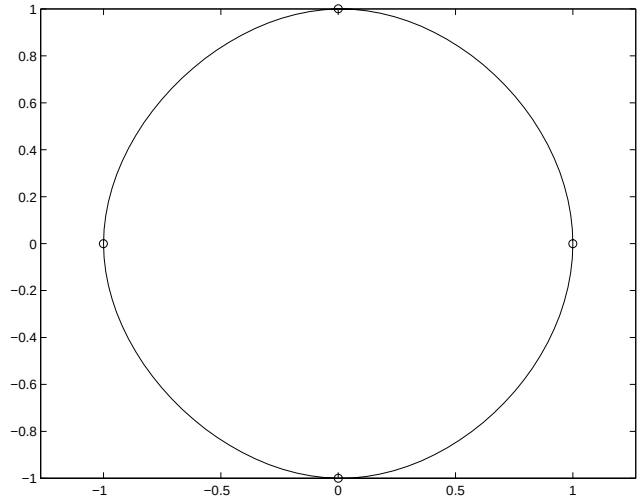
uses the cubic spline to extrapolate and predict the population in the year 2000. The result is

```
ans =
    270.6060
```

The statements

```
x = pi*[0:.5:2]; y = [0 1 0 -1 0 1 0; 1 0 1 0 -1 0 1];
pp = spline(x,y);
yy = ppval(pp, linspace(0,2*pi,101));
plot(yy(1,:),yy(2,:),'-b',y(1,2:5),y(2,2:5),'or'), axis equal
```

generate the plot of a circle, with the five data points `y(:,2),...,y(:,6)` marked with o's. Note that this `y` contains two more values (i.e., two more columns) than does `x`, hence `y(:,1)` and `y(:,end)` are used as endslopes.



Algorithm

A tridiagonal linear system (with, possibly, several right sides) is being solved for the information needed to describe the coefficients of the various cubic polynomials which make up the interpolating spline. `spline` uses the functions `ppval`, `mkpp`, and `unmkpp`. These routines form a small suite of functions for working with piecewise polynomials. `spline` uses these functions in a fairly simple fashion to perform cubic spline interpolation. For access to the more advanced features, see the on-line help for these M-files and the Spline Toolbox.

See Also `interp1`, `interp2`, `interp3`, `interpn`

References [1] de Boor, C., *A Practical Guide to Splines*, Springer-Verlag, 1978.

Purpose

Replace nonzero sparse matrix elements with ones

Syntax

```
R = spones(S)
```

Description

`R = spones(S)` generates a matrix `R` with the same sparsity structure as `S`, but with `1`'s in the nonzero positions.

Examples

`c = sum(spones(S))` is the number of nonzeros in each column.

`r = sum(spones(S'))'` is the number of nonzeros in each row.

`sum(c)` and `sum(r)` are equal, and are equal to `nnz(S)`.

See Also

`nnz`, `spalloc`, `spfun`

spparms

Purpose

Set parameters for sparse matrix routines

Syntax

```
spparms('key',value)
spparms
values = spparms
[keys,values] = spparms
spparms(values)
value = spparms('key')
spparms('default')
spparms('tight')
```

Description

`spparms('key',value)` sets one or more of the *tunable* parameters used in the sparse linear equation operators, `\` and `/`, and the minimum degree orderings, `colmmd` and `symmmd`. In ordinary use, you should never need to deal with this function.

The meanings of the `key` parameters are

`'spumoni'`	Sparse Monitor flag. `0` produces no diagnostic output, the default. `1` produces information about choice of algorithm based on matrix structure, and about storage allocation. `2` also produces very detailed information about the minimum degree algorithms.
`'thr_rel'`, `'thr_abs'`	Minimum degree threshold is `thr_rel*mindegree+thr_abs`.
`'exact_d'`	Nonzero to use exact degrees in minimum degree. Zero to use approximate degrees.
`'supernd'`	If positive, minimum degree amalgamates the supernodes every `supernd` stages.
`'rreduce'`	If positive, minimum degree does row reduction every `rreduce` stages.
`'wh_frac'`	Rows with `density > wh_frac` are ignored in `colmmd`.

`'autommd'`	Nonzero to use minimum degree orderings with `\` and `/`.
`'aug_rel'`, `'aug_abs'`	Residual scaling parameter for augmented equations is `aug_rel*max(max(abs(A))) + aug_abs`. For example, `aug_rel = 0`, `aug_abs = 1` puts an unscaled identity matrix in the (1,1) block of the augmented matrix.

`spparms`, by itself, prints a description of the current settings.

`values = spparms` returns a vector whose components give the current settings.

`[keys,values] = spparms` returns that vector, and also returns a character matrix whose rows are the keywords for the parameters.

`spparms(values)`, with no output argument, sets all the parameters to the values specified by the argument vector.

`value = spparms('`*key*`')` returns the current setting of one parameter.

`spparms('default')` sets all the parameters to their default settings.

`spparms('tight')` sets the minimum degree ordering parameters to their *tight* settings, which can lead to orderings with less fill-in, but which make the ordering functions themselves use more execution time.

The key parameters for `default` and `tight` settings are

	Keyword	Default	Tight
values(1)	'spumoni'	0.0	
values(2)	'thr_rel'	1.1	1.0
values(3)	'thr_abs'	1.0	0.0
values(4)	'exact_d'	0.0	1.0
values(5)	'supernd'	3.0	1.0
values(6)	'rreduce'	3.0	1.0
values(7)	'wh_frac'	0.5	0.5
values(8)	'autommd'	1.0	
values(9)	'aug_rel'	0.001	
values(10)	'aug_abs'	0.0	

See Also

The arithmetic operator \

`colmmd`, `symmmd`

References

[1] Gilbert, John R., Cleve Moler and Robert Schreiber, “Sparse Matrices in MATLAB: Design and Implementation,” *SIAM Journal on Matrix Analysis and Applications 13*, 1992, pp. 333-356.

Purpose

Sparse uniformly distributed random matrix

Syntax

```
R = sprand(S)
R = sprand(m,n,density)
R = sprand(m,n,density,rc)
```

Description

`R = sprand(S)` has the same sparsity structure as `S`, but uniformly distributed random entries.

`R = sprand(m,n,density)` is a random, `m`-by-`n`, sparse matrix with approximately `density*m*n` uniformly distributed nonzero entries (`0 ≤ density ≤ 1`).

`R = sprand(m,n,density,rc)` also has reciprocal condition number approximately equal to `rc`. `R` is constructed from a sum of matrices of rank one.

If `rc` is a vector of length `lr`, where `lr ≤ min(m,n)`, then `R` has `rc` as its first `lr` singular values, all others are zero. In this case, `R` is generated by random plane rotations applied to a diagonal matrix with the given singular values. It has a great deal of topological and algebraic structure.

See Also

`sprandn`, `sprandsym`

sprandn

Purpose

Sparse normally distributed random matrix

Syntax

```
R = sprandn(S)
R = sprandn(m,n,density)
R = sprandn(m,n,density,rc)
```

Description

`R = sprandn(S)` has the same sparsity structure as `S`, but normally distributed random entries with mean `0` and variance `1`.

`R = sprandn(m,n,density)` is a random, `m`-by-`n`, sparse matrix with approximately `density*m*n` normally distributed nonzero entries (`0 ≤ density ≤ 1`).

`R = sprandn(m,n,density,rc)` also has reciprocal condition number approximately equal to `rc`. `R` is constructed from a sum of matrices of rank one.

If `rc` is a vector of length `lr`, where `lr ≤ min(m,n)`, then `R` has `rc` as its first `lr` singular values, all others are zero. In this case, `R` is generated by random plane rotations applied to a diagonal matrix with the given singular values. It has a great deal of topological and algebraic structure.

See Also

`sprand`, `sprandn`

Purpose

Sparse symmetric random matrix

Syntax

```
R = sprandsym(S)
R = sprandsym(n,density)
R = sprandsym(n,density,rc)
R = sprandsym(n,density,rc,kind)
```

Description

`R = sprandsym(S)` returns a symmetric random matrix whose lower triangle and diagonal have the same structure as `S`. Its elements are normally distributed, with mean `0` and variance `1`.

`R = sprandsym(n,density)` returns a symmetric random, `n`-by-`n`, sparse matrix with approximately `density`$*$`n`$*$`n` nonzeros; each entry is the sum of one or more normally distributed random samples, and (`0` $\leq$ `density` $\leq$ `1`).

`R = sprandsym(n,density,rc)` returns a matrix with a reciprocal condition number equal to `rc`. The distribution of entries is nonuniform; it is roughly symmetric about 0; all are in [–1, 1].

If `rc` is a vector of length `n`, then `R` has eigenvalues `rc`. Thus, if `rc` is a positive (nonnegative) vector then `R` is a positive definite matrix. In either case, `R` is generated by random Jacobi rotations applied to a diagonal matrix with the given eigenvalues or condition number. It has a great deal of topological and algebraic structure.

`R = sprandsym(n,density,rc,kind)` returns a positive definite matrix. Argument `kind` can be:

- `1` to generate `R` by random Jacobi rotation of a positive definite diagonal matrix. `R` has the desired condition number exactly.
- `2` to generate an `R` that is a shifted sum of outer products. `R` has the desired condition number only approximately, but has less structure.
- `3` to generate an `R` that has the same structure as the matrix `S` and approximate condition number `1/rc`. `density` is ignored.

See Also

`sprand`, `sprandn`

sprintf

Purpose

Write formatted data to a string

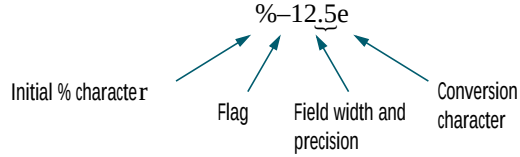
Syntax

```
s = sprintf(format,A,...)
[s,errmsg] = sprintf(format,A,...)
```

Description

`s = sprintf(format,A,...)` formats the data in matrix `A` (and in any additional matrix arguments) under control of the specified `format` string, and returns it in the MATLAB string variable `s`. `sprintf` is the same as `fprintf` except that it returns the data in a MATLAB string variable rather than writing it to a file.

The `format` string specifies notation, alignment, significant digits, field width, and other aspects of output format. It can contain ordinary alphanumeric characters; along with escape characters, conversion specifiers, and other characters, organized as shown below.



`[s,errmsg] = sprintf(format,A,...)` returns an error message string `errmsg` if an error occurred, or an empty matrix if an error did not occur.

Remarks

The `sprintf` function behaves like its ANSI C language `sprintf()` namesake with certain exceptions and extensions, including the following.

These non-standard subtype specifiers are supported for conversion specifiers %o, %u, %x, and %X.	b	The underlying C data type is a double rather than an unsigned integer. For example, to print a double-precision value in hexadecimal, use a format like '%bx'.

	t	The underlying C data type is a float rather than an unsigned integer.
When input matrix `A` is nonscalar, `sprintf` is *vectorized*.		The format string is cycled through the elements of `A` (columnwise) until all the elements are used up. It is then cycled in a similar manner, without reinitializing, through any additional matrix arguments.

The following tables describe the nonalphanumeric characters found in format specification strings.

Escape Characters

Character	Description
\b	Backspace
\f	Form feed
\n	New line
\r	Carriage return
\t	Horizontal tab
\\	Backslash
\" or " (two single quotes)	Single quotation mark
%%	Percent character

Conversion Specifiers

Conversion characters specify the notation of the output.

Specifier	Description
%c	Single character
%d	Decimal notation (signed)
%e	Exponential notation (using a lowercase e as in 3.1415e+00)
%E	Exponential notation (using an uppercase E as in 3.1415E+00)
%f	Fixed-point notation
%g	The more compact of %e or %f, as defined in [2]. Insignificant zeros do not print.

Specifier	Description
%G	Same as %g, but using an uppercase E
%o	Octal notation (unsigned)
%s	String of characters
%u	Decimal notation (unsigned)
%x	Hexadecimal notation (using lowercase letters a–f)
%X	Hexadecimal notation (using uppercase letters A–F)

Other Characters

Other characters can be inserted into the conversion specifier between the % and the conversion character.

Character	Description	Example
A minus sign (–)	Left-justifies the converted argument in its field.	%-5.2d
A plus sign (+)	Always prints a sign character (+ or –).	%+5.2d
Zero (0)	Pad with zeros rather than spaces.	%05.2d
Digits (field width)	A digit string specifying the minimum number of digits to be printed.	%6f
Digits (precision)	A digit string including a period (.) specifying the number of digits to be printed to the right of the decimal point.	%6.2f

Examples

Command	Result
sprintf('%0.5g',(1+sqrt(5))/2)	1.618
sprintf('%0.5g',1/eps)	4.5036e+15

Command	Result
`sprintf('%15.5f',1/eps)`	`4503599627370496.00000`
`sprintf('%d',round(pi))`	`3`
`sprintf('%s','hello')`	`hello`
`sprintf('The array is %dx%d.',2,3)`	`The array is 2x3`
`sprintf('\n')`	Line termination character on all platforms

See Also

`int2str`, `num2str`, `sscanf`

References

[1] Kernighan, B.W. and D.M. Ritchie, *The C Programming Language*, Second Edition, Prentice-Hall, Inc., 1988.

[2] ANSI specification X3.159-1989: "Programming Language C," ANSI, 1430 Broadway, New York, NY 10018.

Purpose

Visualize sparsity pattern

Syntax

```
spy(S)
spy(S,markersize)
spy(S,'LineSpec')
spy(S,'LineSpec',markersize)
```

Description

`spy(S)` plots the sparsity pattern of any matrix `S`.

`spy(S,marksize)`, where `markersize` is an integer, plots the sparsity pattern using markers of the specified point size.

`spy(S,'LineSpec')`, where *LineSpec* is a string, uses the specified plot marker type and color.

`spy(S,'LineSpec',markersize)` uses the specified type, color, and size for the plot markers.

`S` is usually a sparse matrix, but full matrices are acceptable, in which case the locations of the nonzero elements are plotted.

`spy` replaces `format +`, which takes much more space to display essentially the same information.

See Also

The `gplot` and `LineSpec` reference entries in the *MATLAB Graphics Guide*, and:

`find`, `symmmd`, `symrcm`

sqrt

Purpose

Square root

Syntax

```
B = sqrt(A)
```

Description

`B = sqrt(A)` returns the square root of each element of the array `X`. For the elements of `X` that are negative or complex, `sqrt(X)` produces complex results.

Remarks

See `sqrtm` for the matrix square root.

Examples

```
sqrt((-2:2)')
ans =
      0 + 1.4142i
      0 + 1.0000i
      0
 1.0000
 1.4142
```

See Also

`sqrtm`

Purpose

Matrix square root

Syntax

```
Y = sqrtm(X)
[Y,esterr] = sqrtm(X)
```

Description

`Y = sqrtm(X)` is the matrix square root of `X`. Complex results are produced if `X` has negative eigenvalues. A warning message is printed if the computed `Y*Y` is not close to `X`.

`[Y,esterr] = sqrtm(X)` does not print any warning message, but returns an estimate of the relative residual, `norm(Y*Y-X)/norm(X)`.

Remarks

If `X` is real, symmetric and positive definite, or complex, Hermitian and positive definite, then so is the computed matrix square root.

Some matrices, like `X = [0 1; 0 0]`, do not have any square roots, real or complex, and `sqrtm` cannot be expected to produce one.

Examples

A matrix representation of the fourth difference operator is

```
X =
     5    -4     1     0     0
    -4     6    -4     1     0
     1    -4     6    -4     1
     0     1    -4     6    -4
     0     0     1    -4     5
```

This matrix is symmetric and positive definite. Its unique positive definite square root, `Y = sqrtm(X)`, is a representation of the second difference operator.

```
Y =
     2    -1    -0     0    -0
    -1     2    -1    -0    -0
    -0    -1     2    -1     0
     0    -0    -1     2    -1
    -0    -0     0    -1     2
```

The matrix

```
X =
     7   10
    15   22
```

has four square roots. Two of them are

```
Y1 =
    1.5667    1.7408
    2.6112    4.1779
```

and

```
Y2 =
     1    2
     3    4
```

The other two are `-Y1` and `-Y2`. All four can be obtained from the eigenvalues and vectors of `X`.

```
[V,D] = eig(X);
D =
    0.1386          0
         0    28.8614
```

The four square roots of the diagonal matrix `D` result from the four choices of sign in

```
S =
    ±0.3723          0
          0    ±5.3723
```

All four `Y`s are of the form

```
Y = V*S/V
```

The `sqrtm` function chooses the two plus signs and produces `Y1`, even though `Y2` is more natural because its entries are integers.

Finally, the matrix

```
 X =
     0    1
     0    0
```

does not have any square roots. There is no matrix `Y`, real or complex, for which `Y*Y = X`. The statement

```
Y = sqrtm(X)
```

produces several warning messages concerning accuracy and the answer

```
Y =

    1.0e+03 *

   0.0000+ 0.0000i   4.9354- 7.6863i
   0.0000+ 0.0000i   0.0000+ 0.0000i
```

Algorithm

The function `sqrtm(X)` is an abbreviation for `funm(X,'sqrt')`. The algorithm used by `funm` is based on a Schur decomposition. It can fail in certain situations where `X` has repeated eigenvalues. See `funm` for details.

See Also

`expm`, `funm`, `logm`

squeeze

Purpose

Remove singleton dimensions

Syntax

```
B = squeeze(A)
```

Description

`B = squeeze(A)` returns an array `B` with the same elements as `A`, but with all singleton dimensions removed. A singleton dimension is any dimension for which `size(A,dim) = 1`.

Examples

Consider the 2-by-1-by-3 array `Y = rand(2,1,3)`. This array has a singleton column dimension — that is, there's only one column per page.

```
Y =

Y(:,:,1) =      Y(:,:,2) =
    0.5194          0.0346
    0.8310          0.0535

Y(:,:,3) =
    0.5297
    0.6711
```

The command `Z = squeeze(Y)` yields a 2-by-3 matrix:

```
Z =
    0.5194    0.0346    0.5297
    0.8310    0.0535    0.6711
```

See Also

`reshape`, `shiftdim`

Purpose

Read string under format control

Syntax

```
A = sscanf(s,format)
A = sscanf(s,format,size)
[A,count,errmsg,nextindex] = sscanf(...)
```

Description

`A = sscanf(s,format)` reads data from the MATLAB string variable `s`, converts it according to the specified `format` string, and returns it in matrix `A`. `format` is a string specifying the format of the data to be read. See "Remarks" for details. `sscanf` is the same as `fscanf` except that it reads the data from a MATLAB string variable rather than reading it from a file.

`A = sscanf(s,format,size)` reads the amount of data specified by `size` and converts it according to the specified `format` string. `size` is an argument that determines how much data is read. Valid options are

`n`	Read `n` elements into a column vector.
`inf`	Read to the end of the file, resulting in a column vector containing the same number of elements as are in the file.
`[m,n]`	Read enough elements to fill an `m`-by-`n` matrix, filling the matrix in column order. `n` can be `Inf`, but not `m`.

If the matrix `A` results from using character conversions only and `size` is not of the form `[M,N]`, a row vector is returned.

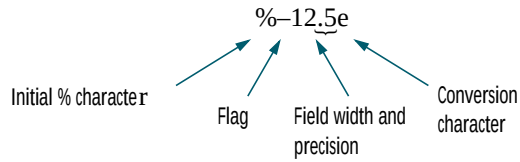
`sscanf` differs from its C language namesakes `scanf()` and `fscanf()` in an important respect — it is *vectorized* in order to return a matrix argument. The `format` string is cycled through the file until an end-of-file is reached or the amount of data specified by `size` is read in.

`[A,count,errmsg,nextindex] = sscanf(...)` reads data from the MATLAB string variable `s`, converts it according to the specified `format` string, and returns it in matrix `A`. `count` is an optional output argument that returns the number of elements successfully read. `errmsg` is an optional output argument that returns an error message string if an error occurred or an empty matrix if an error did not occur. `nextindex` is an optional output argument specifying one more than the number of characters scanned in `s`.

Remarks

When MATLAB reads a specified file, it attempts to match the data in the file to the format string. If a match occurs, the data is written into the matrix in column order. If a partial match occurs, only the matching data is written to the matrix, and the read operation stops.

The `format` string consists of ordinary characters and/or conversion specifications. Conversion specifications indicate the type of data to be matched and involve the character `%`, optional width fields, and conversion characters, organized as shown below:



Add one or more of these characters between the `%` and the conversion character.

An asterisk (*)	Skip over the matched value if the value is matched but not stored in the output matrix.
A digit string	Maximum field width.
A letter	The size of the receiving object; for example, `h` for short as in `%hd` for a short integer, or `l` for long as in `%ld` for a long integer or `%lg` for a double floating-point number.

Valid conversion characters are as shown.

`%c`	Sequence of characters; number specified by field width
`%d`	Decimal numbers
`%e`, `%f`, `%g`	Floating-point numbers
`%i`	Signed integer
`%o`	Signed octal integer
`%s`	A series of non-whitespace characters

%u	Signed decimal integer
%x	Signed hexadecimal integer
[...]	Sequence of characters (scanlist)

If %s is used, an element read may use several MATLAB matrix elements, each holding one character. Use %c to read space characters, or %s to skip all white space.

Mixing character and numeric conversion specifications cause the resulting matrix to be numeric and any characters read to appear as their ASCII values, one character per MATLAB matrix element.

For more information about format strings, refer to the `scanf()` and `fscanf()` routines in a C language reference manual.

Examples

The statements

```
s = '2.7183  3.1416';
A = sscanf(s,'%f')
```

create a two-element vector containing poor approximations to `e` and `pi`.

See Also

`eval`, `sprintf`, `textread`

startup

Purpose

Run MATLAB startup M-file

Syntax

```
startup
```

Description

At startup time, MATLAB automatically executes the master M-file `matlabrc.m` and, if it exists, `startup.m`. On multiuser or networked systems, `matlabrc.m` is reserved for use by the system manager. The file `matlabrc.m` invokes the file `startup.m` if it exists on MATLAB's search path. You can create a `startup` file in your own MATLAB directory. The file can include physical constants, handle graphics defaults, engineering conversion factors, or anything else you want predefined in your workspace.

Algorithm

Only `matlabrc.m` is actually invoked by MATLAB at startup. However, `matlabrc.m` contains the statements

```
if exist('startup')==2
    startup
end
```

that invoke `startup.m`. You can extend this process to create additional startup M-files, if required.

Remarks

You can also start MATLAB using options you define at the command line or in your Windows shortcut for MATLAB. See Chapter 2 of *Using MATLAB* for details.

See Also

`exist`, `matlabrc`, `path`, `quit`

Purpose

Standard deviation

Syntax

```
s = std(X)
s = std(X,flag)
s = std(X,flag,dim)
```

Definition

There are two common textbook definitions for the standard deviation `s` of a data vector `X`:

$$(1)\ s = \left(\frac{1}{n-1}\sum_{i=1}^{n}(x_i-\bar{x})^2\right)^{\frac{1}{2}} \qquad \text{and} \qquad (2)\ s = \left(\frac{1}{n}\sum_{i=1}^{n}(x_i-\bar{x})^2\right)^{\frac{1}{2}}$$

where

$$\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i$$

and n is the number of elements in the sample. The two forms of the equation differ only in $n-1$ versus n in the divisor.

Description

`s = std(X)`, where `X` is a vector, returns the standard deviation using (1) above. If `X` is a random sample of data from a normal distribution, s^2 is the best *unbiased* estimate of its variance.

If `X` is a matrix, `std(X)` returns a row vector containing the standard deviation of the elements of each column of `X`. If `X` is a multidimensional array, `std(X)` is the standard deviation of th elements along the first nonsingleton dimension of `X`.

`s = std(X,flag)` for `flag = 0`, is the same as `std(X)`. For `flag = 1`, `std(X,1)` returns the standard deviation using (2) above, producing the second moment of the sample about its mean.

`s = std(X,flag,dim)` computes the standard deviations along the dimension of `X` specified by scalar `dim`.

Examples

For matrix `X`

```
X =
     1     5     9
     7    15    22

s = std(X,0,1)
s =
   4.2426   7.0711   9.1924

s = std(X,0,2)
s =
   4.000
   7.5056
```

See Also

`corrcoef`, `cov`, `mean`, `median`

Purpose

Convert string to double-precision value

Syntax

```
x = str2double('str')
X = str2double(C)
```

Description

`= str2double('str')` converts the string *str*, which should be an ASCII character representation of a real or complex scalar value, to MATLAB's double-precision representation. The string may contain digits, a comma (thousands separator), a decimal point, a leading `+` or `–` sign, an `e` preceeding a power of 10 scale factor, and an `i` for a complex unit.

If *str* does not represent a valid scalar value, `str2double` returns `NaN`.

`X = str2double(C)` converts the strings in the cell array of strings `C` to double precision. The matrix `X` returned will be the same size as `C`.

Examples

Here are some valid `str2double` conversions.

```
str2double('123.45e7')
str2double('123 + 45i')
str2double('3.14159')
str2double('2.7i - 3.14')
str2double({'2.71' '3.1415'})
str2double('1,200.34')
```

See Also

`char`, `hex2num`, `num2str`, `str2num`

str2num

Purpose

String to number conversion

Syntax

```
x = str2num('str')
```

Description

`x = str2num('str')` converts the string *str*, which is an ASCII character representation of a numeric value, to MATLAB's numeric representation. The string can contain:

- Digits
- A decimal point
- A leading + or – sign
- A letter `e` preceding a power of 10 scale factor
- A letter `i` indicating a complex or imaginary number.

The `str2num` function can also convert string matrices.

Examples

`str2num('3.14159e0')` is approximately π.

To convert a string matrix:

```
str2num(['1 2';'3 4'])

ans =

     1     2
     3     4
```

See Also

The special characters `[]` and `;`

`hex2num`, `num2str`, `sparse`, `sscanf`

Purpose

String concatenation

Syntax

```
t = strcat(s1,s2,s3,...)
```

Description

`t = strcat(s1,s2,s3,...)` horizontally concatenates corresponding rows of the character arrays `s1`, `s2`, `s3`, etc. The trailing padding is ignored. All the inputs must have the same number of rows (or any can be a single string). When the inputs are all character arrays, the output is also a character array.

When any of the inputs is a cell array of strings, `strcat` returns a cell array of strings formed by concatenating corresponding elements of `s1`,`s2`, etc. The inputs must all have the same size (or any can be a scalar). Any of the inputs can also be a character array.

Examples

Given two 1-by-2 cell arrays `a` and `b`,

```
a =                         b =
    'abcde'    'fghi'           'jkl'    'mn'
```

the command `t = strcat(a,b)` yields:

```
t =
    'abcdejkl'    'fghimn'
```

Given the 1-by-1 cell array `c = {'Q'}`, the command `t = strcat(a,b,c)` yields:

```
t =
    'abcdejklQ'    'fghimnQ'
```

Remarks

`strcat` and matrix operation are different for strings that contain trailing spaces:

```
a = 'hello '
b = 'goodby'
strcat(a,b)
ans =
hellogoodby
[a b]
ans =
hello goodby
```

See Also cat, cellstr, strvcat

Purpose

String compare

Syntax

```
k = strcmp('str1','str2')
TF = strcmp(S,T)
```

Description

`k = strcmp(str1,str2)` compares the strings `str1` and `str2` and returns logical true (`1`) if the two are identical, and logical false (`0`) otherwise.

`TF = strcmp(S,T)` where either `S` or `T` is a cell array of strings, returns an array `TF` the same size as `S` and `T` containing `1` for those elements of `S` and `T` that match, and `0` otherwise. `S` and `T` must be the same size (or one can be a scalar cell). Either one can also be a character array with the right number of rows.

Remarks

The `strcmp` function is case sensitive. When comparing a string array to a cell or cell array, the string array is deblanked (trailing spaces are removed) before comparison.

Examples

These examples show the comparison of two strings:

```
strcmp('Yes','No')

ans =

     0

strcmp('Yes ','Yes')

ans =

     0
```

This example compares a string to a cell array of strings:

```
A = {'MATLAB';'Simulink';'The MathWorks'}

A =

    'MATLAB'
    'Simulink'
    'The MathWorks'

strcmp('The MathWorks',A)

ans =

     0
     0
     1
```

Thes examples compare two cell arrays of strings:

```
A = {'MATLAB       ';'Simulink     ';'The MathWorks'};
B = {'MATLAB';'Stateflow' ;'The MathWorks'};
strcmp(A,B)

ans =

     0
     0
     1

strcmp({'Simulink'}, B)

ans =
     0
     0
     0
```

These examples demonstrate scalar expansion:

```
strcmp('hello', {'hello','world'})

ans =

1     0

strcmp({'hello'}, ['hello';'world'])

ans =
     1
     0

strcmp({'hello'}, ['hello  '; 'world  '])

ans =
     1
     0
```

See Also

`findstr`, `strcmpi`, `strmatch`, `strncmp`

strcmpi

Purpose

Compare strings ignoring case

Syntax

```
strcmpi(str1,str2)
strcmpi(S,T)
```

Description

`strcmpi(str1,str2)` returns 1 if strings *str1* and *str2* are the same except for case and 0 otherwise.

`strcmpi(S,T)` when either `S` or `T` is a cell array of strings, returns an array the same size as `S` and `T` containing 1 for those elements of `S` and `T` that match except for case, and 0 otherwise. `S` and `T` must be the same size (or one can be a scalar cell). Either one can also be a character array with the right number of rows.

`strcmpi` supports international character sets.

See Also

`findstr`, `strcmp`, `strmatch`, `strncmpi`

Purpose

MATLAB string handling

Syntax

```
S = 'Any Characters'
S = string(X)
X = numeric(S)
```

Description

`S = 'Any Characters'` is a vector whose components are the numeric codes for the characters (the first 127 codes are ASCII). The actual characters displayed depend on the character set encoding for a given font. The length of `S` is the number of characters. A quote within the string is indicated by two quotes.

`S = string(X)` can be used to convert an array that contains positive integers representing numeric codes into a MATLAB character array.

`X = double(S)` converts the string to its equivalent numeric codes.

`isstr(S)` tells if `S` is a string variable.

Use the `strcat` function for concatenating cell arrays of strings, for arrays of multiple strings, and for padded character arrays. For concatenating two single strings, it is more efficient to use square brackets, as shown in the example, than to use `strcat`.

Example

```
s = ['It is 1 o''clock', 7]
```

See Also

`char`, `strcat`

strjust

Purpose

Justify a character array

Syntax

```
T = strjust(S)
T = strjust(S,'right')
T = strjust(S,'left')
T = strjust(S,'center')
```

Description

`T = strjust(S)` or `T = strjust(S,'right')` returns a right-justified version of the character array S.

`T = strjust(S,'left')` returns a left-justified version of S.

`T = strjust(S,'center')` returns a center-justified version of S.

See Also

`deblank`

Purpose

Find possible matches for a string

Syntax

```
i = strmatch('str',STRS)
i = strmatch('str',STRS,'exact')
```

Description

`i = strmatch('str',STRS)` looks through the rows of the character array or cell array of strings `STRS` to find strings that begin with string *str*, returning the matching row indices. `strmatch` is fastest when `STRS` is a character array.

`i = strmatch('str',STRS,'exact')` returns only the indices of the strings in `STRS` matching *str* exactly.

Examples

The statement

```
i = strmatch('max',strvcat('max','minimax','maximum'))
```

returns `i = [1; 3]` since rows 1 and 3 begin with `'max'`. The statement

```
i = strmatch('max',strvcat('max','minimax','maximum'),'exact')
```

returns `i = 1`, since only row 1 matches `'max'` exactly.

See Also

`findstr`, `strcmp`, `strncmp`, `strvcat`

strncmp

Purpose

Compare the first n characters of two strings

Syntax

```
k = strncmp('str1','str2',n)
TF = strncmp(S,T,n)
```

Description

`k = strncmp('str1','str2',n)` returns logical true (`1`) if the first `n` characters of the strings *str1* and *str2* are the same, and returns logical false (`0`) otherwise. Arguments *str1* and *str2* may also be cell arrays of strings.

`TF = strncmp(S,T,N)` where either `S` or `T` is a cell array of strings, returns an array `TF` the same size as `S` and `T` containing `1` for those elements of `S` and `T` that match (up to `n` characters), and `0` otherwise. `S` and `T` must be the same size (or one can be a scalar cell). Either one can also be a character array with the right number of rows.

Remarks

The command `strncmp` is case sensitive. Any leading and trailing blanks in either of the strings are explicitly included in the comparison.

See Also

`findstr`, `strcmp`, `strcmpi`, `strmatch`, `strncmpi`

Purpose

Compare first n characters of strings ignoring case

Syntax

```
strncmpi('str1','str2',n)
TF = strncmpi(S,T,n)
```

Description

`strncmpi('str1','str2',n)` returns 1 if the first `n` characters of the strings *str1* and *str2* are the same except for case, and 0 otherwise.

`TF = strncmpi(S,T,n)` when either `S` or `T` is a cell array of strings, returns an array the same size as `S` and `T` containing 1 for those elements of `S` and `T` that match except for case (up to `n` characters), and 0 otherwise. `S` and `T` must be the same size (or one can be a scalar cell). Either one can also be a character array with the right number of rows.

`strncmpi` supports international character sets.

See Also

`findstr`, `strmatch`, `strncmp`, `strncmpi`

strrep

Purpose

String search and replace

Syntax

```
str = strrep(str1,str2,str3)
```

Description

`str = strrep(str1,str2,str3)` replaces all occurrences of the string *str2* within string *str1* with the string `str3`.

`strrep(str1,str2,str3)`, when any of *str1*, *str2*, or *str3* is a cell array of strings, returns a cell array the same size as *str1*, *str2* and *str3* obtained by performing a `strrep` using corresponding elements of the inputs. The inputs must all be the same size (or any can be a scalar cell). Any one of the strings can also be a character array with the right number of rows.

Examples

```
s1 = 'This is a good example.';
str = strrep(s1,'good','great')
str =
This is a great example.

A =
    'MATLAB'             'SIMULINK'
    'Toolboxes'          'The MathWorks'

B =
    'Handle Graphics'    'Real Time Workshop'
    'Toolboxes'          'The MathWorks'

C =
    'Signal Processing'    'Image Processing'
    'MATLAB'               'SIMULINK'

strrep(A,B,C)
ans =
    'MATLAB'    'SIMULINK'
    'MATLAB'    'SIMULINK'
```

See Also

`findstr`

Purpose

First token in string

Syntax

```
token = strtok('str',delimiter)
token = strtok('str')
[token,rem] = strtok(...)
```

Description

`token = strtok('str',delimiter)` returns the first token in the text string *str*, that is, the first set of characters before a delimiter is encountered. The vector `delimiter` contains valid delimiter characters.

`token = strtok('str')` uses the default delimiters, the white space characters. These include tabs (ASCII 9), carriage returns (ASCII 13), and spaces (ASCII 32).

`[token,rem] = strtok(...)` returns the remainder `rem` of the original string. The remainder consists of all characters from the first delimiter on.

Examples

```
s = 'This is a good example.';
[token,rem] = strtok(s)
token =
This
rem =
 is a good example.
```

See Also

`findstr`, `strmatch`

struct

Purpose

Create structure array

Syntax

```
s = struct('field1',values1,'field2',values2,...)
```

Description

`s = struct('field1',values1,'field2',values2,...)` creates a structure array with the specified fields and values. The value arrays `values1`, `values2`, etc. must be cell arrays of the same size or scalar cells. Corresponding elements of the value arrays are placed into corresponding structure array elements. The size of the resulting structure is the same size as the value cell arrays or 1-by-1 if none of the values is a cell.

Examples

The command

```
s = struct('type',{'big','little'},'color',{'red'},'x',{3 4})
```

produces a structure array `s`:

```
s =
1x2 struct array with fields:
    type
    color
    x
```

The value arrays have been distributed among the fields of `s`:

```
s(1)
ans =
     type: 'big'
    color: 'red'
        x: 3

s(2)
ans =
     type: 'little'
    color: 'red'
        x: 4
```

See Also

`fieldnames`, `getfield`, `rmfield`, `setfield`

Purpose

Convert structure array to cell array

Syntax

```
c = struct2cell(s)
```

Description

`c = struct2cell(s)` converts the `m`-by-`n` structure `s` (with `p` fields) into a `p`-by-`m`-by-`n` cell array `c`.

If structure `s` is multidimensional, cell array `c` has size `[p size(s)]`.

Examples

The commands

```
clear s, s.category = 'tree';
s.height = 37.4; s.name = 'birch';
```

create the structure

```
s =
    category: 'tree'
      height: 37.4000
        name: 'birch'
```

Converting the structure to a cell array,

```
c = struct2cell(s)

c =
    'tree'
    [37.4000]
    'birch'
```

See Also

`cell2struct`

strvcat

Purpose

Vertical concatenation of strings

Syntax

```
S = strvcat(t1,t2,t3,...)
```

Description

`S = strvcat(t1,t2,t3,...)` forms the character array `S` containing the text strings (or string matrices) `t1,t2,t3,...` as rows. Spaces are appended to each string as necessary to form a valid matrix. Empty arguments are ignored.

Remarks

If each text parameter, `ti`, is itself a character array, `strvcat` appends them vertically to create arbitrarily large string matrices.

Examples

The command `strvcat('Hello','Yes')` is the same as `['Hello';'Yes  ']`, except that `strvcat` performs the padding automatically.

```
t1 = 'first';t2 = 'string';t3 = 'matrix';t4 = 'second';

S1 = strvcat(t1,t2,t3)          S2 = strvcat(t4,t2,t3)

S1 =                            S2 =

first                           second
string                          string
matrix                          matrix

S3 = strvcat(S1,S2)

S3 =
first
string
matrix
second
string
matrix
```

See Also

`cat`, `int2str`, `mat2str`, `num2str`

Purpose

Single index from subscripts

Syntax

```
IND = sub2ind(siz,I,J)
IND = sub2ind(siz,I1,I2,...,In)
```

Description

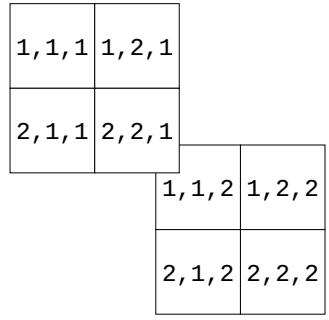
The sub2ind command determines the equivalent single index corresponding to a set of subscript values.

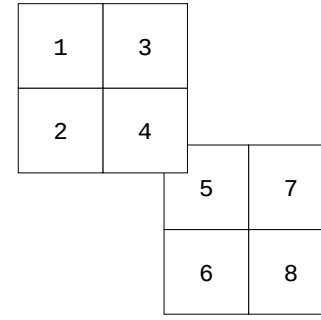
`IND = sub2ind(siz,I,J)` returns the linear index equivalent to the row and column subscripts in the arrays `I` and `J` for an matrix of size *siz*.

`IND = sub2ind(siz,I1,I2,...,In)` returns the linear index equivalent to the `n` subscripts in the arrays `I1`,`I2`,...,`In` for an array of size *siz*.

Examples

The mapping from subscripts to linear index equivalents for a 2-by-2-by-2 array is:





See Also

`ind2sub`, `find`

subsasgn

Purpose

Overloaded method for `A(i)=B`, `A{i}=B`, and `A.field=B`

Syntax

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

Description

`A = subsasgn(A,S,B)` is called for the syntax `A(i)=B`, `A{i}=B`, or `A.i=B` when `A` is an object. `S` is a structure array with the fields:

- `type`: A string containing `'()'`, `'{}'`, or `'.'`, where `'()'` specifies integer subscripts; `'{}'` specifies cell array subscripts, and `'.'` specifies subscripted structure fields.
- `subs`: A cell array or string containing the actual subscripts.

Examples

The syntax `A(1:2,:)=B` calls `A=subsasgn(A,S,B)` where `S` is a 1-by-1 structure with `S.type='()'` and `S.subs = {1:2,':'}`. A colon used as a subscript is passed as the string `':'`.

The syntax `A{1:2}=B` calls `A=subsasgn(A,S,B)` where `S.type='{}'` .

The syntax `A.field=B` calls `subsasgn(A,S,B)` where `S.type='.'` and `S.subs='field'`.

These simple calls are combined in a straightforward way for more complicated subscripting expressions. In such cases `length(S)` is the number of subscripting levels. For instance, `A(1,2).name(3:5)=B` calls `A=subsasgn(A,S,B)` where `S` is 3-by-1 structure array with the following values:

```
S(1).type='()'        S(2).type='.'         S(3).type='()'
S(1).subs={1,2}       S(2).subs='name'      S(3).subs={3:5}
```

See Also

`subsref`

Purpose

Overloaded method for `X(A)`

Syntax

```
i = subsindex(A)
```

Description

`i = subsindex(A)` is called for the syntax `'X(A)'` when `A` is an object. `subsindex` must return the value of the object as a zero-based integer index (`i` must contain integer values in the range `0` to `prod(size(X))-1`). `subsindex` is called by the default `subsref` and `subsasgn` functions, and you can call it if you overload these functions.

See Also

`subsasgn`, `subsref`

subsref

Purpose

Overloaded method for `A(I)`, `A{I}` and `A.field`

Syntax

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

Description

`B = subsref(A,S)` is called for the syntax `A(i)`, `A{i}`, or `A.i` when `A` is an object. `S` is a structure array with the fields:

- `type`: A string containing `'()'`, `'{}'`, or `'.'`, where `'()'` specifies integer subscripts; `'{}'` specifies cell array subscripts, and `'.'` specifies subscripted structure fields.
- `subs`: A cell array or string containing the actual subscripts.

Examples

The syntax `A(1:2,:)` calls `subsref(A,S)` where `S` is a 1-by-1 structure with `S.type='()'` and `S.subs = {1:2,':'}`. A colon used as a subscript is passed as the string `':'`.

The syntax `A{1:2}` calls `subsref(A,S)` where `S.type='{}'` .

The syntax `A.field` calls `subsref(A,S)` where `S.type='.'` and `S.subs='field'`.

These simple calls are combined in a straightforward way for more complicated subscripting expressions. In such cases `length(S)` is the number of subscripting levels. For instance, `A(1,2).name(3:5)` calls `subsref(A,S)` where `S` is 3-by-1 structure array with the following values:

```
S(1).type='()'      S(2).type='.'       S(3).type='()'
S(1).subs={1,2}     S(2).subs='name'    S(3).subs={3:5}
```

See Also

`subsasgn`

Purpose

Angle between two subspaces

Syntax

```
theta = subspace(A,B)
```

Description

`theta = subspace(A,B)` finds the angle between two subspaces specified by the columns of `A` and `B`. If `A` and `B` are column vectors of unit length, this is the same as `acos(A'*B)`.

Remarks

If the angle between the two subspaces is small, the two spaces are nearly linearly dependent. In a physical experiment described by some observations `A`, and a second realization of the experiment described by `B`, `subspace(A,B)` gives a measure of the amount of new information afforded by the second experiment not associated with statistical errors of fluctuations.

Examples

Consider two subspaces of a Hadamard matrix, whose columns are orthogonal.

```
H = hadamard(8);
A = H(:,2:4);
B = H(:,5:8);
```

Note that matrices `A` and `B` are different sizes—`A` has three columns and `B` four. It is not necessary that two subspaces be the same size in order to find the angle between them. Geometrically, this is the angle between two hyperplanes embedded in a higher dimensional space.

```
theta = subspace(A,B)
theta =
    1.5708
```

That `A` and `B` are orthogonal is shown by the fact that `theta` is equal to $\pi/2$.

```
theta - pi/2
ans =
     0
```

sum

Purpose

Sum of array elements

Syntax

```
B = sum(A)
B = sum(A,dim)
```

Description

`B = sum(A)` returns sums along different dimensions of an array.

If `A` is a vector, `sum(A)` returns the sum of the elements.

If `A` is a matrix, `sum(A)` treats the columns of `A` as vectors, returning a row vector of the sums of each column.

If `A` is a multidimensional array, `sum(A)` treats the values along the first non-singleton dimension as vectors, returning an array of row vectors.

`B = sum(A,dim)` sums along the dimension of `A` specified by scalar `dim`.

Remarks

`sum(diag(X))` is the `trace` of `X`.

Examples

The magic square of order 3 is

```
M = magic(3)
M =
     8    1    6
     3    5    7
     4    9    2
```

This is called a magic square because the sums of the elements in each column are the same.

```
sum(M) =
     15    15    15
```

as are the sums of the elements in each row, obtained by transposing:

```
sum(M') =
     15    15    15
```

See Also

`cumsum`, `diff`, `prod`, `trace`

Purpose

Superior class relationship

Syntax

```
superiorto('class1','class2',...)
```

Description

The `superiorto` function establishes a hierarchy that determines the order in which MATLAB calls object methods.

`superiorto('class1','class2',...)` invoked within a class constructor method (say `myclass.m`) indicates that `myclass`'s method should be invoked if a function is called with an object of class `myclass` and one or more objects of class `class1`, `class2`, and so on.

Remarks

Suppose `A` is of class `'class_a'`, `B` is of class `'class_b'` and `C` is of class `'class_c'`. Also suppose the constructor `class_c.m` contains the statement: `superiorto('class_a')`. Then `e = fun(a,c)` or `e = fun(c,a)` invokes `class_c/fun`.

If a function is called with two objects having an unspecified relationship, the two objects are considered to have equal precedence, and the leftmost object's method is called. So, `fun(b,c)` calls `class_b/fun`, while `fun(c,b)` calls `class_c/fun`.

See Also

`inferiorto`

svd

Purpose

Singular value decomposition

Syntax

```
s = svd(X)
[U,S,V] = svd(X)
[U,S,V] = svd(X,0)
```

Description

The svd command computes the matrix singular value decomposition.

`s = svd(X)` returns a vector of singular values.

`[U,S,V] = svd(X)` produces a diagonal matrix `S` of the same dimension as `X`, with nonnegative diagonal elements in decreasing order, and unitary matrices `U` and `V` so that `X = U*S*V'`.

`[U,S,V] = svd(X,0)` produces the "economy size" decomposition. If `X` is `m`-by-`n` with `m > n`, then `svd` computes only the first `n` columns of `U` and `S` is `n`-by-`n`.

Examples

For the matrix

```
X =
     1     2
     3     4
     5     6
     7     8
```

the statement

```
[U,S,V] = svd(X)
```

produces

```
U =
    0.1525    0.8226   -0.3945   -0.3800
    0.3499    0.4214    0.2428    0.8007
    0.5474    0.0201    0.6979   -0.4614
    0.7448   -0.3812   -0.5462    0.0407
```

```
S =
    14.2691         0
          0    0.6268
          0         0
          0         0
V =
    0.6414   -0.7672
    0.7672    0.6414
```

The economy size decomposition generated by

```
[U,S,V] = svd(X,0)
```

produces

```
U =
    0.1525    0.8226
    0.3499    0.4214
    0.5474    0.0201
    0.7448   -0.3812
S =
   14.2691         0
         0    0.6268
V =
    0.6414   -0.7672
    0.7672    0.6414
```

Algorithm

The svd command uses the LINPACK routine ZSVDC.

Diagnostics

If the limit of 75 QR step iterations is exhausted while seeking a singular value, this message appears:

```
Solution will not converge.
```

References

[1] Dongarra, J.J., J.R. Bunch, C.B. Moler, and G.W. Stewart, *LINPACK Users' Guide*, SIAM, Philadelphia, 1979.

See Also

svds, gsvd

svds

Purpose

Find a few singular values

Syntax

```
s = svds(A)
s = svds(A,k)
s = svds(A,k,0)
[U,S,V] = svds(A,...)
```

Description

`svds(A)` computes the five largest singular values and associated singular vectors of the matrix `A`.

`svds(A,k)` computes the `k` largest singular values and associated singular vectors of the matrix `A`.

`svds(A,k,0)` computes the `k` smallest singular values and associated singular vectors.

With one output argument, `s` is a vector of singular values. With three output arguments and if `A` is `m`-by-`n`:

- `U` is `m`-by-`k` with orthonormal columns
- `S` is `k`-by-`k` diagonal
- `V` is `n`-by-`k` with orthonormal columns
- `U*S*V'` is the closest rank `k` approximation to `A`

Algorithm

`svds(A,k)` uses `eigs` to find the `k` largest magnitude eigenvalues and corresponding eigenvectors of `B = [0 A; A' 0]`.

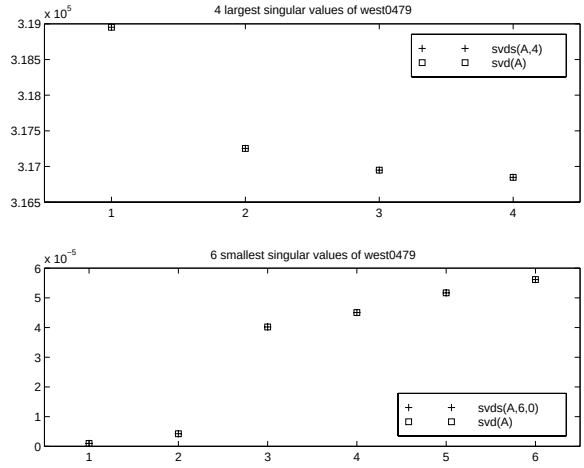
`svds(A,k,0)` uses `eigs` to find the `2k` smallest magnitude eigenvalues and corresponding eigenvectors of `B = [0 A; A' 0]`, and then selects the `k` positive eigenvalues and their eigenvectors.

Example

`west0479` is a real 479-by-479 sparse matrix. `svd` calculates all 479 singular values. `svds` picks out the largest and smallest singular values.

```
load west0479
s = svd(full(west0479))
sl = svds(west0479,4)
ss = svds(west0479,6,0)
```

These plots show some of the singular values of `west0479` as computed by `svd` and `svds`.



The largest singular value of `west0479` can be computed a few different ways:

```
svds(west0479,1) =
 3.189517598808622e+05

max(svd(full(west0479))) =
 3.18951759880862e+05

norm(full(west0479)) =
 3.189517598808623e+05
```

and estimated:

```
normest(west0479) =
 3.189385666549991e+05
```

See Also

`svd`, `eigs`

switch

Purpose

Switch among several cases based on a conditional expression

Syntax

```
switch switch_expr
  case case_expr
    statements
  case {case_expr1,case_expr2,case_expr3,...}
    statements
...
  otherwise
    statements
end
```

Description

The `switch` statement syntax is a means of conditionally executing code. In particular, `switch` executes one set of statements selected from an arbitrary number of alternatives, called `case` groups. Each `case` group consists of:

- A `case` statement, consisting of a `case` label and one or more conditional expressions
- One or more *statements*, where a statement can be another `switch` statement

Execution of the `switch` statement begins with an evaluation of *switch_expr*. The determined value is then compared to each *case_expr* in the order in which they appear in the `switch` statement. The *statements* associated with the first `case` where *switch_expr* matches *case_expr* are executed.

A cell array can be used to associate a list of `case` expressions with a set of statements. The cell array syntax is shown in the second `case` group above. A match of the *switch_expr* with any element in the cell array will result in a match to the `case` group.

The *switch_expr* can be a scalar or a string. A scalar *switch_expr* matches a *case_expr* if *switch_expr* `==` *case_expr*. A string *switch_expr* matches a *case_expr* if `strcmp(`*switch_expr*`,`*case_expr*`)` returns `1` (true).

If *switch_expr* does not match the case expression for any of the case groups, control is passed to the optional `otherwise` case. The `otherwise` statement does not include any conditional expressions and therefore matches all values of *switch_expr*.

After executing the appropriate case or otherwise group, program execution continues with the statement after the end statement.

Note for C Programmers: The MATLAB switch construct is different from the C programming language switch construct. The C switch construct allows execution to "fall through" many case groups before ending, using break statements to control execution. The MATLAB switch construct executes one case group at most and therefore break statements are not required.

Examples

Assume method exists as a string variable:

```
switch lower(method)
    case {'linear','bilinear'}
         disp('Method is linear')
    case 'cubic'
         disp('Method is cubic')
    case 'nearest'
         disp('Method is nearest')
    otherwise
         disp('Unknown method.')
end
```

See Also

case, end, if, otherwise, while

symmmd

Purpose

Sparse symmetric minimum degree ordering

Syntax

```
p = symmmd(S)
```

Description

`p = symmmd(S)` returns a symmetric minimum degree ordering of `S`. For a symmetric positive definite matrix `S`, this is a permutation `p` such that `S(p,p)` tends to have a sparser Cholesky factor than `S`. Sometimes `symmmd` works well for symmetric indefinite matrices too.

Remarks

The minimum degree ordering is automatically used by `\` and `/` for the solution of symmetric, positive definite, sparse linear systems.

Some options and parameters associated with heuristics in the algorithm can be changed with `spparms`.

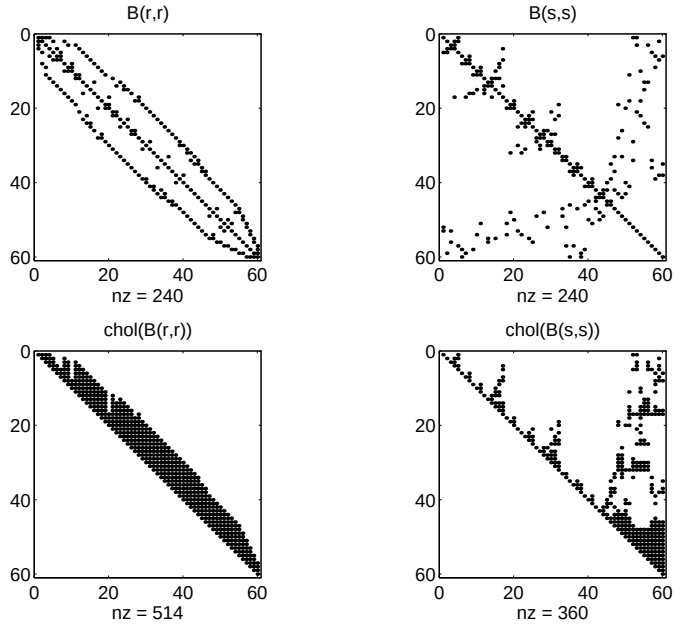
Algorithm

The symmetric minimum degree algorithm is based on the column minimum degree algorithm. In fact, `symmmd(A)` just creates a nonzero structure `K` such that `K'*K` has the same nonzero structure as `A` and then calls the column minimum degree code for `K`.

Examples

Here is a comparison of reverse Cuthill-McKee and minimum degree on the Bucky ball example mentioned in the `symrcm` reference page.

```
B = bucky+4*speye(60);
r = symrcm(B);
p = symmmd(B);
R = B(r,r);
S = B(p,p);
subplot(2,2,1), spy(R), title('B(r,r)')
subplot(2,2,2), spy(S), title('B(s,s)')
subplot(2,2,3), spy(chol(R)), title('chol(B(r,r))')
subplot(2,2,4), spy(chol(S)), title('chol(B(s,s))')
```



Even though this is a very small problem, the behavior of both orderings is typical. RCM produces a matrix with a narrow bandwidth which fills in almost completely during the Cholesky factorization. Minimum degree produces a structure with large blocks of contiguous zeros which do not fill in during the factorization. Consequently, the minimum degree ordering requires less time and storage for the factorization.

See Also

`colmmd`, `colperm`, `symrcm`

References

[1] Gilbert, John R., Cleve Moler, and Robert Schreiber, “Sparse Matrices in MATLAB: Design and Implementation,” *SIAM Journal on Matrix Analysis and Applications 13*, 1992, pp. 333-356.

symrcm

Purpose

Sparse reverse Cuthill-McKee ordering

Syntax

```
r = symrcm(S)
```

Description

`r = symrcm(S)` returns the symmetric reverse Cuthill-McKee ordering of `S`. This is a permutation `r` such that `S(r,r)` tends to have its nonzero elements closer to the diagonal. This is a good preordering for LU or Cholesky factorization of matrices that come from long, skinny problems. The ordering works for both symmetric and nonsymmetric `S`.

For a real, symmetric sparse matrix, `S`, the eigenvalues of `S(r,r)` are the same as those of `S`, but `eig(S(r,r))` probably takes less time to compute than `eig(S)`.

Algorithm

The algorithm first finds a pseudoperipheral vertex of the graph of the matrix. It then generates a level structure by breadth-first search and orders the vertices by decreasing distance from the pseudoperipheral vertex. The implementation is based closely on the SPARSPAK implementation described by George and Liu.

Examples

The statement

```
B = bucky
```

uses an M-file in the `demos` toolbox to generate the adjacency graph of a truncated icosahedron. This is better known as a soccer ball, a Buckminster Fuller geodesic dome (hence the name `bucky`), or, more recently, as a 60-atom carbon molecule. There are 60 vertices. The vertices have been ordered by numbering half of them from one hemisphere, pentagon by pentagon; then reflecting into the other hemisphere and gluing the two halves together. With this numbering, the matrix does not have a particularly narrow bandwidth, as the first spy plot shows

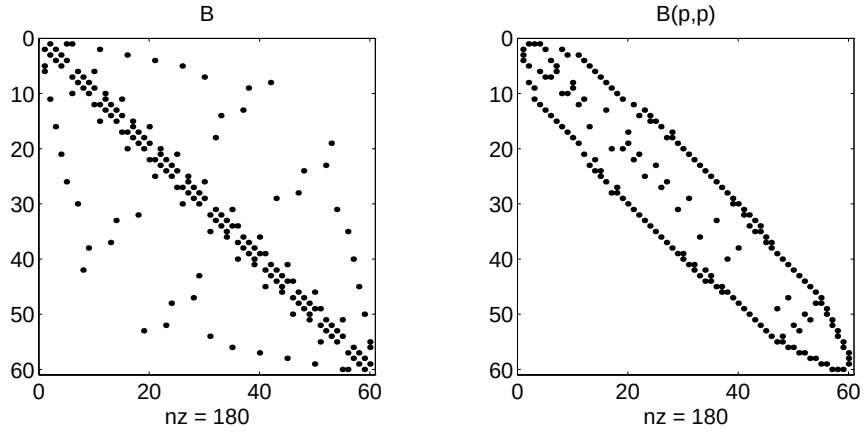
```
subplot(1,2,1), spy(B), title('B')
```

The reverse Cuthill-McKee ordering is obtained with

```
p = symrcm(B);
R = B(p,p);
```

The spy plot shows a much narrower bandwidth:

```
subplot(1,2,2), spy(R), title('B(p,p)')
```



This example is continued in the reference pages for `symmmd`.

The bandwidth can also be computed with

```
[i,j] = find(B);
bw = max(i-j) + 1
```

The bandwidths of `B` and `R` are 35 and 12, respectively.

See Also

`colmmd`, `colperm`, `symmmd`

References

[1] George, Alan and Joseph Liu, *Computer Solution of Large Sparse Positive Definite Systems*, Prentice-Hall, 1981.

[2] Gilbert, John R., Cleve Moler, and Robert Schreiber, "Sparse Matrices in MATLAB: Design and Implementation," to appear in *SIAM Journal on Matrix Analysis*, 1992. A slightly expanded version is also available as a technical report from the Xerox Palo Alto Research Center.

symvar

Purpose

Determine symbolic variables in an expression

Syntax

```
symvar('str')
```

Description

`symvar('str')` searches the string *str* for identifiers other than `i`, `j`, `pi`, `inf`, `nan`, `eps`, and common functions. The variables are returned as a cell array of strings. If no such variable exists, `symvar` returns the empty cell array `{}`.

Example

`symvar('cos(pi*x - beta1)')` returns `{'beta1','x'}`.
`symvar('pi eps nan')` returns `{}`.

See Also

`findstr`

Purpose

Tangent and hyperbolic tangent

Syntax

```
Y = tan(X)
Y = tanh(X)
```

Description

The `tan` and `tanh` functions operate element-wise on arrays. The functions' domains and ranges include complex values. All angles are in radians.

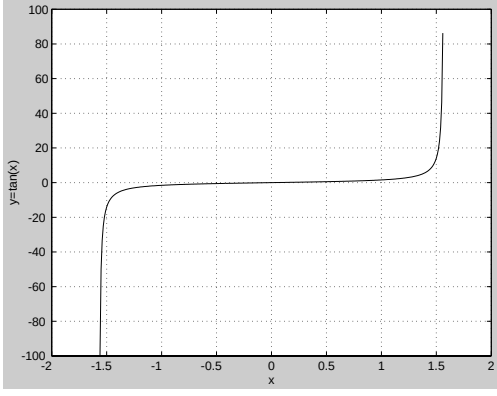
`Y = tan(X)` returns the circular tangent of each element of `X`.

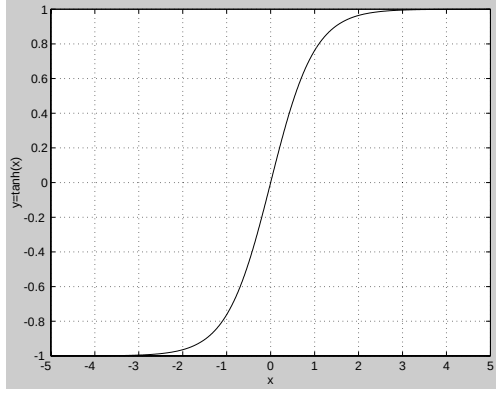
`Y = tanh(X)` returns the hyperbolic tangent of each element of `X`.

Examples

Graph the tangent function over the domain $-\pi/2 < x < \pi/2$, and the hyperbolic tangent function over the domain $-5 \le x \le 5$.

```
x = (-pi/2)+0.01:0.01:(pi/2)-0.01; plot(x,tan(x))
x = -5:0.01:5; plot(x,tanh(x))
```





The expression `tan(pi/2)` does not evaluate as infinite but as the reciprocal of the floating point accuracy `eps` since `pi` is only a floating-point approximation to the exact value of π.

Algorithm

$$\tan(z) = \frac{\sin(z)}{\cos(z)}$$

$$\tanh(z) = \frac{\sinh(z)}{\cosh(z)}$$

See Also `atan`, `atan2`

Purpose

Return the name of the system's temporary directory

Syntax

```
tmp_dir = tempdir
```

Description

`tmp_dir = tempdir` returns the name of the system's temporary directory, if one exists. This function does not create a new directory.

See Also

`tempname`

tempname

Purpose Unique name for temporary file

Syntax `tempname`

Description `tempname` returns a unique string beginning with the characters `tp`. This string is useful as a name for a temporary file.

See Also `tempdir`

Purpose

Read formatted data from text file

Syntax

```
[A,B,C,...] = textread('filename','format')
[A,B,C,...] = textread('filename','format',N)
[...] = textread(...,'param','value',...)
```

Description

`[A,B,C,...] = textread('filename','format')` reads data from the file `'filename'` into the variables `A,B,C,` and so on, using the specified `format`, until the entire file is read. `textread` is useful for reading text files with a known format. Both fixed and free format files can be handled.

`textread` matches and converts groups of characters from the input. Each input field is defined as a string of non-whitespace characters that extends to the next whitespace or delimiter character, or to the maximum field width. Repeated delimiter characters are significant, while repeated whitespace characters are treated as one.

The `format` string determines the number and types of return arguments. The number of return arguments is the number of items in the `format` string. The `format` string supports a subset of the conversion specifiers and conventions of the C language `FSCANF` function. Values for the `format` string are listed in the table below. Whitespace characters in the `format` string are ignored.

format	Action	Output
Literals (ordinary characters)	Ignore the matching characters. For example, in a file that has `Dept` followed by a number (for department number), to skip the `Dept` and read only the number, use `'Dept'` in the `format` string.	None
`%d`	Read a signed integer value.	Double array
`%u`	Read an integer value.	Double array
`%f`	Read a floating point value.	Double array
`%s`	Read a whitespace-separated string.	Cell array of strings

format	Action	Output
%q	Read a string, which could be in double quotes.	Cell array of strings. Does not include the double quotes.
%c	Read characters, including white space.	Character array
%[...]	Read the longest string containing characters specified in the brackets.	Cell array of strings
%[^...]	Read the longest non-empty string containing characters that are not specified in the brackets.	Cell array of strings
%*... instead of %	Ignore the matching characters specified by *.	No output
%w... instead of %	Read field width specified by w. The %f format supports %w.pf, where w is the field width and p is the precision.	

`[A,B,C,...] = textread('filename','format',N)` reads the data, reusing the `format` string `N` times, where `N` is an integer greater than zero. If `N` is smaller than zero, `textread` reads the entire file.

`[...] = textread(...,'param','value',...)` customizes `textread` using `param/value` pairs, as listed in the table below.

param	value	Action
`whitespace`	`\*` where `*` can be:	Treats vector of characters, `*`, as whitespace. Default is `\b\r\n\t`.

	`b`
	`f`
	`n`
	`r`
	`t`
	`\\`
	`\''` or `''`
	`%%`
		Backspace
		Form feed
		New line
		Carriage return
		Horizontal tab
		Backslash
		Single quotation mark
		Percent sign

`delimiter`	Delimiter character	Specifies delimiter character. Default is none.
`expchars`	Exponent characters	Default is `eEdD`.
`bufsize`	positive integer	Specifies the maximum string length, in bytes. Default is `4095`.
`headerlines`	positive integer	Ignores the specified number of lines at the beginning of the file.
`commentstyle`	`matlab`	Ignores characters after `%`
`commentstyle`	`shell`	Ignores characters after `#`.
`commentstyle`	`c`	Ignores characters between `/*` and `*/`.
`commentstyle`	`c++`	Ignores characters after `//`.

Examples

Example 1 – Read All Fields in Free Format File Using %

The first line of `mydata.dat` is

```
Sally    Type1 12.34 45 Yes
```

Read the first line of the file as a free format file using the `%` format.

```
[names,types,x,y,answer] = textread('mydata.dat','%s %s %f ...
   %d %s',1)
```

returns

```
names =
    'Sally'
types =
    'Type1'
x =
  12.34000000000000
y =
    45
answer =
    'Yes'
```

Example 2 – Read as Fixed Format File, Ignoring the Floating Point Value

The first line of `mydata.dat` is

```
Sally    Type1 12.34 45 Yes
```

Read the first line of the file as a fixed format file, ignoring the floating point value.

```
[names,types,y,answer] = textread('mydata.dat','%9c %5s %*f ...
...
   %2d %3s',1)
```

returns

```
names =
Sally
types =
    'Type1'
y =
    45
answer =
    'Yes'
```

`%*f` in the `format` string causes `textread` to ignore the floating point value, in this case, `12.34`.

Example 3 – Read Using Literal to Ignore Matching Characters

The first line of `mydata.dat` is

```
Sally    Type1 12.34 45 Yes
```

Read the first line of the file, ignoring the characters `Type` in the second field.

```
[names,typenum,x,y,answer] = textread('mydata.dat','%s Type%d %f
%d %s',1)
```

returns

```
names =
    'Sally'
typenum =
     1
x =
  12.34000000000000
y =
    45
answer =
    'Yes'
```

`Type%d` in the `format` string causes the characters `Type` in the second field to be ignored, while the rest of the second field is read as a signed integer, in this case, `1`.

Example 4 – Read M-file into a Cell Array of Strings

Read the file `fft.m` into cell array of strings.

```
file = textread('fft.m','%s','delimiter','\n','whitespace','');
```

See Also

`dlmread`, `sscanf`

tic, toc

Purpose

Stopwatch timer

Syntax

```
tic
    any statements
toc
t = toc
```

Description

`tic` starts a stopwatch timer.

`toc` prints the elapsed time since `tic` was used.

`t = toc` returns the elapsed time in `t`.

Examples

This example measures how the time required to solve a linear system varies with the order of a matrix.

```
for n = 1:100
    A = rand(n,n);
    b = rand(n,1);
    tic
    x = A\b;
    t(n) = toc;
end
plot(t)
```

See Also

`clock`, `cputime`, `etime`

Purpose

Toeplitz matrix

Syntax

```
T = toeplitz(c,r)
T = toeplitz(r)
```

Description

A *Toeplitz* matrix is defined by one row and one column. A *symmetric Toeplitz* matrix is defined by just one row. `toeplitz` generates Toeplitz matrices given just the row or row and column description.

`T = toeplitz(c,r)` returns a nonsymmetric Toeplitz matrix `T` having `c` as its first column and `r` as its first row. If the first elements of `c` and `r` are different, a message is printed and the column element is used.

`T = toeplitz(r)` returns the symmetric or Hermitian Toeplitz matrix formed from vector `r`, where `r` defines the first row of the matrix.

Examples

A Toeplitz matrix with diagonal disagreement is

```
c = [1  2  3  4  5];
r = [1.5  2.5  3.5  4.5  5.5];
toeplitz(c,r)
Column wins diagonal conflict:
ans =
    1.000    2.500    3.500    4.500    5.500
    2.000    1.000    2.500    3.500    4.500
    3.000    2.000    1.000    2.500    3.500
    4.000    3.000    2.000    1.000    2.500
    5.000    4.000    3.000    2.000    1.000
```

See Also

`hankel`

trace

Purpose Sum of diagonal elements

Syntax `b = trace(A)`

Description `b = trace(A)` is the sum of the diagonal elements of the matrix `A`.

Algorithm `trace` is a single-statement M-file.

```
t = sum(diag(A));
```

See Also `det`, `eig`

Purpose

Trapezoidal numerical integration

Syntax

```
Z = trapz(Y)
Z = trapz(X,Y)
Z = trapz(...,dim)
```

Description

`Z = trapz(Y)` computes an approximation of the integral of `Y` via the trapezoidal method (with unit spacing). To compute the integral for spacing other than one, multiply `Z` by the spacing increment.

If `Y` is a vector, `trapz(Y)` is the integral of `Y`.

If `Y` is a matrix,`trapz(Y)` is a row vector with the integral over each column.

If `Y` is a multidimensional array, `trapz(Y)` works across the first nonsingleton dimension.

`Z = trapz(X,Y)` computes the integral of `Y` with respect to `X` using trapezoidal integration.

If `X` is a column vector and `Y` an array whose first nonsingleton dimension is `length(X)`, `trapz(X,Y)` operates across this dimension.

`Z = trapz(...,dim)` integrates across the dimension of `Y` specified by scalar `dim`. The length of `X`, if given, must be the same as `size(Y,dim)`.

Examples

The exact value of $\int_0^{\pi} \sin(x)dx$ is 2.

To approximate this numerically on a uniformly spaced grid, use

```
X = 0:pi/100:pi;
Y = sin(x);
```

Then both

```
Z = trapz(X,Y)
```

and

```
Z = pi/100*trapz(Y)
```

produce

```
Z =
    1.9998
```

A nonuniformly spaced example is generated by

```
X = sort(rand(1,101)*pi);
Y = sin(X);
Z = trapz(X,Y);
```

The result is not as accurate as the uniformly spaced grid. One random sample produced

```
Z =
    1.9984
```

See Also

`cumsum`, `cumtrapz`

Purpose

Lower triangular part of a matrix

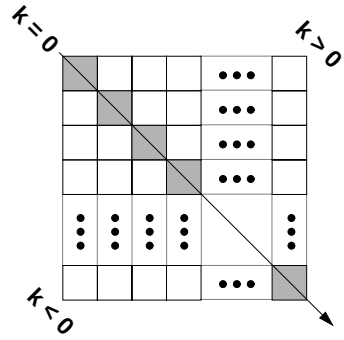
Syntax

```
L = tril(X)
L = tril(X,k)
```

Description

`L = tril(X)` returns the lower triangular part of `X`.

`L = tril(X,k)` returns the elements on and below the kth diagonal of `X`. `k = 0` is the main diagonal, `k > 0` is above the main diagonal, and `k < 0` is below the main diagonal.



Examples

`tril(ones(4,4),-1)` is

```
     0     0     0     0
     1     0     0     0
     1     1     0     0
     1     1     1     0
```

See Also

`diag`, `triu`

triu

Purpose

Upper triangular part of a matrix

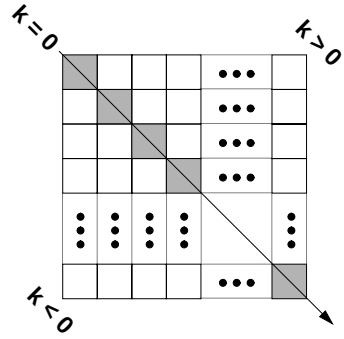
Syntax

```
U = triu(X)
U = triu(X,k)
```

Description

`U = triu(X)` returns the upper triangular part of `X`.

`U = triu(X,k)` returns the element on and above the kth diagonal of `X`. `k = 0` is the main diagonal, `k > 0` is above the main diagonal, and `k < 0` is below the main diagonal.



Examples

`triu(ones(4,4),-1)` is

```
     1     1     1     1
     1     1     1     1
     0     1     1     1
     0     0     1     1
```

See Also

`diag`, `tril`

Purpose

Begin `try` block

Description

The general form of a `try` statement is:

`try` statement, ..., statement, `catch` statement, ..., statement `end`

Normally, only the statements between the `try` and `catch` are executed. However, if an error occurs while executing any of the statements, the error is captured into `lasterr`, and the statements between the `catch` and `end` are executed. If an error occurs within the `catch` statements, execution stops unless caught by another `try...catch` block. The error string produced by a failed `try` block can be obtained with `lasterr`.

See Also

`catch`, `end`, `eval`, `evalin`

tsearch

Purpose

Search for enclosing Delaunay triangle

Syntax

```
T = tsearch(x,y,TRI,xi,yi)
```

Description

`T = tsearch(x,y,TRI,xi,yi)` returns an index into the rows of `TRI` for each point in `xi,yi`. The `tsearch` command returns `NaN` for all points outside the convex hull. Requires a triangulation `TRI` of the points `x,y` obtained from `delaunay`.

See Also

`delaunay`, `dsearch`

Purpose

List file

Syntax

```
type filename
```

Description

`type filename` displays the contents of the specified file in the MATLAB command window given a full pathname or a `MATLABPATH` relative partial pathname. Use pathnames and drive designators in the usual way for your computer's operating system.

If you do not specify a filename extension, the `type` command adds the `m` extension by default. The `type` command checks the directories specified in MATLAB's search path, which makes it convenient for listing the contents of M-files on the screen.

Examples

`type foo.bar` lists the file `foo.bar`.

`type foo` lists the file `foo.m`.

See Also

`cd`, `dbtype`, `delete`, `dir`, `partialpath`, `path`, `what`, `who`

uint8, uint16, uint32

Purpose

Convert to unsigned integer

Syntax

```
i = uint8(x)
i = uint16(x)
i = uint32(x)
```

Description

`i = uint*(x)` converts the vector `x` into an unsigned integer. `x` can be any numeric object (such as a `double`). The results of a `uint*` operation are shown in the next table.

Operation	Output Range	Output Type	Bytes per Element	Output Class
`uint8`	0 to 255	Unsigned 8-bit integer	1	`uint8`
`uint16`	0 to 65535	Unsigned 16-bit integer	2	`uint16`
`uint32`	0 to 4294967295	Unsigned 32-bit integer	4	`uint32`

A value of `x` above or below the range for a class is mapped to one of the endpoints of the range. If `x` is already an unsigned integer of the same class, `uint*` has no effect.

The `uint*` class is primarily meant to store integer values. Most operations that manipulate arrays without changing their elements are defined (examples are `reshape`, `size`, the logical and relational operators, subscripted assignment, and subscripted reference). No math operations except for `sum` are defined for `uint*` since such operations are ambiguous on the boundary of the set (for example they could wrap or truncate there). You can define your own methods for `uint*` (as you can for any object) by placing the appropriately named method in an `@uint*` directory within a directory on your path.

Type `help datatypes` for the names of the methods you can overload.

See Also

`double`, `int8`, `int16`, `int32`, `single`

Purpose

Set union of two vectors

Syntax

```
c = union(a,b)
c = union(A,B,'rows')
[c,ia,ib] = union(...)
```

Description

`c = union(a,b)` returns the combined values from `a` and `b` but with no repetitions. The resulting vector is sorted in ascending order. In set theoretic terms, `c = a` $\cup$ `b`. `a` and `b` can be cell arrays of strings.

`c = union(A,B,'rows')` when `A` and `B` are matrices with the same number of columns returns the combined rows from `A` and `B` with no repetitions.

`[c,ia,ib] = union(...)` also returns index vectors `ia` and `ib` such that `c = a(ia)` and `c = b(ib)` or, for row combinations, `c = a(ia,:)` and `c = b(ib,:)`.

Examples

```
a = [-1 0 2 4 6];
b = [-1 0 1 3];
[c,ia,ib] = union(a,b);
c =

    -1     0     1     2     3     4     6

ia =

     3     4     5

ib =

     1     2     3     4
```

See Also

`intersect`, `setdiff`, `setxor`, `unique`

unique

Purpose

Unique elements of a vector

Syntax

```
b = unique(a)
b = unique(A,'rows')
[b,i,j] = unique(...)
```

Description

`b = unique(a)` returns the same values as in `a` but with no repetitions. The resulting vector is sorted in ascending order. `a` can be a cell array of strings.

`b = unique(A,'rows')` returns the unique rows of `A`.

`[b,i,j] = unique(...)` also returns index vectors `i` and `j` such that `b = a(i)` and `a = b(j)` (or `b = a(i,:)` and `a = b(j,:)`).

Examples

```
a = [1 1 5 6 2 3 3 9 8 6 2 4]
a =
1     1     5     6     2     3     3     9     8     6     2     4
[b,i,j] = unique(a)
b =
     1     2     3     4     5     6     8     9
i =
     2    11     7    12     3    10     9     8
j =
1     1     5     6     2     3     3     8     7     6     2     4
a(i)
ans =
     1     2     3     4     5     6     8     9
b(j)
ans =
1     1     5     6     2     3     3     9     8     6     2     4
```

See Also

`intersect`, `ismember`, `setdiff`, `setxor`, `union`

Purpose

Correct phase angles

Syntax

```
Q = unwrap(P)
Q = unwrap(P,tol)
Q = unwrap(P,[],dim)
Q = unwrap(P,tol,dim)
```

Description

`Q = unwrap(P)` corrects the radian phase angles in array `P` by adding multiples of $\pm 2\pi$ when absolute jumps between consecutive array elements are greater than π radians. If `P` is a matrix, `unwrap` operates columnwise. If `P` is a multidimensional array, `unwrap` operates on the first nonsingleton dimension.

`Q = unwrap(P,tol)` uses a jump tolerance `tol` instead of the default value, π.

`Q = unwrap(P,[],dim)` unwraps along `dim` using the default tolerance.

`Q = unwrap(P,tol,dim)` uses a jump tolerance of `tol`.

Examples

Array `P` features smoothly increasing phase angles except for discontinuities at elements `(3,1)` and `(1,2)`.

```
P =
         0    7.0686    1.5708    2.3562
    0.1963    0.9817    1.7671    2.5525
    6.6759    1.1781    1.9635    2.7489
    0.5890    1.3744    2.1598    2.9452
```

The function `Q = unwrap(P)` eliminates these discontinuities.

```
Q =
         0    0.7854    1.5708    2.3562
    0.1963    0.9817    1.7671    2.5525
    0.3927    1.1781    1.9635    2.7489
    0.5890    1.3744    2.1598    2.9452
```

Limitations

The `unwrap` function detects branch cut crossings, but it can be fooled by sparse, rapidly changing phase values.

See Also

`abs`, `angle`

upper

Purpose

Convert string to upper case

Syntax

```
t  = upper('str')
B = upper(A)
```

Description

`t  = upper('str')` converts any lower-case characters in the string *str* to the corresponding upper-case characters and leaves all other characters unchanged.

`B = upper(A)` when `A` is a cell array of strings, returns a cell array the same size as `A` containing the result of applying `upper` to each string within `A`.

Examples

`upper('attention!')` is `ATTENTION!`.

Remarks

Character sets supported:

- PC: Windows Latin-1
- Other: ISO Latin-1 (ISO 8859-1)

See Also

`lower`

Purpose

Variance

Syntax

```
var(X)
var(X,1)
var(X,w)
```

Description

`var(X)` returns the variance of `X` for vectors. For matrices, `var(X)`is a row vector containing the variance of each column of `X`. `var(X)` normalizes by N-1 where N is the sequence length. This makes `var(X)` the best unbiased estimate of the variance if `X` is a sample from a normal distribution.

`var(X,1)` normalizes by N and produces the second moment of the sample about its mean.

`var(X,W)` computes the variance using the weight vector `W`. The number of elements in `W` must equal the number of rows in `X` unless `W = 1`, which is treated as a short-cut for a vector of ones. The elements of `W` must be positive. `var` normalizes `W` by dividing each element in `W` by the sum of all its elements.

The variance is the square of the standard deviation (STD).

See Also

`corrcoef`, `cov`, `std`

varargin, varargout

Purpose

Pass or return variable numbers of arguments

Syntax

```
function varargout = foo(n)
y = function bar(varargin)
```

Description

`function varargout = foo(n)` returns a variable number of arguments from function `foo.m`.

`y = function bar(varargin)` accepts a variable number of arguments into function `bar.m`.

The `varargin` and `varargout` statements are used only inside a function M-file to contain the optional arguments to the function. Each must be declared as the last argument to a function, collecting all the inputs or outputs from that point onwards. In the declaration, `varargin` and `varargout` must be lowercase.

Examples

The function

```
function myplot(x,varargin)
plot(x,varargin{:})
```

collects all the inputs starting with the second input into the variable `varargin`. `myplot` uses the comma-separated list syntax `varargin{:}` to pass the optional parameters to `plot`. The call

```
myplot(sin(0:.1:1),'color',[.5 .7 .3],'linestyle',':')
```

results in `varargin` being a 1-by-4 cell array containing the values `'color'`, [.5 .7 .3], `'linestyle'`, and `':'`.

The function

```
function [s,varargout] = mysize(x)
nout = max(nargout,1)-1;
s = size(x);
for i=1:nout, varargout(i) = {s(i)}; end
```

returns the size vector and, optionally, individual sizes. So

```
[s,rows,cols] = mysize(rand(4,5));
```

returns `s = [4 5], rows = 4, cols = 5`.

See Also `nargin` , `nargout`, `nargchk`

vectorize

Purpose

Vectorize expression

Syntax

```
vectorize(string)
vectorize(function)
```

Description

`vectorize(`*`string`*`)` inserts a `.` before any `^`, `*` or `/` in *`string`*. The result is a character string.

`vectorize(`*`function`*`)` when function is an inline function object, vectorizes the formula for *`function`*. The result is the vectorized version of the inline function.

See Also

`inline`

`cd`, `dbtype`, `delete`, `dir`, `partialpath`, `path`, `what`, `who`

Purpose

Display version information for MATLAB, Simulink, and toolboxes

Syntax

```
ver
ver toolbox
```

Description

`ver` displays the current version numbers and release dates for MATLAB, Simulink, and toolboxes.

`ver toolbox` displays the current version number and release date for the toolbox specified by `toolbox`.

Remarks

See `ver.m` for information on how your own toolboxes can use the `ver` command.

Examples

```
ver fuzzy
```

returns the version information for the Fuzzy Logic Toolbox

```
Fuzzy Logic Toolbox.                    Version 2.0  15-Nov-1997
```

See Also

`help`, `info`, `version`, `whatsnew`

version

Purpose

Return MATLAB version number

Syntax

```
v = version
[v,d] = version
```

Description

`v = version` returns a string `v` containing the MATLAB version number.

`[v,d] = version` also returns a string `d` containing the date of the version.

See Also

`help`, `info`, `ver`, `whatsnew`

Purpose

Voronoi diagram

Syntax

```
voronoi(x,y)
voronoi(x,y,TRI)
h = voronoi(...,'LineSpec')
[vx,vy] = voronoi(...)
```

Definition

Consider a set of coplanar points P. For each point P_x in the set P, you can draw a boundary enclosing all the intermediate points lying closer to P_x than to other points in the set P. Such a boundary is called a *Voronoi polygon*, and the set of all Voronoi polygons for a given point set is called a *Voronoi diagram*.

Description

`voronoi(x,y)` plots the Voronoi diagram for the points `x,y`.

`voronoi(x,y,TRI)` uses the triangulation `TRI` instead of computing it via `delaunay`.

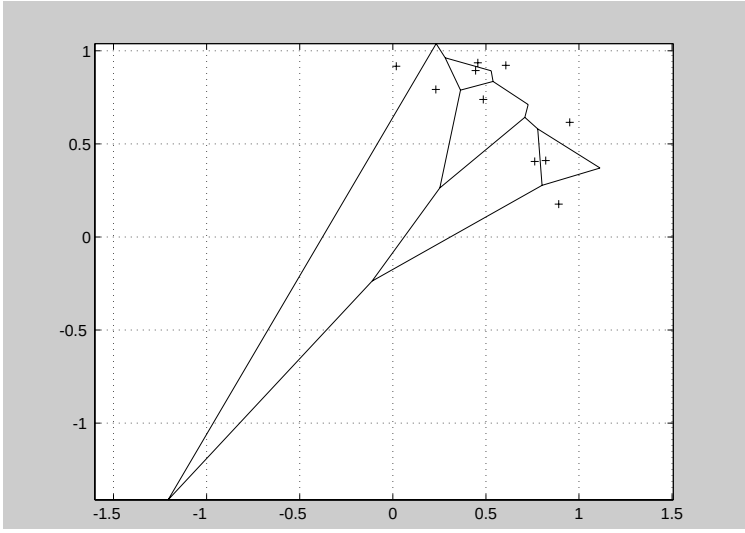
`h = voronoi(...,'LineSpec')` plots the diagram with color and line style specified and returns handles to the line objects created in `h`.

`[vx,vy] = voronoi(...)` returns the vertices of the Voronoi edges in `vx` and `vy` so that `plot(vx,vy,'-',x,y,'.')` creates the Voronoi diagram.

Examples

This code plots the Voronoi diagram for 10 randomly generated points.

```
rand('state',0);
x = rand(1,10); y = rand(1,10);
[vx, vy] = voronoi(x,y);
plot(x,y,'r+',vx,vy,'b-'); axis equal
```



See Also

convhull, delaunay, dsearch, linespec

Purpose

Display warning message

Syntax

```
warning('message')
warning on
warning off
warning backtrace
warning debug
warning once
warning always
[s,f] = warning
```

Description

`warning('message')` displays the text `'message'` as does the `disp` function, except that with `warning`, message display can be suppressed.

`warning off` suppresses all subsequent warning messages.

`warning on` re-enables them.

`warning backtrace` is the same as `warning on` except that the file and line number that produced the warning are displayed.

`warning debug` is the same as `dbstop if warning` and triggers the debugger when a warning is encountered.

`warning once` displays Handle Graphics backwards compatibility warnings only once per session.

`warning always` displays Handle Graphics backwards compatibility warnings as they are encountered (subject to current warning state).

`[s,f] = warning` returns the current warning state `s` and the current warning frequency `f` as strings.

Remarks

Use `dbstop on warning` to trigger the debugger when a warning is encountered.

See Also

`dbstop`, `disp`, `error`

wavread

Purpose

Read Microsoft WAVE (.wav) sound file

Syntax

```
y = wavread('filename')
[y,Fs,bits] = wavread('filename')
[...] = wavread('filename',N)
[...] = wavread('filename',[N1 N2])
[...] = wavread('filename','size')
```

Description

wavread supports multichannel data, with up to 16 bits per sample.

`y = wavread('filename')` loads a WAVE file specified by the string `filename`, returning the sampled data in `y`. The `.wav` extension is appended if no extension is given. Amplitude values are in the range `[-1,+1]`.

`[y,Fs,bits] = wavread('filename')` returns the sample rate (`Fs`) in Hertz and the number of bits per sample (`bits`) used to encode the data in the file.

`[...] = wavread('filename',N)` returns only the first `N` samples from each channel in the file.

`[...] = wavread('filename',[N1 N2])` returns only samples `N1` through `N2` from each channel in the file.

`siz = wavread('filename','size')` returns the size of the audio data contained in the file in place of the actual audio data, returning the vector `siz = [samples channels]`.

See Also

auread, wavwrite

Purpose

Write Microsoft WAVE (.wav) sound file

Syntax

```
wavwrite(y,'filename')
wavwrite(y,Fs,'filename')
wavwrite(y,Fs,N,'filename')
```

Description

`wavwrite` supports multi-channel 8- or 16-bit WAVE data.

`wavwrite(y,'filename')` writes a WAVE file specified by the string `filename`. The data should be arranged with one channel per column. Amplitude values outside the range `[-1,+1]` are clipped prior to writing.

`wavwrite(y,Fs,'filename')` specifies the sample rate `Fs`, in Hertz, of the data.

`wavwrite(y,Fs,N,'filename')` forces an `N`-bit file format to be written, where `N <= 16`.

See Also

`auwrite`, `wavread`

web

Purpose

Point Web browser at file or Web site

Syntax

```
web url
stat = web(...)
```

Description

`web url` opens a Web browser and loads the file or Web site specified by `url` (Uniform Resource Locator). `url` can be in any form your browser supports. Generally, `url` specifies a local file or a Web site on the Internet.

`stat = web(...)` returns the status of `web` to the variable `stat`.

Value of stat	Description of web Status
`0`	Successful execution.
`1`	Browser was not found.
`2`	Browser was found but could not be launched.

Remarks

On UNIX, the Web browser used is specified in the `docopt` M-file, in the `doccmd` string.

On Windows, the Web browser is determined by the operating system.

Examples

`web file:/disk/dir1/dir2/foo.html` points the browser to the file `foo.html`. If the file is on the MATLAB path, `web(['file:' which('foo.html')])` also works.

`web http://www.mathworks.com` loads The MathWorks Web page into your browser.

Use `web mailto:email_address` to send e-mail to another site.

See Also

`doc`, `docopt`

Purpose

Day of the week

Syntax

```
[N,S] = weekday(D)
```

Description

`[N,S] = weekday(D)` returns the day of the week in numeric (`N`) and string (`S`) form for each element of a serial date number array or date string. The days of the week are assigned these numbers and abbreviations:

N	S	N	S
1	Sun	5	Thu
2	Mon	6	Fri
3	Tue	7	Sat
4	Wed		

Examples

Either

```
[n,s] = weekday(728647)
```

or

```
[n,s] = weekday('19-Dec-1994')
```

returns `n = 2` and `s = Mon`.

See Also

`datenum`, `datevec`, `eomday`

what

Purpose

List M-files, MAT-files, and MEX-files in current directory

Syntax

```
what
what dirname
what('dirname')
```

Description

`what` lists the M-files, MAT-files, and MEX-files in the current directory.

`what dirname` lists the files in directory `dirname` on MATLAB's search path. It is not necessary to enter the full pathname of the directory. The last component, or last couple of components, is sufficient. Use `what class` or `what dirname/private` to list the files in a method directory or a private directory (for the class named `class`).

`w = what('dirname')` returns the results of `what` in a structure array with these fields.

Field	Description
`path`	path to directory
`M`	cell array of M-file names
`MAT`	cell array of MAT-file names
`MEX`	cell array of MEX-file names
`MDL`	cell array of MDL-file names
`P`	cell array of P-file names
`classes`	cell array of class names

Examples

The statements

```
what general
```

and

```
what matlab/general
```

both list the M-files in the `general` directory. The syntax of the path depends on your operating system.

UNIX	`matlab/general`
VMS	`MATLAB.GENERAL`
Windows	`MATLAB\GENERAL`

See Also

`dir`, `lookfor`, `path`, `which`, `who`

whatsnew

Purpose

Display README files for MATLAB and toolboxes

Syntax

```
whatsnew
whatsnew matlab
whatsnew toolboxpath
```

Description

`whatsnew` displays the `README` file for the MATLAB product or a specified toolbox. If present, the `README` file summarizes new functionality that is not described in the documentation.

`whatsnew matlab` displays the `README` file for MATLAB.

`whatsnew toolboxpath` displays the `README` file for the toolbox specified by the string `toolboxpath`.

Examples

```
whatsnew matlab % MATLAB README file
whatsnew signal % Signal Processing Toolbox README file
```

See Also

`help`, `lookfor`, `path`, `version`, `which`

Purpose

Locate functions and files

Syntax

```
which fun
which fun -all
which file.ext
which fun1 in fun2
which fun(a,b,c,...)
s = which(...)
```

Description

`which fun` displays the full pathname of the specified function. The function can be an M-file, MEX-file, workspace variable, built-in function, or SIMULINK model. The latter three display a message indicating that they are variable, built in to MATLAB, or are part of SIMULINK. Use `which private/fun` or `which class/fun` or `which class/private/fun` to further qualify the function name for private functions, methods, and private methods (for the class named `class`).

`which fun -all` displays the paths to all functions with the name `fun`. The first one in the list is the one normally returned by `which`. The others are either shadowed or can be executed in special circumstances. The `-all` flag can be used with all forms of `which`.

`which file.ext` displays the full pathname of the specified file.

`which fun1 in fun2` displays the pathname to function `fun1` in the context of the M-file `fun2`. While debugging `fun2`, `which fun1` does the same thing. You can use this to determine if a local or private version of a function is being called instead of a function on the path.

`which fun(a,b,c,...)` displays the path to the specified function with the given input arguments. For example, `which feval(g)`, when `g=inline('sin(x)')`, indicates that `inline/feval.m` is invoked.

`s = which(...)` returns the results of `which` in the string `s` instead of printing it to the screen. `s` will be the string `built-in` or `variable` for built-in functions or variables in the workspace. You must use the functional form of `which` when there is an output argument.

Examples

For example,

```
which inv
```

reveals that `inv` is a built-in function, and

```
which pinv
```

indicates that `pinv` is in the `matfun` directory of the MATLAB Toolbox.

The statement

```
which jacobian
```

probably says

```
jacobian not found
```

because there is no file `jacobian.m` on MATLAB's search path. Contrast this with `lookfor jacobian`, which takes longer to run, but finds several matches to the keyword `jacobian` in its search through all the help entries. (If `jacobian.m` does exist in the current directory, or in some private directory that has been added to MATLAB's search path, `which jacobian` finds it.)

See Also

`dir`, `exist`, `help`, `lookfor`, `path`, `type`, `what`, `who`

Purpose

Repeat statements an indefinite number of times

Syntax

```
while expression
    statements
end
```

Description

`while` repeats `statements` an indefinite number of times. The `statements` are executed while the real part of *expression* has all nonzero elements. *expression* is usually of the form

```
expression rop expression
```

where *rop* is ==, <, >, <=, >=, or ~=.

The scope of a `while` statement is always terminated with a matching `end`.

Examples

The variable `eps` is a tolerance used to determine such things as near singularity and rank. Its initial value is the *machine epsilon*, the distance from `1.0` to the next largest floating-point number on your machine. Its calculation demonstrates `while` loops:

```
eps = 1;
while (1+eps) > 1
    eps = eps/2;
end
eps = eps*2
```

See Also

`all`, `any`, `break`, `end`, `for`, `if`, `return`, `switch`

who, whos

Purpose

List directory of variables in memory

Syntax

```
who
whos
who global
whos global
who –file filename
whos –file filename
who ... var1 var2
whos ... var1 var2
s = who(...)
s = whos(...)
```

Description

`who` lists the variables currently in memory.

`whos` lists the current variables, their sizes, and whether they have nonzero imaginary parts.

`who global` and `whos global` list the variables in the global workspace.

`who –file filename` and `whos –file filename` list the variables in the specified MAT-file.

`who ... var1 var2` and `whos ... var1 var2` restrict the display to the variables specified. The wildcard character `*` can be used to display variables that match a pattern. For instance, `who A*` finds all variables in the current workspace that start with `A`. Use the functional form, such as `whos('–file',filename,v1,v2)`, when the filename or variable names are stored in strings.

`s = who(...)` returns a cell array containing the names of the variables in the workspace or file. Use the functional form of `who` when there is an output argument.

`s = whos(...)` returns a structure with the fields

`name`	variable name
`bytes`	number of bytes allocated for the array
`class`	class of variable

Use the functional form of `whos` when there is an output argument.

See Also

`dir`, `exist`, `help`, `what`, `workspace`

wilkinson

Purpose

Wilkinson's eigenvalue test matrix

Syntax

```
W = wilkinson(n)
```

Description

`W = wilkinson(n)` returns one of J. H. Wilkinson's eigenvalue test matrices. It is a symmetric, tridiagonal matrix with pairs of nearly, but not exactly, equal eigenvalues.

Examples

`wilkinson(7)` is

```
3    1    0    0    0    0    0
1    2    1    0    0    0    0
0    1    1    1    0    0    0
0    0    1    0    1    0    0
0    0    0    1    1    1    0
0    0    0    0    1    2    1
0    0    0    0    0    1    3
```

The most frequently used case is `wilkinson(21)`. Its two largest eigenvalues are both about 10.746; they agree to 14, but not to 15, decimal places.

See Also

`eig`, `gallery`, `pascal`

Purpose

Read a Lotus123 WK1 spreadsheet file into a matrix

Syntax

```
M = wk1read(filename)
M = wk1read(filename,r,c)
M = wk1read(filename,r,c,range)
```

Description

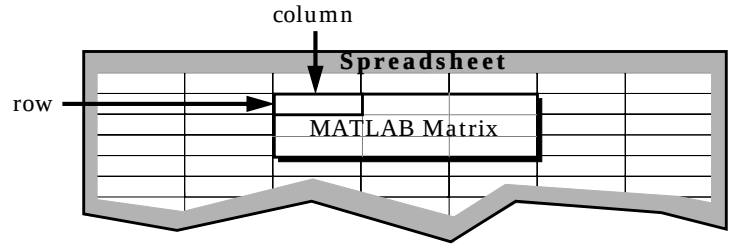
`M = wk1read(filename)` reads a Lotus123 WK1 spreadsheet file into the matrix `M`.

`M = wk1read(filename,r,c)` starts reading at the row-column cell offset specified by `(r,c)`. `r` and `c` are zero based so that `r=0`, `c=0` specifies the first value in the file.

`M = wk1read(filename,r,c,range)` reads the range of values specified by the parameter `range`, where `range` can be:

- A four-element vector specifying the cell range in the format

  `[upper_left_row upper_left_col lower_right_row lower_right_col]`



- A cell range specified as a string; for example, `'A1...C5'`.
- A named range specified as a string; for example, `'Sales'`.

See Also

`wk1write`

wk1write

Purpose

Write a matrix to a Lotus123 WK1 spreadsheet file

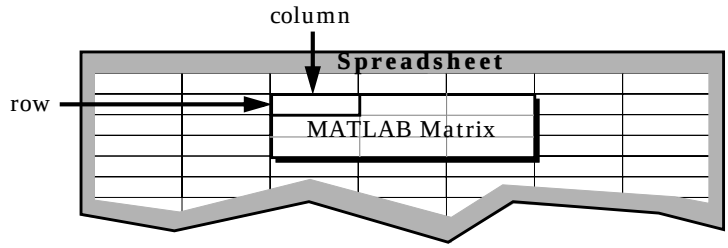
Syntax

```
wk1write(filename,M)
wk1write(filename,M,r,c)
```

Description

`wk1write(filename,M)` writes the matrix `M` into a Lotus123 WK1 spreadsheet file named filename.

`wk1write(filename,M,r,c)` writes the matrix starting at the spreadsheet location `(r,c)`. `r` and `c` are zero based so that `r=0`, `c=0` specifies the first cell in the spreadsheet.



See Also

`wk1read`

Purpose

Display the Workspace Browser, a GUI for managing the workspace

Syntax

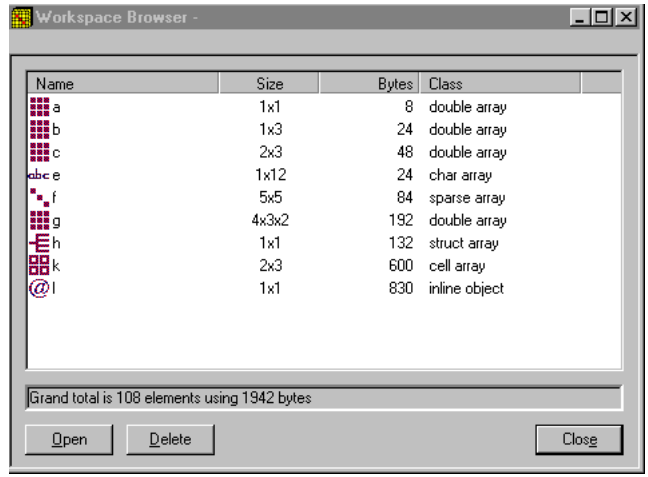
```
workspace
```

Description

`workspace` displays the Workspace Browser, a GUI that allows you to view and manage the contents of the current MATLAB workspace. It provides a graphical representation of the `whos` display.

Remarks

On Windows platforms, to open the Workspace Browser, select **Show Workspace** from the **File** menu, or click the **Workspace Browser** toolbar button.



Drag the column header borders to resize the columns. The workspace is sorted by variable name. Sorting by other fields is not supported.

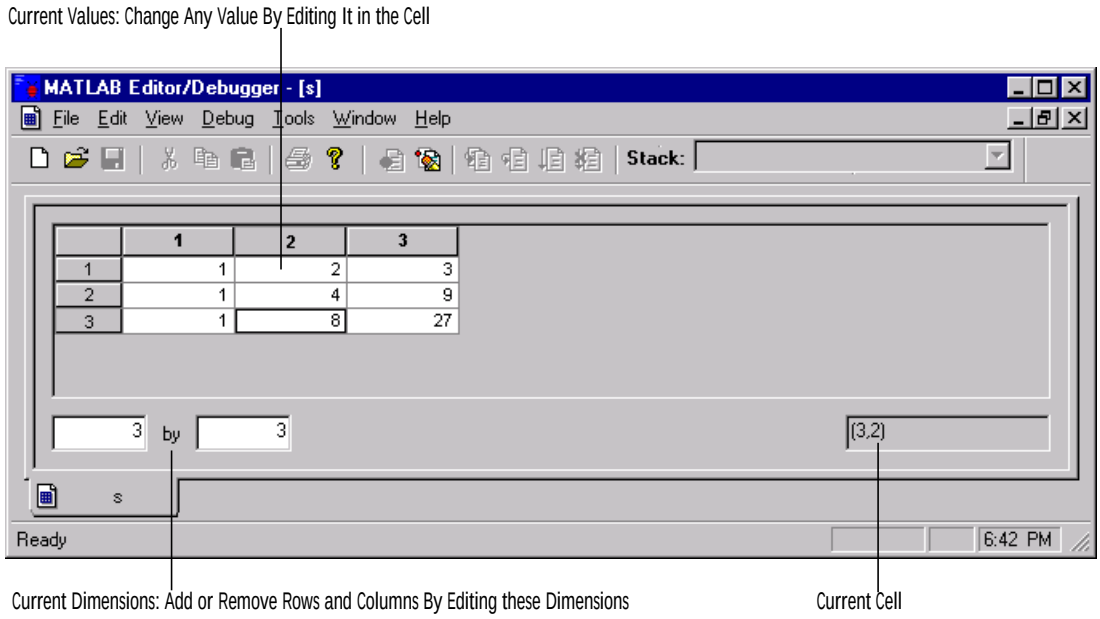
To clear a variable, select the variable and click **Delete**. Shift-click to select multiple variables.

To rename a variable, first select it, then click its name. After a short delay, type a new name and press **Enter** to complete the name change.

Editing Arrays

To see and edit a graphical representation of a variable, select a variable's icon in the Workspace Browser and click **Open**, or double-click the icon. The

variable is displayed in the Editor/Debugger window, where you can edit it. You can only use this feature with numeric arrays.



See Also `edit, who`

Purpose

Exclusive or

Syntax

```
C = xor(A,B)
```

Description

`C = xor(A,B)` performs an exclusive OR operation on the corresponding elements of arrays `A` and `B`. The resulting element `C(i,j,...)` is logical true (`1`) if `A(i,j,...)` or `B(i,j,...)`, but not both, is nonzero.

A	B	C
zero	zero	0
zero	nonzero	1
nonzero	zero	1
nonzero	nonzero	0

Examples

Given `A = [0 0 pi eps]` and `B = [0 -2.4 0 1]`, then

```
C = xor(A,B)
C =
   0   1   1   0
```

To see where either `A` or `B` has a nonzero element and the other matrix does not,

```
spy(xor(A,B))
```

See Also

`all`, `any`, `find`

The logical operators `&` and `|`

zeros

Purpose

Create an array of all zeros

Syntax

```
B = zeros(n)
B = zeros(m,n)
B = zeros([m n])
B = zeros(d1,d2,d3...)
B = zeros([d1 d2 d3...])
B = zeros(size(A))
```

Description

`B = zeros(n)` returns an `n`-by-`n` matrix of zeros. An error message appears if `n` is not a scalar.

`B = zeros(m,n)` or `B = zeros([m n])` returns an `m`-by-`n` matrix of zeros.

`B = zeros(d1,d2,d3...)` or `B = zeros([d1 d2 d3...])` returns an array of zeros with dimensions `d1`-by-`d2`-by-`d3`-by-`...` .

`B = zeros(size(A))` returns an array the same size as `A` consisting of all zeros.

Remarks

The MATLAB language does not have a dimension statement—MATLAB automatically allocates storage for matrices. Nevertheless, most MATLAB programs execute faster if the `zeros` function is used to set aside storage for a matrix whose elements are to be generated one at a time, or a row or column at a time.

Examples

With `n = 1000`, the `for` loop

```
for i = 1:n, x(i) = i; end
```

takes about 1.2 seconds to execute on a Sun SPARC-1. If the loop is preceded by the statement `x = zeros(1,n);` the computations require less than 0.2 seconds.

See Also

`eye`, `ones`, `rand`, `randn`

A

List of Commands

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