

# MATLAB<sup>®</sup>

The Language of Technical Computing

**Computation**

**Visualization**

**Programming**

## Language Reference Manual

*Version 5*

#### How to Contact The MathWorks:



508-647-7000 Phone



508-647-7001 Fax



The MathWorks, Inc. Mail  
24 Prime Park Way  
Natick, MA 01760-1500



<http://www.mathworks.com> Web  
<ftp.mathworks.com> Anonymous FTP server  
<comp.soft-sys.matlab> Newsgroup



[support@mathworks.com](mailto:support@mathworks.com) Technical support  
[suggest@mathworks.com](mailto:suggest@mathworks.com) Product enhancement suggestions  
[bugs@mathworks.com](mailto:bugs@mathworks.com) Bug reports  
[doc@mathworks.com](mailto:doc@mathworks.com) Documentation error reports  
[subscribe@mathworks.com](mailto:subscribe@mathworks.com) Subscribing user registration  
[service@mathworks.com](mailto:service@mathworks.com) Order status, license renewals, passcodes  
[info@mathworks.com](mailto:info@mathworks.com) Sales, pricing, and general information

#### *MATLAB Language Reference*

© COPYRIGHT 1984 - 1997 by The MathWorks, Inc. All Rights Reserved.

The software described in this document is furnished under a license agreement. The software may be used or copied only under the terms of the license agreement. No part of this manual may be photocopied or reproduced in any form without prior written consent from The MathWorks, Inc.

U.S. GOVERNMENT: If Licensee is acquiring the software on behalf of any unit or agency of the U. S. Government, the following shall apply:

(a) for units of the Department of Defense:

RESTRICTED RIGHTS LEGEND: Use, duplication, or disclosure by the Government is subject to restrictions as set forth in subparagraph (c)(1)(ii) of the Rights in Technical Data and Computer Software Clause at DFARS 252.227-7013.

(b) for any other unit or agency:

NOTICE - Notwithstanding any other lease or license agreement that may pertain to, or accompany the delivery of, the computer software and accompanying documentation, the rights of the Government regarding its use, reproduction and disclosure are as set forth in Clause 52.227-19(c)(2) of the FAR.

Contractor/manufacture is The MathWorks Inc., 24 Prime Park Way, Natick, MA 01760-1500.

MATLAB, Simulink, Handle Graphics, and Real-Time Workshop are registered trademarks and Stateflow and Target Language Compiler are trademarks of The MathWorks, Inc.

Other product or brand names are trademarks or registered trademarks of their respective holders.

Printing History: December 1996 First printing (for MATLAB 5)  
June 1997 Revised for 5.1 (online version)

## Preface

|                                   |           |
|-----------------------------------|-----------|
| <b>What Is MATLAB?</b> .....      | <b>ii</b> |
| <b>MATLAB Documentation</b> ..... | <b>iv</b> |

## Command Summary

### 1

|                                                            |             |
|------------------------------------------------------------|-------------|
| <b>General Purpose Commands</b> .....                      | <b>1-2</b>  |
| <b>Operators and Special Characters</b> .....              | <b>1-3</b>  |
| <b>Logical Functions</b> .....                             | <b>1-4</b>  |
| <b>Language Constructs and Debugging</b> .....             | <b>1-4</b>  |
| <b>Elementary Matrices and Matrix Manipulation</b> .....   | <b>1-5</b>  |
| <b>Specialized Matrices</b> .....                          | <b>1-7</b>  |
| <b>Elementary Math Functions</b> .....                     | <b>1-7</b>  |
| <b>Specialized Math Functions</b> .....                    | <b>1-8</b>  |
| <b>Coordinate System Conversion</b> .....                  | <b>1-8</b>  |
| <b>Matrix Functions - Numerical Linear Algebra</b> .....   | <b>1-9</b>  |
| <b>Data Analysis and Fourier Transform Functions</b> ..... | <b>1-10</b> |
| <b>Polynomial and Interpolation Functions</b> .....        | <b>1-11</b> |

**Function Functions – Nonlinear Numerical Methods . . . . . 1-12**

**Sparse Matrix Functions . . . . . 1-12**

**Sound Processing Functions . . . . . 1-14**

**Character String Functions . . . . . 1-14**

**Low-Level File I/O Functions . . . . . 1-15**

**Bitwise Functions . . . . . 1-16**

**Structure Functions . . . . . 1-17**

**Object Functions . . . . . 1-17**

**Cell Array Functions . . . . . 1-17**

**Multidimensional Array Functions . . . . . 1-17**

|   |                                     |
|---|-------------------------------------|
| 2 | <b>Reference</b>                    |
|   | <b>List of Commands</b>             |
|   | <b>Function Names . . . . . A-2</b> |

# 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.....                | page 2-24  |
| doc      | Load hypertext documentation .....                          | page 2-199 |
| help     | Online help for MATLAB functions and M-files.....           | page 2-350 |
| lasterr  | Last error message.....                                     | page 2-408 |
| lookfor  | Keyword search through all help entries.....                | page 2-425 |
| path     | Control MATLAB's directory search path .....                | page 2-503 |
| profile  | Measure and display M-file execution profiles.....          | page 2-533 |
| rmpath   | Remove directories from MATLAB's search path .....          | page 2-571 |
| type     | List file .....                                             | page 2-684 |
| version  | MATLAB version number .....                                 | page 2-693 |
| what     | Directory listing of M-files, MAT-files, and MEX-files..... | page 2-701 |
| whatsnew | Display README files for MATLAB and toolboxes.....          | page 2-702 |
| which    | Locate functions and files.....                             | page 2-703 |

Managing Variables and the Workspace

|           |                                             |            |
|-----------|---------------------------------------------|------------|
| clear     | Remove items from memory .....              | page 2-111 |
| disp      | Display text or array .....                 | page 2-195 |
| length    | Length of vector.....                       | page 2-413 |
| load      | Retrieve variables from disk.....           | page 2-416 |
| pack      | Consolidate workspace memory .....          | page 2-499 |
| save      | Save workspace variables on disk.....       | page 2-581 |
| size      | Array dimensions .....                      | page 2-597 |
| who, whos | List directory of variables in memory ..... | page 2-706 |

Controlling the Command Window

|        |                                                   |            |
|--------|---------------------------------------------------|------------|
| echo   | Echo M-files during execution.....                | page 2-202 |
| format | Control the output display format .....           | page 2-278 |
| more   | Control paged output for the command window ..... | page 2-454 |

Working with Files and the Operating Environment

|             |                                                             |           |
|-------------|-------------------------------------------------------------|-----------|
| acopy       | Copy Macintosh file from one folder to another.....         | page 2-19 |
| amove       | Move Macintosh file from one folder to another.....         | page 2-29 |
| applescript | Load a compiled AppleScript from a file and execute it .... | page 2-34 |
| arename     | Rename Macintosh File .....                                 | page 2-35 |
| areveal     | Reveal filename on Macintosh desktop.....                   | page 2-36 |
| cd          | Change working directory .....                              | page 2-88 |

|                         |                                                          |            |
|-------------------------|----------------------------------------------------------|------------|
| <code>delete</code>     | Delete files and graphics objects.....                   | page 2-188 |
| <code>diary</code>      | Save session in a disk file.....                         | page 2-191 |
| <code>dir</code>        | Directory listing.....                                   | page 2-194 |
| <code>edit</code>       | Edit an M-file.....                                      | page 2-203 |
| <code>fileparts</code>  | Filename parts.....                                      | page 2-254 |
| <code>fullfile</code>   | Build full filename from parts.....                      | page 2-295 |
| <code>gestalt</code>    | Macintosh gestalt function.....                          | page 2-330 |
| <code>inmem</code>      | Functions in memory.....                                 | page 2-375 |
| <code>matlabroot</code> | Root directory of MATLAB installation.....               | page 2-442 |
| <code>tempdir</code>    | Return the name of the system's temporary directory..... | page 2-674 |
| <code>tempname</code>   | Unique name for temporary file.....                      | page 2-675 |
| <code>!</code>          | Execute operating system command.....                    | page 2-13  |

## Starting and Quitting MATLAB

|                       |                            |            |
|-----------------------|----------------------------|------------|
| <code>matlabrc</code> | MATLAB startup M-file..... | page 2-441 |
| <code>quit</code>     | Terminate MATLAB.....      | page 2-547 |
| <code>startup</code>  | MATLAB startup M-file..... | page 2-638 |

## Operators and Special Characters

|                                     |                                     |            |
|-------------------------------------|-------------------------------------|------------|
| <code>+</code>                      | Plus.....                           | page 2-2   |
| <code>-</code>                      | Minus.....                          | page 2-2   |
| <code>*</code>                      | Matrix multiplication.....          | page 2-2   |
| <code>.*</code>                     | Array multiplication.....           | page 2-2   |
| <code>^</code>                      | Matrix power.....                   | page 2-2   |
| <code>.^</code>                     | Array power.....                    | page 2-2   |
| <code>kron</code>                   | Kronecker tensor product.....       | page 2-407 |
| <code>\</code>                      | Backslash or left division.....     | page 2-2   |
| <code>/</code>                      | Slash or right division.....        | page 2-2   |
| <code>./</code> and <code>.\</code> | Array division, right and left..... | page 2-2   |
| <code>:</code>                      | Colon.....                          | page 2-16  |
| <code>( )</code>                    | Parentheses.....                    | page 2-13  |
| <code>[ ]</code>                    | Brackets.....                       | page 2-13  |
| <code>{ }</code>                    | Curly braces.....                   | page 2-13  |
| <code>.</code>                      | Decimal point.....                  | page 2-13  |
| <code>...</code>                    | Continuation.....                   | page 2-13  |
| <code>,</code>                      | Comma.....                          | page 2-13  |
| <code>;</code>                      | Semicolon.....                      | page 2-13  |
| <code>%</code>                      | Comment.....                        | page 2-13  |
| <code>!</code>                      | Exclamation point.....              | page 2-13  |
| <code>'</code>                      | Transpose and quote.....            | page 2-13  |

|     |   |                              |            |
|-----|---|------------------------------|------------|
| .   | ' | Nonconjugated transpose..... | page 2-13  |
| =   |   | Assignment .....             | page 2-13  |
| ==  |   | Equality .....               | page 2-9   |
| <   | > | Relational operators .....   | page 2-9   |
| &   |   | Logical AND .....            | page 2-11  |
|     |   | Logical OR.....              | page 2-11  |
| ~   |   | Logical NOT .....            | page 2-11  |
| xor |   | Logical EXCLUSIVE OR .....   | page 2-714 |

Logical Functions

|         |                                                    |            |
|---------|----------------------------------------------------|------------|
| all     | Test to determine if all elements are nonzero..... | page 2-27  |
| any     | Test for any nonzeros .....                        | page 2-32  |
| exist   | Check if a variable or file exists .....           | page 2-231 |
| find    | Find indices and values of nonzero elements.....   | page 2-258 |
| is*     | Detect state.....                                  | page 2-398 |
| *isa    | Detect an object of a given class.....             | page 2-402 |
| logical | Convert numeric values to logical.....             | page 2-421 |

Language Constructs and Debugging

MATLAB as a Programming Language

|          |                                                       |            |
|----------|-------------------------------------------------------|------------|
| builtin  | Execute builtin function from overloaded method ..... | page 2-80  |
| eval     | Interpret strings containing MATLAB expressions.....  | page 2-228 |
| feval    | Function evaluation .....                             | page 2-244 |
| function | Function M-files .....                                | page 2-296 |
| global   | Define global variables .....                         | page 2-332 |
| nargchk  | Check number of input arguments .....                 | page 2-457 |
| script   | Script M-files .....                                  | page 2-586 |

Control Flow

|        |                                                                              |            |
|--------|------------------------------------------------------------------------------|------------|
| break  | Break out of flow control structures .....                                   | page 2-79  |
| case   | Case switch.....                                                             | page 2-86  |
| else   | Conditionally execute statements .....                                       | page 2-217 |
| elseif | Conditionally execute statements .....                                       | page 2-218 |
| end    | Terminate for, while, switch, and if statements or indicate last index ..... | page 2-220 |
| error  | Display error messages .....                                                 | page 2-225 |
| for    | Repeat statements a specific number of times .....                           | page 2-276 |

|           |                                                       |            |
|-----------|-------------------------------------------------------|------------|
| if        | Conditionally execute statements .....                | page 2-354 |
| otherwise | Default part of switch statement .....                | page 2-497 |
| return    | Return to the invoking function .....                 | page 2-569 |
| switch    | Switch among several cases based on expression .....  | page 2-666 |
| warning   | Display warning message .....                         | page 2-696 |
| while     | Repeat statements an indefinite number of times ..... | page 2-705 |

## Interactive Input

|          |                                                 |            |
|----------|-------------------------------------------------|------------|
| input    | Request user input. ....                        | page 2-377 |
| keyboard | Invoke the keyboard in an M-file. ....          | page 2-406 |
| menu     | Generate a menu of choices for user input ..... | page 2-446 |
| pause    | Halt execution temporarily. ....                | page 2-505 |

## Object-Oriented Programming

|            |                                               |            |
|------------|-----------------------------------------------|------------|
| class      | Create object or return class of object ..... | page 2-110 |
| double     | Convert to double precision .....             | page 2-200 |
| inferiorto | Inferior class relationship .....             | page 2-371 |
| inline     | Construct an inline object .....              | page 2-372 |
| isa        | Detect an object of a given class .....       | page 2-402 |
| superiorto | Superior class relationship .....             | page 2-661 |
| uint8      | Convert to unsigned 8-bit integer .....       | page 2-685 |

## Debugging

|          |                                                   |            |
|----------|---------------------------------------------------|------------|
| dbclear  | Clear breakpoints. ....                           | page 2-148 |
| dbcont   | Resume execution .....                            | page 2-150 |
| dbdown   | Change local workspace context .....              | page 2-151 |
| dbmex    | Enable MEX-file debugging .....                   | page 2-154 |
| dbquit   | Quit debug mode. ....                             | page 2-155 |
| dbstack  | Display function call stack .....                 | page 2-156 |
| dbstatus | List all breakpoints .....                        | page 2-157 |
| dbstep   | Execute one or more lines from a breakpoint. .... | page 2-158 |
| dbstop   | Set breakpoints in an M-file function .....       | page 2-159 |
| dbtype   | List M-file with line numbers. ....               | page 2-162 |
| dbup     | Change local workspace context .....              | page 2-163 |

# Elementary Matrices and Matrix Manipulation

## Elementary Matrices and Arrays

|           |                                                      |            |
|-----------|------------------------------------------------------|------------|
| eye       | Identity matrix. ....                                | page 2-238 |
| linspace  | Generate linearly spaced vectors ....                | page 2-415 |
| logspace  | Generate logarithmically spaced vectors. ....        | page 2-424 |
| ones      | Create an array of all ones ....                     | page 2-495 |
| rand      | Uniformly distributed random numbers and arrays .... | page 2-549 |
| randn     | Normally distributed random numbers and arrays. .... | page 2-551 |
| zeros     | Create an array of all zeros. ....                   | page 2-715 |
| : (colon) | Regularly spaced vector ....                         | page 2-16  |

## Special Variables and Constants

|                     |                                                                 |            |
|---------------------|-----------------------------------------------------------------|------------|
| ans                 | The most recent answer ....                                     | page 2-31  |
| computer            | Identify the computer on which MATLAB is running ....           | page 2-119 |
| eps                 | Floating-point relative accuracy ....                           | page 2-222 |
| flops               | Count floating-point operations ....                            | page 2-266 |
| i                   | Imaginary unit. ....                                            | page 2-353 |
| Inf                 | Infinity ....                                                   | page 2-370 |
| inputname           | Input argument name. ....                                       | page 2-378 |
| j                   | Imaginary unit. ....                                            | page 2-405 |
| NaN                 | Not-a-Number ....                                               | page 2-456 |
| nargin, nargsout    | Number of function arguments. ....                              | page 2-458 |
| pi                  | Ratio of a circle's circumference to its diameter, $\pi$ . .... | page 2-513 |
| realmax             | Largest positive floating-point number ....                     | page 2-561 |
| realmin             | Smallest positive floating-point number. ....                   | page 2-562 |
| varargin, varargout | Pass or return variable numbers of arguments. ....              | page 2-690 |

## Time and Dates

|          |                                    |            |
|----------|------------------------------------|------------|
| calendar | Calendar. ....                     | page 2-82  |
| clock    | Current time as a date vector .... | page 2-113 |
| cputime  | Elapsed CPU time ....              | page 2-136 |
| date     | Current date string ....           | page 2-143 |
| datenum  | Serial date number ....            | page 2-144 |
| datestr  | Date string format. ....           | page 2-145 |
| datevec  | Date components ....               | page 2-147 |
| eomday   | End of month ....                  | page 2-221 |
| etime    | Elapsed time. ....                 | page 2-227 |

|          |                             |            |
|----------|-----------------------------|------------|
| now      | Current date and time. .... | page 2-470 |
| tic, toc | Stopwatch timer. ....       | page 2-676 |
| weekday  | Day of the week. ....       | page 2-700 |

## Matrix Manipulation

|           |                                                   |            |
|-----------|---------------------------------------------------|------------|
| cat       | Concatenate arrays. ....                          | page 2-87  |
| diag      | Diagonal matrices and diagonals of a matrix. .... | page 2-190 |
| fliplr    | Flip matrices left-right. ....                    | page 2-263 |
| flipud    | Flip matrices up-down. ....                       | page 2-264 |
| repmat    | Replicate and tile an array. ....                 | page 2-565 |
| reshape   | Reshape array. ....                               | page 2-566 |
| rot90     | Rotate matrix 90 degrees. ....                    | page 2-574 |
| tril      | Lower triangular part of a matrix. ....           | page 2-681 |
| triu      | Upper triangular part of a matrix. ....           | page 2-682 |
| : (colon) | Index into array, rearrange array. ....           | page 2-16  |

## Specialized Matrices

|           |                                          |            |
|-----------|------------------------------------------|------------|
| compan    | Companion matrix. ....                   | page 2-118 |
| gallery   | Test matrices. ....                      | page 2-306 |
| hadamard  | Hadamard matrix. ....                    | page 2-344 |
| hankel    | Hankel matrix. ....                      | page 2-345 |
| hilb      | Hilbert matrix. ....                     | page 2-352 |
| invhilb   | Inverse of the Hilbert matrix. ....      | page 2-396 |
| magic     | Magic square. ....                       | page 2-438 |
| pascal    | Pascal matrix. ....                      | page 2-502 |
| toeplitz  | Toeplitz matrix. ....                    | page 2-677 |
| wilkinson | Wilkinson's eigenvalue test matrix. .... | page 2-708 |

## Elementary Math Functions

|             |                                                          |           |
|-------------|----------------------------------------------------------|-----------|
| abs         | Absolute value and complex magnitude. ....               | page 2-18 |
| acos, acosh | Inverse cosine and inverse hyperbolic cosine. ....       | page 2-20 |
| acot, acoth | Inverse cotangent and inverse hyperbolic cotangent. .... | page 2-21 |
| acsc, acsch | Inverse cosecant and inverse hyperbolic cosecant. ....   | page 2-22 |
| angle       | angle Phase angle. ....                                  | page 2-30 |
| asec, asech | Inverse secant and inverse hyperbolic secant. ....       | page 2-37 |
| asin, asinh | Inverse sine and inverse hyperbolic sine. ....           | page 2-38 |
| atan, atanh | Inverse tangent and inverse hyperbolic tangent. ....     | page 2-40 |
| atan2       | Four-quadrant inverse tangent. ....                      | page 2-42 |

|           |                                                                                      |            |
|-----------|--------------------------------------------------------------------------------------|------------|
| ceil      | Round toward infinity .....                                                          | page 2-91  |
| conj      | Complex conjugate .....                                                              | page 2-124 |
| cos, cosh | Cosine and hyperbolic cosine .....                                                   | page 2-131 |
| cot, coth | Cotangent and hyperbolic cotangent .....                                             | page 2-132 |
| csc, csch | Cosecant and hyperbolic cosecant .....                                               | page 2-138 |
| exp       | Exponential .....                                                                    | page 2-233 |
| fix       | Round towards zero .....                                                             | page 2-261 |
| floor     | Round towards minus infinity .....                                                   | page 2-265 |
| gcd       | Greatest common divisor .....                                                        | page 2-328 |
| imag      | Imaginary part of a complex number .....                                             | page 2-359 |
| lcm       | Least common multiple .....                                                          | page 2-410 |
| log       | Natural logarithm .....                                                              | page 2-418 |
| log2      | Base 2 logarithm and dissect floating-point numbers into exponent and mantissa ..... | page 2-419 |
| log10     | Common (base 10) logarithm .....                                                     | page 2-420 |
| mod       | Modulus (signed remainder after division) .....                                      | page 2-453 |
| real      | Real part of complex number .....                                                    | page 2-560 |
| rem       | Remainder after division .....                                                       | page 2-564 |
| round     | Round to nearest integer .....                                                       | page 2-575 |
| sec, sech | Secant and hyperbolic secant .....                                                   | page 2-587 |
| sign      | Signum function .....                                                                | page 2-594 |
| sin, sinh | Sine and hyperbolic sine .....                                                       | page 2-595 |
| sqrt      | Square root .....                                                                    | page 2-630 |
| tan, tanh | Tangent and hyperbolic tangent .....                                                 | page 2-672 |

Specialized Math Functions

|                          |                                                                |            |
|--------------------------|----------------------------------------------------------------|------------|
| airy                     | Airy functions .....                                           | page 2-25  |
| besselh                  | Bessel functions of the third kind (Hankel functions) .....    | page 2-49  |
| besseli, bessell         | Modified Bessel functions .....                                | page 2-51  |
| besselj, bessely         | Bessel functions .....                                         | page 2-53  |
| beta, betainc, betaln    | Beta functions .....                                           | page 2-56  |
| ellipj                   | Jacobi elliptic functions .....                                | page 2-213 |
| ellipke                  | Complete elliptic integrals of the first and second kind ..... | page 2-215 |
| erf, erfc, erfcx, erfinv | Error functions .....                                          | page 2-223 |
| expint                   | Exponential integral .....                                     | page 2-234 |
| gamma, gammainc, gammaln | Gamma functions .....                                          | page 2-326 |

|           |                                                     |            |
|-----------|-----------------------------------------------------|------------|
| legendre  | Associated Legendre functions. ....                 | page 2-411 |
| pow2      | Base 2 power and scale floating-point numbers. .... | page 2-530 |
| rat, rats | Rational fraction approximation. ....               | page 2-555 |

## Coordinate System Conversion

|          |                                                            |            |
|----------|------------------------------------------------------------|------------|
| cart2pol | Transform Cartesian coordinates to polar or cylindrical .. | page 2-83  |
| cart2sph | Transform Cartesian coordinates to spherical. ....         | page 2-85  |
| pol2cart | Transform polar or cylindrical coordinates to Cartesian .. | page 2-517 |
| sph2cart | Transform spherical coordinates to Cartesian. ....         | page 2-615 |

## Matrix Functions - Numerical Linear Algebra

### Matrix Analysis

|                 |                                                    |            |
|-----------------|----------------------------------------------------|------------|
| cond            | Condition number with respect to inversion. ....   | page 2-121 |
| condeig         | Condition number with respect to eigenvalues. .... | page 2-122 |
| det             | Matrix determinant. ....                           | page 2-189 |
| norm            | Vector and matrix norms. ....                      | page 2-468 |
| null            | Null space of a matrix. ....                       | page 2-471 |
| orth            | Range space of a matrix. ....                      | page 2-496 |
| rank            | Rank of a matrix. ....                             | page 2-554 |
| rcond           | Matrix reciprocal condition number estimate. ....  | page 2-558 |
| rref, rrefmovie | Reduced row echelon form. ....                     | page 2-576 |
| subspace        | Angle between two subspaces. ....                  | page 2-659 |
| trace           | Sum of diagonal elements. ....                     | page 2-678 |

### Linear Equations

|      |                                                                  |            |
|------|------------------------------------------------------------------|------------|
| \ /  | Linear equation solution. ....                                   | page 2-2   |
| chol | Cholesky factorization. ....                                     | page 2-103 |
| inv  | Matrix inverse. ....                                             | page 2-393 |
| lsq  | Least squares solution in the presence of known covariance. .... | page 2-427 |
| lu   | LU matrix factorization. ....                                    | page 2-428 |
| nnls | Nonnegative least squares. ....                                  | page 2-464 |
| pinv | Moore-Penrose pseudoinverse of a matrix. ....                    | page 2-514 |
| qr   | Orthogonal-triangular decomposition. ....                        | page 2-539 |

Eigenvalues and Singular Values

|         |                                                           |            |
|---------|-----------------------------------------------------------|------------|
| balance | Improve accuracy of computed eigenvalues. . . . .         | page 2-45  |
| cdf2rdf | Convert complex diagonal form to real block diagonal form | page 2-89  |
| eig     | Eigenvalues and eigenvectors. . . . .                     | page 2-204 |
| hess    | Hessenberg form of a matrix . . . . .                     | page 2-348 |
| poly    | Polynomial with specified roots. . . . .                  | page 2-518 |
| qz      | QZ factorization for generalized eigenvalues . . . . .    | page 2-548 |
| rsf2csf | Convert real Schur form to complex Schur form . . . . .   | page 2-578 |
| schur   | Schur decomposition . . . . .                             | page 2-584 |
| svd     | Singular value decomposition . . . . .                    | page 2-662 |

Matrix Functions

|       |                                         |            |
|-------|-----------------------------------------|------------|
| expm  | Matrix exponential . . . . .            | page 2-236 |
| funm  | Evaluate functions of a matrix. . . . . | page 2-298 |
| logm  | Matrix logarithm. . . . .               | page 2-422 |
| sqrtn | Matrix square root . . . . .            | page 2-631 |

Low Level Functions

|          |                                               |            |
|----------|-----------------------------------------------|------------|
| qrdelete | Delete column from QR factorization . . . . . | page 2-542 |
| qrinsert | Insert column in QR factorization . . . . .   | page 2-543 |

Data Analysis and Fourier Transform Functions

Basic Operations

|           |                                                        |            |
|-----------|--------------------------------------------------------|------------|
| convhull  | Convex hull . . . . .                                  | page 2-128 |
| cumprod   | Cumulative product . . . . .                           | page 2-139 |
| cumsum    | Cumulative sum . . . . .                               | page 2-140 |
| cumtrapz  | Cumulative trapezoidal numerical integration . . . . . | page 2-141 |
| delaunay  | Delaunay triangulation. . . . .                        | page 2-185 |
| dsearch   | Search for nearest point . . . . .                     | page 2-201 |
| factor    | Prime factors . . . . .                                | page 2-240 |
| inpolygon | Detect points inside a polygonal region . . . . .      | page 2-376 |
| max       | Maximum elements of an array. . . . .                  | page 2-443 |
| mean      | Average or mean value of arrays . . . . .              | page 2-444 |
| median    | Median value of arrays . . . . .                       | page 2-445 |
| min       | Minimum elements of an array. . . . .                  | page 2-452 |
| perms     | All possible permutations. . . . .                     | page 2-511 |
| polyarea  | Area of polygon. . . . .                               | page 2-521 |
| primes    | Generate list of prime numbers. . . . .                | page 2-531 |

|          |                                              |            |
|----------|----------------------------------------------|------------|
| prod     | Product of array elements. ....              | page 2-532 |
| sort     | Sort elements in ascending order. ....       | page 2-599 |
| sortrows | Sort rows in ascending order. ....           | page 2-600 |
| std      | Standard deviation. ....                     | page 2-639 |
| sum      | Sum of array elements. ....                  | page 2-660 |
| trapz    | Trapezoidal numerical integration. ....      | page 2-679 |
| tsearch  | Search for enclosing Delaunay triangle. .... | page 2-683 |
| voronoi  | Voronoi diagram. ....                        | page 2-694 |

## Finite Differences

|          |                                               |            |
|----------|-----------------------------------------------|------------|
| del2     | Discrete Laplacian. ....                      | page 2-182 |
| diff     | Differences and approximate derivatives. .... | page 2-192 |
| gradient | Numerical gradient. ....                      | page 2-338 |

## Correlation

|          |                                |            |
|----------|--------------------------------|------------|
| corrcoef | Correlation coefficients. .... | page 2-130 |
| cov      | Covariance matrix. ....        | page 2-133 |

## Filtering and Convolution

|         |                                                                                                   |            |
|---------|---------------------------------------------------------------------------------------------------|------------|
| conv    | Convolution and polynomial multiplication. ....                                                   | page 2-125 |
| conv2   | Two-dimensional convolution. ....                                                                 | page 2-126 |
| deconv  | Deconvolution and polynomial division. ....                                                       | page 2-181 |
| filter  | Filter data with an infinite impulse response (IIR) or finite impulse response (FIR) filter. .... | page 2-255 |
| filter2 | Two-dimensional digital filtering. ....                                                           | page 2-257 |

## Fourier Transforms

|          |                                                                          |            |
|----------|--------------------------------------------------------------------------|------------|
| abs      | Absolute value and complex magnitude. ....                               | page 2-18  |
| angle    | Phase angle. ....                                                        | page 2-30  |
| cplxpair | Sort complex numbers into complex conjugate pairs. ....                  | page 2-135 |
| fft      | One-dimensional fast Fourier transform. ....                             | page 2-245 |
| fft2     | Two-dimensional fast Fourier transform. ....                             | page 2-248 |
| fftshift | Shift DC component of fast Fourier transform to center of spectrum. .... | page 2-250 |
| ifft     | Inverse one-dimensional fast Fourier transform. ....                     | page 2-356 |
| ifft2    | Inverse two-dimensional fast Fourier transform. ....                     | page 2-357 |
| nextpow2 | Next power of two. ....                                                  | page 2-463 |
| unwrap   | Correct phase angles. ....                                               | page 2-688 |

Vector Functions

|           |                                               |            |
|-----------|-----------------------------------------------|------------|
| cross     | Vector cross product. ....                    | page 2-137 |
| intersect | Set intersection of two vectors. ....         | page 2-392 |
| ismember  | Detect members of a set ....                  | page 2-403 |
| setdiff   | Return the set difference of two vectors .... | page 2-589 |
| setxor    | Set exclusive-or of two vectors. ....         | page 2-592 |
| union     | Set union of two vectors. ....                | page 2-686 |
| unique    | Unique elements of a vector. ....             | page 2-687 |

Polynomial and Interpolation Functions

Polynomials

|          |                                                                                 |            |
|----------|---------------------------------------------------------------------------------|------------|
| conv     | Convolution and polynomial multiplication ....                                  | page 2-125 |
| deconv   | Deconvolution and polynomial division ....                                      | page 2-181 |
| poly     | Polynomial with specified roots. ....                                           | page 2-518 |
| polyder  | Polynomial derivative. ....                                                     | page 2-522 |
| polyeig  | Polynomial eigenvalue problem ....                                              | page 2-523 |
| polyfit  | Polynomial curve fitting ....                                                   | page 2-524 |
| polyval  | Polynomial evaluation ....                                                      | page 2-527 |
| polyvalm | Matrix polynomial evaluation ....                                               | page 2-528 |
| residue  | Convert between partial fraction expansion and polynomial coefficients<br>..... | page 2-567 |
| roots    | Polynomial roots. ....                                                          | page 2-572 |

Data Interpolation

|          |                                                                           |            |
|----------|---------------------------------------------------------------------------|------------|
| griddata | Data gridding. ....                                                       | page 2-341 |
| interp1  | One-dimensional data interpolation (table lookup) ....                    | page 2-380 |
| interp2  | Two-dimensional data interpolation (table lookup) ....                    | page 2-383 |
| interp3  | Three-dimensional data interpolation (table lookup) ....                  | page 2-387 |
| interpft | One-dimensional interpolation using the FFT method ...                    | page 2-389 |
| interpn  | Multidimensional data interpolation (table lookup) ....                   | page 2-390 |
| meshgrid | Generate X and Y matrices for three-dimensional plots ...                 | page 2-447 |
| ndgrid   | Generate arrays for multidimensional functions and interpolation<br>..... | page 2-461 |
| spline   | Cubic spline interpolation ....                                           | page 2-616 |

Function Functions – Nonlinear Numerical Methods

|         |                                   |            |
|---------|-----------------------------------|------------|
| dblquad | Numerical double integration .... | page 2-152 |
|---------|-----------------------------------|------------|

|                                      |                                                                                         |            |
|--------------------------------------|-----------------------------------------------------------------------------------------|------------|
| fmin                                 | Minimize a function of one variable . . . . .                                           | page 2-267 |
| fmins                                | Minimize a function of several variables . . . . .                                      | page 2-269 |
| fzero                                | Zero of a function of one variable . . . . .                                            | page 2-303 |
| ode45, ode23, ode113, ode15s, ode23s | Solve differential equations . . . . .                                                  | page 2-475 |
| odefile                              | Define a differential equation problem for ODE solvers . . .                            | page 2-483 |
| odeget                               | Extract properties from <code>options</code> structure created with <code>odeset</code> | page 2-488 |
| odeset                               | Create or alter <code>options</code> structure for input to ODE solvers                 | page 2-489 |
| quad, quad8                          | Numerical evaluation of integrals . . . . .                                             | page 2-545 |
| vectorize                            | Vectorize expression . . . . .                                                          | page 2-692 |

## Sparse Matrix Functions

### Elementary Sparse Matrices

|           |                                                              |            |
|-----------|--------------------------------------------------------------|------------|
| spdiags   | Extract and create sparse band and diagonal matrices . . . . | page 2-609 |
| speye     | Sparse identity matrix . . . . .                             | page 2-613 |
| sprand    | Sparse uniformly distributed random matrix . . . . .         | page 2-622 |
| sprandn   | Sparse normally distributed random matrix . . . . .          | page 2-623 |
| sprandsym | Sparse symmetric random matrix . . . . .                     | page 2-624 |

### Full to Sparse Conversion

|           |                                                            |            |
|-----------|------------------------------------------------------------|------------|
| find      | Find indices and values of nonzero elements . . . . .      | page 2-258 |
| full      | Convert sparse matrix to full matrix . . . . .             | page 2-294 |
| sparse    | Create sparse matrix . . . . .                             | page 2-605 |
| spconvert | Import matrix from sparse matrix external format . . . . . | page 2-607 |

### Working with Nonzero Entries of Sparse Matrices

|          |                                                            |            |
|----------|------------------------------------------------------------|------------|
| nnz      | Number of nonzero matrix elements . . . . .                | page 2-466 |
| nonzeros | Nonzero matrix elements . . . . .                          | page 2-467 |
| nzmax    | Amount of storage allocated for nonzero matrix elements .  | page 2-474 |
| spalloc  | Allocate space for sparse matrix . . . . .                 | page 2-604 |
| spfun    | Apply function to nonzero sparse matrix elements . . . . . | page 2-614 |
| spones   | Replace nonzero sparse matrix elements with ones . . . . . | page 2-618 |

### Visualizing Sparse Matrices

|     |                                      |            |
|-----|--------------------------------------|------------|
| spy | Visualize sparsity pattern . . . . . | page 2-629 |
|-----|--------------------------------------|------------|

Reordering Algorithms

|          |                                                       |            |
|----------|-------------------------------------------------------|------------|
| colmmd   | Sparse column minimum degree permutation .....        | page 2-114 |
| colperm  | Sparse column permutation based on nonzero count..... | page 2-117 |
| dmperm   | Dulmage-Mendelsohn decomposition .....                | page 2-198 |
| randperm | Random permutation .....                              | page 2-553 |
| symmmd   | Sparse symmetric minimum degree ordering .....        | page 2-668 |
| symrcm   | Sparse reverse Cuthill-McKee ordering .....           | page 2-670 |

Norm, Condition Number, and Rank

|         |                                               |            |
|---------|-----------------------------------------------|------------|
| condest | 1-norm matrix condition number estimate ..... | page 2-123 |
| normest | 2-norm estimate .....                         | page 2-469 |

Sparse Systems of Linear Equations

|          |                                                         |            |
|----------|---------------------------------------------------------|------------|
| bicg     | BiConjugate Gradients method .....                      | page 2-58  |
| bicgstab | BiConjugate Gradients Stabilized method .....           | page 2-65  |
| cgs      | Conjugate Gradients Squared method .....                | page 2-97  |
| cholinc  | Incomplete Cholesky factorizations .....                | page 2-105 |
| gmres    | Generalized Minimum Residual method (with restarts) ... | page 2-334 |
| luinc    | Incomplete LU matrix factorizations .....               | page 2-431 |
| pcg      | Preconditioned Conjugate Gradients method .....         | page 2-506 |
| qmr      | Quasi-Minimal Residual method .....                     | page 2-535 |

Sparse Eigenvalues and Singular Values

|      |                                              |            |
|------|----------------------------------------------|------------|
| eigs | Find a few eigenvalues and eigenvectors..... | page 2-207 |
| svds | A few singular values.....                   | page 2-664 |

Miscellaneous

|         |                                                 |            |
|---------|-------------------------------------------------|------------|
| spparms | Set parameters for sparse matrix routines ..... | page 2-619 |
|---------|-------------------------------------------------|------------|

Sound Processing Functions

General Sound Functions

|       |                                 |            |
|-------|---------------------------------|------------|
| sound | Convert vector into sound ..... | page 2-601 |
|-------|---------------------------------|------------|

SPARCstation-specific Sound Functions

|        |                                      |           |
|--------|--------------------------------------|-----------|
| auread | Read NeXT/SUN (.au) sound file ..... | page 2-43 |
|--------|--------------------------------------|-----------|

`auwrite` Write NeXT/SUN (.au) sound file. . . . . page 2-44

## **.WAV Sound Functions**

`wavread` Read Microsoft WAVE (.wav) sound file . . . . . page 2-697  
`wavwrite` Write Microsoft WAVE (.wav) sound file . . . . . page 2-698

## **Macintosh Sound Functions**

`readsnd` Read snd resources and files . . . . . page 2-559  
`recordsound` Record sound. . . . . page 2-563  
`soundcap` Sound capabilities . . . . . page 2-602  
`speak` Speak text string. . . . . page 2-612  
`writesnd` Write snd resources and files . . . . . page 2-711

# **Character String Functions**

## **General**

`abs` Absolute value and complex magnitude . . . . . page 2-18  
`eval` Interpret strings containing MATLAB expressions . . . . . page 2-228  
`real` Real part of complex number. . . . . page 2-560  
`strings` MATLAB string handling. . . . . page 2-646

## **String Manipulation**

`deblank` Strip trailing blanks from the end of a string . . . . . page 2-177  
`findstr` Find one string within another. . . . . page 2-260  
`lower` Convert string to lower case . . . . . page 2-426  
`strcat` String concatenation . . . . . page 2-642  
`strcmp` Compare strings. . . . . page 2-644  
`strjust` Justify a character array. . . . . page 2-647  
`strmatch` Find possible matches for a string . . . . . page 2-648  
`strncmp` Compare the first n characters of two strings. . . . . page 2-649  
`strrep` String search and replace . . . . . page 2-650  
`strtok` First token in string. . . . . page 2-651  
`strvcat` Vertical concatenation of strings . . . . . page 2-654  
`upper` Convert string to upper case. . . . . page 2-689

## **String to Number Conversion**

`char` Create character array (string) . . . . . page 2-101

|         |                                            |            |
|---------|--------------------------------------------|------------|
| int2str | Integer to string conversion . . . . .     | page 2-379 |
| mat2str | Convert a matrix into a string . . . . .   | page 2-440 |
| num2str | Number to string conversion . . . . .      | page 2-473 |
| sprintf | Write formatted data to a string . . . . . | page 2-625 |
| sscanf  | Read string under format control . . . . . | page 2-635 |
| str2num | String to number conversion . . . . .      | page 2-641 |

Radix Conversion

|         |                                                         |            |
|---------|---------------------------------------------------------|------------|
| bin2dec | Binary to decimal number conversion . . . . .           | page 2-69  |
| dec2bin | Decimal to binary number conversion . . . . .           | page 2-179 |
| dec2hex | Decimal to hexadecimal number conversion . . . . .      | page 2-180 |
| hex2dec | IEEE hexadecimal to decimal number conversion . . . . . | page 2-350 |
| hex2num | Hexadecimal to double number conversion . . . . .       | page 2-351 |

Low-Level File I/O Functions

File Opening and Closing

|        |                                                              |            |
|--------|--------------------------------------------------------------|------------|
| fclose | Close one or more open files . . . . .                       | page 2-241 |
| fopen  | Open a file or obtain information about open files . . . . . | page 2-273 |

Unformatted I/O

|        |                                      |            |
|--------|--------------------------------------|------------|
| fread  | Read binary data from file . . . . . | page 2-284 |
| fwrite | Write binary data to a file. . . . . | page 2-300 |

Formatted I/O

|         |                                                                                    |            |
|---------|------------------------------------------------------------------------------------|------------|
| fgetl   | Return the next line of a file as a string without line terminator(s)<br>. . . . . | page 2-251 |
| fgets   | Return the next line of a file as a string with line terminator(s)<br>. . . . .    | page 2-252 |
| fprintf | Write formatted data to file . . . . .                                             | page 2-279 |
| fscanf  | Read formatted data from file . . . . .                                            | page 2-289 |

File Positioning

|         |                                                             |            |
|---------|-------------------------------------------------------------|------------|
| feof    | Test for end-of-file . . . . .                              | page 2-242 |
| ferror  | Query MATLAB about errors in file input or output . . . . . | page 2-243 |
| frewind | Rewind an open file . . . . .                               | page 2-288 |
| fseek   | Set file position indicator . . . . .                       | page 2-292 |

|                    |                                  |            |
|--------------------|----------------------------------|------------|
| <code>ftell</code> | Get file position indicator..... | page 2-293 |
|--------------------|----------------------------------|------------|

## String Conversion

|                      |                                        |            |
|----------------------|----------------------------------------|------------|
| <code>sprintf</code> | Write formatted data to a string.....  | page 2-625 |
| <code>sscanf</code>  | Read string under format control ..... | page 2-635 |

## Specialized File I/O

|                         |                                                          |            |
|-------------------------|----------------------------------------------------------|------------|
| <code>qtwrite</code>    | Write QuickTime movie file to disk .....                 | page 2-544 |
| <code>d1mread</code>    | Read an ASCII delimited file into a matrix.....          | page 2-196 |
| <code>d1mwrite</code>   | Write a matrix to an ASCII delimited file .....          | page 2-197 |
| <code>imfinfo</code>    | Return information about a graphics file .....           | page 2-360 |
| <code>imread</code>     | Read image from graphics file .....                      | page 2-363 |
| <code>imwrite</code>    | Write an image to a graphics file .....                  | page 2-366 |
| <code>wk1read</code>    | Read a Lotus123 WK1 spreadsheet file into a matrix. .... | page 2-709 |
| <code>wk1write</code>   | Write a matrix to a Lotus123 WK1 spreadsheet file.....   | page 2-710 |
| <code>xlgetrange</code> | Get range of cells from Microsoft Excel worksheet .....  | page 2-712 |
| <code>xlsetrange</code> | Set range of cells in Microsoft Excel worksheet .....    | page 2-713 |

## Bitwise Functions

|                       |                                     |           |
|-----------------------|-------------------------------------|-----------|
| <code>bitand</code>   | Bit-wise AND.....                   | page 2-70 |
| <code>bitcmp</code>   | Complement bits.....                | page 2-71 |
| <code>bitor</code>    | Bit-wise OR .....                   | page 2-74 |
| <code>bitmax</code>   | Maximum floating-point integer..... | page 2-73 |
| <code>bitset</code>   | Set bit .....                       | page 2-75 |
| <code>bitshift</code> | Bit-wise shift.....                 | page 2-76 |
| <code>bitget</code>   | Get bit.....                        | page 2-72 |
| <code>bitxor</code>   | Bit-wise XOR .....                  | page 2-77 |

## Structure Functions

|                          |                                          |            |
|--------------------------|------------------------------------------|------------|
| <code>fieldnames</code>  | Field names of a structure.....          | page 2-253 |
| <code>getfield</code>    | Get field of structure array .....       | page 2-331 |
| <code>rmfield</code>     | Remove structure fields.....             | page 2-570 |
| <code>setfield</code>    | Set field of structure array.....        | page 2-590 |
| <code>struct</code>      | Create structure array .....             | page 2-652 |
| <code>struct2cell</code> | Structure to cell array conversion ..... | page 2-653 |

Object Functions

|       |                                              |            |
|-------|----------------------------------------------|------------|
| class | Create object or return class of object..... | page 2-110 |
| isa   | Detect an object of a given class.....       | page 2-402 |

Cell Array Functions

|             |                                                         |            |
|-------------|---------------------------------------------------------|------------|
| cell        | Create cell array.....                                  | page 2-92  |
| cellstr     | Create cell array of strings from character array ..... | page 2-96  |
| cell2struct | Cell array to structure array conversion .....          | page 2-93  |
| celldisp    | Display cell array contents.....                        | page 2-94  |
| cellplot    | Graphically display the structure of cell arrays.....   | page 2-95  |
| num2cell    | Convert a numeric array into a cell array .....         | page 2-472 |

Multidimensional Array Functions

|          |                                                                        |            |
|----------|------------------------------------------------------------------------|------------|
| cat      | Concatenate arrays .....                                               | page 2-87  |
| flipdim  | Flip array along a specified dimension .....                           | page 2-262 |
| ind2sub  | Subscripts from linear index .....                                     | page 2-369 |
| ipermute | Inverse permute the dimensions of a multidimensional array .....       | page 2-397 |
| ndgrid   | Generate arrays for multidimensional functions and interpolation ..... | page 2-461 |
| ndims    | Number of array dimensions.....                                        | page 2-462 |
| permute  | Rearrange the dimensions of a multidimensional array ....              | page 2-512 |
| reshape  | Reshape array.....                                                     | page 2-566 |
| shiftdim | Shift dimensions .....                                                 | page 2-593 |
| squeeze  | Remove singleton dimensions.....                                       | page 2-634 |
| sub2ind  | Single index from subscripts .....                                     | page 2-655 |

# Reference

---

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

# Arithmetic Operators + - \* / \ ^ '

**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,  $A \backslash B$  is roughly the same as  $\text{inv}(A) * B$ , 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  $X = A \backslash B$  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  $m \sim n$  and B is a column vector with m components, or a matrix with several such columns, then  $X = A \backslash B$  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  $\text{pinv}(A) * B$ , which is the least squares solution with the smallest  $\|X\|$ .
- . \    Array left division.  $A . \backslash B$  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  $[V, D] = \text{eig}(X)$ , 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.

# Arithmetic Operators + - \* / \ ^ '

**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<br>2<br>3                  | y                | 4<br>5<br>6    |
| x'                | 1 2 3                        | y'               | 4 5 6          |
| x+y               | 5<br>7<br>9                  | x-y              | -3<br>-3<br>-3 |
| x + 2             | 3<br>4<br>5                  | x-2              | -1<br>0<br>1   |
| x * y             | Error                        | x.*y             | 4<br>10<br>18  |
| x'*y              | 32                           | x'.*y            | Error          |
| x*y'              | 4 5 6<br>8 10 12<br>12 15 18 | x.*y'            | Error          |
| x*2               | 2<br>4<br>6                  | x.*2             | 2<br>4<br>6    |
| x\y               | 16/7                         | x.\y             | 4<br>5/2<br>2  |
| 2\x               | 1/2<br>1<br>3/2              | 2./x             | 2<br>1<br>2/3  |

# Arithmetic Operators + - \* / \ ^ '

| Matrix Operations |                               |  | Array Operations |                   |
|-------------------|-------------------------------|--|------------------|-------------------|
| x/y               | 0 0 1/6<br>0 0 1/3<br>0 0 1/2 |  | x./y             | 1/4<br>2/5<br>1/2 |
| x/2               | 1/2<br>1<br>3/2               |  | x./2             | 1/2<br>1<br>3/2   |
| x^y               | Error                         |  | x.^y             | 1<br>32<br>729    |
| x^2               | Error                         |  | x.^2             | 1<br>4<br>9       |
| 2^x               | Error                         |  | 2.^x             | 2<br>4<br>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  $X = A \backslash B$  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 reordering is applied (see symmd 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,

$$X = R \setminus (R' \setminus B)$$

- 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 reordering 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.

$$X = U \setminus (L \setminus B)$$

- 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

$$X = P * (R \setminus (Q' * B))$$

- 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  $c = \max(\max(\text{abs}(A))) / 1000$  (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 reordering 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 ZQRS� 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 NaNs or Infs 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  | Matrix determinant                  |
| inv  | Matrix inverse                      |
| lu   | LU matrix factorization             |
| orth | Range space of a matrix             |
| qr   | Orthogonal-triangular decomposition |
| rref | Reduced row echelon form            |

## References

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

# 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 over-loaded.
- 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    | Number of function arguments (input)                   |
| nargout   | Number of function arguments (output)                  |
| pcode     | Create preparsed pseudocode file (P-file)              |
| varargin  | Pass or return variable numbers of arguments (input)   |
| varargout | Pass or return variable numbers of arguments (output)  |
| what      | Directory listing of M-files, MAT-files, and MEX-files |