Engineering and Scientific Applications: Using MatLab® for Data Processing and Visualization

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Abstract: MatLab® (MATrix LABoratory) is a numerical computation and simulation tool that is used by thousands Scientists and Engineers in many countries. MatLab does purely numerical calculations, which can be used as a glorified calculator or interpreter programming language; its real strength is in matrix manipulations. Computer algebra functionalities are achieved within the MatLab environment using "symbolic" toolbox. This feature is similar to computer algebra programs, provided by Maple or Mathematica to calculate with mathematical equations using symbolic operations.

MatLab in its interpreter programming language form (command interface) is similar with well known programming languages such as C/C++, support data structures and cell arrays to define classes in object oriented programming. As such, MatLab is equipped with most of the essential constructs of a higher programming language. MatLab is packaged with an editor and debugging functionality useful to perform analysis of large MatLab programs and find errors.

We believe there are many ways to approach real-world problems; prescribed methods to ensure foregoing solutions are incorporated in design and analysis of data processing and visualization can benefit engineers and scientist in gaining wider insight in actual implementation of their perspective experiments. This presentation will focus on data processing and visualizations aspects of engineering and scientific applications. Specifically, it will discuss methods and techniques to perform intermediate-level data processing covering engineering and scientific problems. MatLab programming techniques including reading various data files formats to produce customized publication-quality graphics, importing engineering and/or scientific data, organizing data in tabular format, exporting data to be used by other software programs such as Microsoft Excel, data presentation and visualization will be discussed.
The presentation will emphasize creating practical scripts (programs) that extend the basic features of MatLab. Topics include:

- Matrix and vector analysis and manipulations
- Mathematical functions
- Symbolic calculations & functions
- Import/export data files
- Program logic and flow control
- Writing function and passing parameters
- Test application programs
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Agenda:

• Abstract
• Matrix and vector analysis and manipulations
• Mathematical functions
• Symbolic calculations & functions
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• Writing function and passing parameters
• Test application programs
Abstract

MatLab® (MATrix LABoratory) is a numerical computation and simulation tool that is used by thousands of Scientists and Engineers in many countries. MatLab does purely numerical calculations, which can be used as a glorified calculator or interpreter programming language; its real strength is in matrix manipulations. Computer algebra functionalities are achieved within the MatLab environment using "symbolic" toolbox. This feature is similar to computer algebra programs, provided by Maple or Mathematica to calculate with mathematical equations using symbolic operations.

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- Symbolic calculations & functions
- Program logic and flow control
- Test application programs
- Mathematical functions
- Import/export data files
- Writing function and passing parameters
Vector

Row vector
There are different ways to declare a row vector

A row vector with 5 different elements declared and initialized below:

```matlab
>> a = [1, 2, 3, 4, 5]
>> a = [1 2 3 4 5]
>> a = 1:5
```

Column vector
Column vector are defined by using a ; between each element of vector

Column vector can also be created by transposing a row vector

```matlab
>> b = [1; 2; 3; 4; 5]
>> b = a'
```

```matlab
>> a = [1:5]
```
Matrix

Matrix (two dimensional)

>> m = [1.2, 3, 4; -3.7, -2, 5; 1, 2, 3]

m =

1.2000  3.0000  4.0000
-3.7000 -2.0000  5.0000
1.0000  2.0000  3.0000

Note: The default representation of numeric values can be changed through the File>Preferences>Numeric Format
Work with Matrix

Add extra row to a Matrix

```
>> a = [1 2 4; 2 4 6]
a =
  1   2   4
  2   4   6
```
```
>> a = [a; 7 7 7]
a =
  1   2   4
  2   4   6
  7   7   7
```

Add extra column to a Matrix

```
>> a = [1 2 4; 2 4 6]
a =
  1   2   4
  2   4   6
```
```
>> a = [a, [9; 9]]
a =
  1   2   4   9
  2   4   6   9
```
Work with Matrix

Colon Operator:
- Used to define new matrices
- Modify existing matrices
- Extract data from existing matrices

Note: \( M(\cdot) \) Converts a two dimensional matrix to a single column

% delete second column
\[
\text{>> } a(:,2) = [ ]
\]
a =
\[
2 \quad 6 \\
3 \quad 7 \\
1 \quad 9 
\]

% delete third row
\[
\text{>> } a(3,:) = [ ]
\]
a =
\[
2 \quad 4 \quad 6 \\
3 \quad 5 \quad 7 
\]
Work with Matrix

Select a row/ column from a Matrix and assign it to a vector

\[ a = \begin{bmatrix} 2 & 4 & 6 \\ 3 & 5 & 7 \\ 1 & 8 & 9 \end{bmatrix} \]

% select the second column of Matrix a and assign it to vector b

\[ b = a(:,2) \]

% select the first row of Matrix a and assign it to vector b

\[ b = a(1,:) \]
Work with Matrix

Select a row/column from a Matrix and assign it to a vector

\[
\begin{align*}
\text{a} &= \begin{bmatrix} 2 & 4 & 6 \\ 3 & 5 & 7 \\ 1 & 8 & 9 \end{bmatrix} \\
\text{b} &= \text{a}(1,:) \\
\text{b} &= \begin{bmatrix} 2 & 4 & 6 \end{bmatrix}
\end{align*}
\]

% select the first row of Matrix a and assign it to vector b

\[
\begin{align*}
\text{a} &= \begin{bmatrix} 2 & 4 & 6 \\ 3 & 5 & 7 \\ 1 & 8 & 9 \end{bmatrix} \\
\text{b} &= \text{a}(1,:) \\
\text{b} &= \begin{bmatrix} 2 & 4 & 6 \end{bmatrix}
\end{align*}
\]
Work with Matrix

Convert a matrix to a column vector use the MatLab colon operator (:)  

$\gg v=b(:)$

>v =

2
1
7
3
6
8

$> b=[2\ 3;1\ 6;7\ 8]$  

b =

2  3  
1  6  
7  8  

Elementary Matrix Manipulations

The command help elmat provides a complete list of elementary matrices and matrix manipulation commands

>> help elmat

- zeros - Zeros array, Creates a matrix of all zeros
- ones - Ones array, Creates a matrix of all ones
- eye - Identity matrix.
- repmat - Replicate and tile array.
- rand - Uniformly distributed random numbers.
- randn - Normally distributed random numbers.
- linspace - Linearly spaced vector.
- logspace - Logarithmically spaced vector.
- freqspace - Frequency spacing for frequency response.
- meshgrid - X and Y arrays for 3-D plots.
- : - Regularly spaced vector and index into matrix.
Elementary Matrix Manipulations

- **reshape** - Change size.
- **diag** - Diagonal matrices and diagonals of matrix, Extracts a diagonal or creates an identity matrix.
- **blkdiag** - Block diagonal concatenation.
- **tril** - Extract lower triangular part.
- **triu** - Extract upper triangular part.
- **fliplr** - Flip matrix in left/right direction.
- **flipud** - Flip matrix in up/down direction.
- **flipdim** - Flip matrix along specified dimension.
- **rot90** - Rotate matrix 90 degrees.
- **find** - Find indices of nonzero elements.
- **end** - Last index.
- **sub2ind** - Linear index from multiple subscripts.
- **ind2sub** - Multiple subscripts from linear index.
Specialized matrices

- `compan` - Companion matrix.
- `gallery` - Higham test matrices.
- `hadamard` - Hadamard matrix.
- `hankel` - Hankel matrix.
- `hilb` - Hilbert matrix.
- `invhilb` - Inverse Hilbert matrix.
- `magic` - Magic square, Creates a "magic" matrix
- `pascal` - Pascal matrix.
- `rosser` - Classic symmetric eigenvalue test problem.
- `toeplitz` - Toeplitz matrix.
- `vander` - Vandermonde matrix.
- `wilkinson` - Wilkinson's eigenvalue test matrix.
Work with Matrix

MatLab ones() function
ones(N) function returns a N-by-N matrix of ones
ones(M,N) returns a M-by-N matrix of ones

Example: Initialize 2 x 3 matrix with ones

```matlab
>> b = ones(2,3)
```

```
b =
     1  1  1
     1  1  1
```

MatLab size() function
size(X) returns the size of a matrix (number of rows and columns in the matrix)

```matlab
>> size(b)
```

```
ans = 2  3
```

MatLab length() function
length(X) returns the length of (row or column) vector X

```matlab
>> length(b)
```

```
ans = 3
```
Matrix Arithmetic Operations

MatLab matrix arithmetic operations are:
A+B  A-B  A*B   A.*B
A\B  A\B  A/B   A./B
A^B  A.^B  A'    A.'

Note: MatLab checks for the computational rules of matrix algebra, an error message is displayed when a rule is violated.

+ **matrix addition** is the operation of adding two matrices by adding the corresponding entries together.

A + B adds A and B
A and B must have the same dimensions, unless one is scalar.

```matlab
>> A= [1 2; 3 4]; B=[3 5; 6 7];
>> A+B
ans =
    4    7
    9   11
```
Matrix Arithmetic Operations

- **matrix subtraction** is the operation of subtracting two matrices by subtracting the corresponding entries together.
A - B subtracts B from A
A and B must have the same dimensions, unless one is scalar.

\[
\begin{bmatrix}
1 & 2 \\
3 & 4
\end{bmatrix}
- \begin{bmatrix}
3 & 5 \\
6 & 7
\end{bmatrix}
= \begin{bmatrix}
-2 & -3 \\
-3 & -3
\end{bmatrix}
\]

- **matrix multiplication** is the operation of multiplying two matrices

\[
\begin{bmatrix}
M \end{bmatrix} \times \begin{bmatrix}
L
\end{bmatrix}
\]
the number of columns in the matrix on the left (M) must equal the number of rows in the matrix on the right (L)

Note: \( M \times L \neq L \times M \)

\[
\begin{bmatrix}
M
\end{bmatrix} = \begin{bmatrix}
1 & 2 & 3; 4 & 5 & 6
\end{bmatrix}
\]
\[
\begin{bmatrix}
N
\end{bmatrix} = \begin{bmatrix}
2 & 3; 5 & 6; 2 & 7
\end{bmatrix}
\]
\[
\begin{bmatrix}
K
\end{bmatrix} = \begin{bmatrix}
M \times N
\end{bmatrix}
\]

\[
\begin{bmatrix}
K
\end{bmatrix} = \begin{bmatrix}
18 & 36 \\
45 & 84
\end{bmatrix}
\]
Matrix Arithmetic Operations

.* term-by-term multiplication (array multiplication)

A.*B is the entry-by-entry product of A and B

A and B must have the same dimensions

>> M = [1 2; 3 4], N=[3 5; 6 7]
>> M.*N
ans =
    3   10
   18   28
Matrix Arithmetic Operations

**matrix division**
MatLab supports two division operators, namely right division `/` and left division `\`

\ Matrix left division
X = A \ B solves the symbolic linear equations A*X=B
Note that A \ B is roughly equivalent to inv(A)*B.

./ Array left division
A./B is the matrix with entries A(i,j)/B(i,j)
A and B must have the same dimensions, unless one is scalar.

/ Matrix right division
X=B/A solves the symbolic linear equation X*A=B
Note that B/A is the same as (A.'\ B. ')

.
 Array right division
A./B is the matrix with entries A(i,j)/B(i,j)
A and B must have the same dimensions, unless one is scalar.
Matrix Arithmetic Operations

\[ X_2 + X_3 = 5 \]
\[ 3X_1 + X_3 = 6 \]
\[ -X_1 + X_2 = 1 \]

\[
A = \begin{bmatrix}
0 & 1 & 1 \\
3 & 0 & 1 \\
-1 & 1 & 0
\end{bmatrix}
\]

\[
b = [5; 6; 1]
\]

\[
x = A\backslash b \quad \text{% left division}
\]

\[
x = \\
1.0000 \\
2.0000 \\
3.0000
\]
MatLab Mathematical Functions

MatLab has several standard (preprogrammed) mathematical functions

These preprogrammed functions are grouped as:

- Trigonometric Functions
- Exponential Functions
- Complex Functions
- Rounding and remainder functions
MatLab Mathematical Functions (Trigonometric)

<table>
<thead>
<tr>
<th>Function</th>
<th>Description</th>
<th>Function</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>acos</td>
<td>Inverse cosine.</td>
<td>cot</td>
<td>Cotangent.</td>
</tr>
<tr>
<td>acosh</td>
<td>Inverse hyperbolic cosine.</td>
<td>coth</td>
<td>Hyperbolic cotangent.</td>
</tr>
<tr>
<td>acot</td>
<td>Inverse cotangent.</td>
<td>csc</td>
<td>Cosecant.</td>
</tr>
<tr>
<td>acoth</td>
<td>Inverse hyperbolic cotangent.</td>
<td>csch</td>
<td>Hyperbolic cosecant.</td>
</tr>
<tr>
<td>acsc</td>
<td>Inverse cosecant.</td>
<td>sec</td>
<td>Secant.</td>
</tr>
<tr>
<td>acsch</td>
<td>Inverse hyperbolic cosecant.</td>
<td>sech</td>
<td>Hyperbolic secant.</td>
</tr>
<tr>
<td>asec</td>
<td>Inverse secant.</td>
<td>sin</td>
<td>Sine.</td>
</tr>
<tr>
<td>asech</td>
<td>Inverse hyperbolic secant.</td>
<td>sinh</td>
<td>Hyperbolic sine.</td>
</tr>
<tr>
<td>asin</td>
<td>Inverse sine.</td>
<td>tan</td>
<td>Tangent.</td>
</tr>
<tr>
<td>asinh</td>
<td>Inverse hyperbolic sine.</td>
<td>tanh</td>
<td>Hyperbolic tangent.</td>
</tr>
<tr>
<td>atan</td>
<td>Inverse tangent.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>atan2</td>
<td>Four quadrant inverse tangent.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>atanh</td>
<td>Inverse hyperbolic tangent.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>cos</td>
<td>Cosine.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>cosh</td>
<td>Hyperbolic cosine.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
MatLab Mathematical Functions (Exponential/Complex Functions)

<table>
<thead>
<tr>
<th>Function</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exp</td>
<td>Exponential (e^x).</td>
</tr>
<tr>
<td>Log</td>
<td>Natural logarithm.</td>
</tr>
<tr>
<td>Log10</td>
<td>Common (base 10) logarithm.</td>
</tr>
<tr>
<td>Log2</td>
<td>Base 2 logarithm and dissect floating-point numbers.</td>
</tr>
<tr>
<td>nextpow2</td>
<td>Next higher power of 2.</td>
</tr>
<tr>
<td>Pow2</td>
<td>Base 2 power and scale floating-point numbers.</td>
</tr>
<tr>
<td>Reallog</td>
<td>Guarantee output from log is a noncomplex matrix.</td>
</tr>
<tr>
<td>reallog10</td>
<td>Guarantee output from log10 is a noncomplex matrix.</td>
</tr>
<tr>
<td>realpow</td>
<td>Guarantee output from power is a noncomplex matrix.</td>
</tr>
<tr>
<td>Realsqrt</td>
<td>Guarantee output from sqrt is a noncomplex matrix.</td>
</tr>
<tr>
<td>Sqrt</td>
<td>Square root.</td>
</tr>
<tr>
<td>Abs</td>
<td>Absolute value.</td>
</tr>
<tr>
<td>Angle</td>
<td>Phase angle.</td>
</tr>
<tr>
<td>Conj</td>
<td>Complex conjugate.</td>
</tr>
<tr>
<td>cplxpair</td>
<td>Sort numbers into complex conjugate pairs.</td>
</tr>
<tr>
<td>Imag</td>
<td>Complex imaginary part.</td>
</tr>
<tr>
<td>Isreal</td>
<td>True for noncomplex arrays.</td>
</tr>
<tr>
<td>Real</td>
<td>Real part of complex array.</td>
</tr>
<tr>
<td>Unwrap</td>
<td>Remove phase angle jumps across 360° boundaries.</td>
</tr>
</tbody>
</table>
MatLab Mathematical Functions (Statistical /Discrete Mathematics Functions)

- **mean**: arithmetic mean or average value of elements
- **median**: median value of elements
- **min**: smallest component
- **max**: largest component
- **var**: variance of the elements in a vector
- **std**: standard deviation from the mean of elements
- **sum**: sum of elements
- **prod**: product of elements
- **sort**: sorting elements within a vector
- **sortrows**: sorting rows within a matrix by values in a column
- **cov**: variance of a vector or covariance of a matrix
- **corrcoef**: correlation coefficient

**Discrete Mathematics**

- **factor(x)**: returns a vector containing the prime factors of x
- **gcd(x,y)**: greatest common denominator
- **lcm(x)**: lowest common multiple
- **rats(x)**: represent x as a fraction
- **factorial(x)**: returns factorial of x
- **primes(x)**: generates a list of prime numbers less than or equal to x
- **isprime(x)**: returns 1 if the elements of x which are prime, 0 otherwise
MatLab plot() function

plot() function is used to plot a two dimensional plot

plot3() function is used to plot a three dimensional plot

A plot can be made using various symbols, colors and line types

Line types, plot symbols and colors for plot() or plot3() functions are represented through a character string

For example, a character string 'go:' means a green dotted line with a circle at each data point

plot(X,Y,'go:') plots a green dotted line with a circle at each data point

plot3(X,Y,Z,'ks-.') plots a black dashdot line with square at each point
MatLab plot() function

```matlab
>> angle = 0:pi/30:2*pi; Y = sin(angle)
>> plot(angle, Y)
```

plot(angle, Y,'r.:') plots a red dotted line with a circle at each data point

```matlab
>> angle = 0:pi/30:2*pi; Y = sin(angle)
>> plot(angle, Y, 'ro:')
```
MatLab plot() function

>> angle=0:0.1:1
>> plot(cos(2*pi*angle),
    sin(2*pi*angle),'ro-'); axis square

>> angle=0:0.05:1
>> plot(cos(2*pi*angle),
    sin(2*pi*angle),'ro-'); axis square
MatLab Multiple function plots

>> angle = 0:pi/30:2*pi
>> f1 = exp(-2*angle)
>> f2 = sin(angle*3)
>> f3 = cos(angle*4)
>> plot(angle,[f1; f2; f3])
>> % or plot(angle, f1, angle, f2, angle ,f3)

>> angle = 0:pi/30:2*pi
>> f1 = exp(-2*angle)
>> f2 = sin(angle*3)
>> f3 = cos(angle*4)
>> plot(angle,f1,'ro:', angle, f2, 'g*-',angle, f3, 'bh--')
MatLab Multiple function plots

```matlab
>> angle = linspace(0,10*pi,100)
>> % generates 100 points between 0 and 10* pi
>> y = cos(angle); z = sin(angle)
>> plot3(angle, y, z); grid ...
>> xlabel('Angle'); ylabel('cos(x)'); zlabel('sin(x)')
```

```matlab
>> angle=-5:0.01:5; plot3(cos(2*pi*angle), sin(2*pi*angle),angle)
```
MatLab three-dimensional plots

```matlab
>> % A three-dimensional plot using the mesh command
>> x = (-3:0.1:3);           % grid frame in x direction
>> y = (-3:0.1:3)';          % grid frame in y direction
>> v = ones(length(x),1);    % auxiliary vector
>> X = v*x;                  % grid matrix of the x values
>> Y = y*v';                 % grid matrix of the y values
>> f = sin(X.^2+Y.^2).*exp(-0.2*(X.^2+Y.^2));
>> % function value
>> mesh(X, Y, f)             % mesh plot with mesh
>> zlabel('f = sin(X.^2+Y.^2).*exp(-0.2*(X.^2+Y.^2))')
>> xlabel('X')
>> ylabel('Y')
```

![Three-dimensional plot](image)
MatLab three-dimensional plots

```matlab
>> % A three-dimensional plot using the mesh command
>> x = [-2:0.2:2]; y = [-2:0.2:2];
>> [X,Y] = meshgrid(x,y);
>> Z=X.*exp(-X.^2-Y.^2);
>> mesh(X,Y,Z);
>> xlabel('X')
>> ylabel('Y')
>> zlabel('Z = X.*exp(-X.^2-Y.^2)')
```
MatLab three-dimensional plots

>> % A three-dimensional plot using the surf command
>> x = [-2:0.2:2]; y = [-2:0.2:2];
>> [X,Y] = meshgrid(x,y);
>> Z = ((8*X+Y).*((cos(x)-cos(2*y)).^2)./(4*sqrt(0.8+(X-4.2).^2+2*(Y-7).^2)))+Y;
>> surf(X,Y,Z);
>> xlabel('X')
>> ylabel('Y')
>> zlabel('Z ')

Z = ((8*X+Y).*((cos(x)-cos(2*y)).^2)./(4*sqrt(0.8+(X-4.2).^2+2*(Y-7).^2)))+Y
MatLab three-dimensional plots

>> % A three-dimensional plot using the surf command
>> x = [-2:0.2:2]; y = [-2:0.2:2];
>> [X,Y] = meshgrid(x,y);
>> Z = Z = (1-X).^2+100*(X.^2-Y).^2
>> surf(X,Y,Z);
>> xlabel('X')
>> ylabel('Y')
>> zlabel('Z')
Symbolic Calculations

MATLAB is a numerical simulation tool (not a symbolic algebraic)

MatLab provides a Symbolic Math toolbox to perform symbolic calculations

Type the command help symbolic to get the MatLab symbolic capabilities

The Symbolic Math Toolbox uses "symbolic objects" produced by the "sym" function. For example, the statement

\[ x = \text{sym('x')} \]

produces a symbolic variable named \( x \)

The statements

\[ x = \text{sym('x')}; \quad y = \text{sym('y')}; \]

can be combined into one statement involving the "syms" function.

\[ \text{syms x y} \]

Symbolic variables can be use in expressions or as arguments to many different functions.
Symbolic Calculations - Simplify a function : `simple(f)`

Simplify \( f = \cos(x)^2 + \sin(x)^2 \)

\[
\begin{align*}
\text{factor: } & \sin(x)^2 + \cos(x)^2 \\
\text{expand: } & \sin(x)^2 + \cos(x)^2 \\
\text{combine: } & 1 \\
\text{convert(exp): } & -1/4*(\exp(i*x)-1/\exp(i*x))^2+(1/2*\exp(i*x)+1/2/\exp(i*x))^2 \\
\text{convert(sincos): } & \sin(x)^2 + \cos(x)^2 \\
\text{convert(tan): } & 4*\tan(1/2*x)^2/(1+\tan(1/2*x)^2)^2+(1-\tan(1/2*x)^2)^2/(1+\tan(1/2*x)^2)^2 \\
\text{collect(x): } & \sin(x)^2 + \cos(x)^2 \\
\text{ans = } & 1 \\
\end{align*}
\]

\[\]
Symbolic Calculations – diff - Differentiate

Steps to execute a symbolic calculation

(1) Use command symbols to declare the variables necessary to perform a symbolic calculation

>> syms x y
% or we can use x = sym('x'); y = sym('y');

(2) Use a MatLab symbolic command

>> f 1 = sin(x*y)*cos(2*y)
f 1 =sin(x*y)*cos(2*y)

>> diff(f1)
>> % differentiate with respect to symbol x
ans =
\[ \cos(x*y) \cdot y \cdot \cos(2*y) \]

>> pretty(ans)
\[ \cos(x \cdot y) \cdot y \cdot \cos(2 \cdot y) \]
Symbolic Calculations – diff - Differentiate

```matlab
>> syms x y  % or we can use  x = sym('x'); y = sym('y);
>> f1 = sin(x*y)*cos(2*y)
  f1 = sin(x*y)*cos(2*y)
>> diff(f1)  % differentiate with respect to symbol x
  ans = 
  cos(x*y)*y*cos(2*y)
>> pretty(ans)
    cos(x y) y cos(2 y)
>> syms x y  % or we can use  x = sym('x'); y = sym('y);
>> f2 = sin(x*y)*cos(2*y)
  f2 = sin(x*y)*cos(2*y)
>> diff(f2,y)  % differentiate with respect to symbol y
  ans = cos(x*y)*x*cos(2*y)-2*sin(x*y)*sin(2*y)
>> pretty(ans)
  cos(x y) x cos(2 y) - 2 sin(x y) sin(2 y)
```
Symbolic Calculations – int - Integrate

Perform the following integrals symbolically, and for the indefinite integrals

$$\int_{0}^{\pi/2} \cos x \sin x \, dx$$

$$\gg \text{int}(\cos(x) \cdot \sin(x), x, 0, \pi/2)$$

ansi = 1/2

$$\int \cos x \sin x \, dx$$

$$\gg \text{int}(\cos(x) \cdot \sin(x), x)$$

ansi = 1/2*\sin(x)^2

$$\int_{-\infty}^{\infty} 3e^{-x^2} \, dx$$

$$\gg f=3*\exp(-x^2);$$

$$\gg \text{int}(f, -\infty, \infty)$$

ansi = 3*pi^(1/2)
Symbolic Calculations - Summation

Compute the following sums:

\[ \sum_{k=1}^{n} k^3 \]

>> syms k n
>> symsum(k^3,k,1,n)
ans = \( \frac{1}{4}(n+1)^4 - \frac{1}{2}(n+1)^3 + \frac{1}{4}(n+1)^2 \)

>> pretty(ans)
\[
\frac{1}{4} (n + 1) - \frac{1}{2} (n + 1) + \frac{1}{4} (n + 1)
\]

>> simplify(ans)
ans = \( \frac{1}{4} n^4 + \frac{1}{2} n^3 + \frac{1}{4} n^2 \)
Symbolic Calculations – MatLab Symbolic functions

```
>> help symbolic

Calculus
  diff    - Differentiate.
  int     - Integrate.
  limit   - Limit.
  taylor  - Taylor series.
  jacobian - Jacobian matrix.
  symsum - Summation of series.

Linear Algebra.
  diag    - Create or extract diagonals.
  triu    - Upper triangle.
  tril    - Lower triangle.
  inv     - Matrix inverse.
  det     - Determinant.
  rank    - Rank.
  rref    - Reduced row echelon form.
  null    - Basis for null space.
  colspace - Basis for column space.
  eig     - Eigenvalues and eigenvectors.
  svd     - Singular values and singular vectors.
  jordan  - Jordan canonical (normal) form.
  poly    - Characteristic polynomial.
  expm    - Matrix exponential.
```
MatLab Programming

MatLab is a programming language in itself; it includes programming language constructs such as loops, branches and writing of functions or scripts

- M-File
- Scripts
- MatLab Functions
- Function Handle
M-files

M-File can be either scripts or functions

Scripts are simply files containing a sequence of MatLab statements/commands

Functions make use of their own local variables and accept input arguments
MATLAB Script

Steps in writing and running a MatLab script program:

Use an editor; to create a file (from the menu) File > New > m-file

Type in the MatLab command sequences

Save the file (e.g. dynamicSys1.m); make sure the file path is accessible to MatLab

Run the file (e.g. dynamicSys1.m); in Command Window, type the file name (e.g. dynamicSys1) M-File name

View the file (e.g. dynamicSys1.m); type LS in Command Window

Note: The name of an M-file begins with an alphabetic character and has a filename extension of .m.
Import/export data files

% Simple program script – Example 1

clear all % clear all variables from memory

% S=load(filename) load data from the specified file into a matrix
% load filename - it uses the file name as the matrix variable name
%
% load student.dat reads all data from the student.dat file into S matrix variable
S=load('student.dat');
height = S(:,1);
weight = S(:,2);
% Calculate Mean and standard deviations
average_weight = mean(weight);
std_weight = std(weight);
maximum_weight = max(weight);
minimum_weight = min(weight);
disp(sprintf('
Average Weight: %6.2f', average_weight));
disp(sprintf('
Standard Deviation: %6.2f', std_weight));
disp(sprintf('
Maximum Weight: %6.2f', maximum_weight));
disp(sprintf('
Minimum Weight: %6.2f', minimum_weight));
disp(sprintf('

'));
%divide figure in one row, two columns, then select pane 1
subplot(1,2,1);% subplot: row=1, column=2, pane=1
% plot (linear 2-D plot) of weight data
plot(weight)
title('Weight of Freshman Class Men')
xlabel('Count(students)')
ylabel('Weight, lbs')
grid on
hold on
% plot average line
plot(1:size(weight),average_weight,'r:');
% subplot: row=1, column=2, pane=2
subplot(1,2,2)
plot(height)
title('Height of Freshman Class Men')
xlabel('Count(students)')
ylabel('Height, inches')
average_height = mean(height);
std_height = std(height);
maximum_height = max(height);
minimum_height = min(height);
disp(sprintf('
	Average Height: %6.2f', average_height));
disp(sprintf('
	Standard Deviation: %6.2f', std_weight));
disp(sprintf('
	Maximum Height: %6.2f', maximum_height));
disp(sprintf('
	Minimum Height: %6.2f', minimum_height));
disp(sprintf('
	Done'));
% Simple program script – Example 2
% clear removes all variables from the workspace; to free up system
% memory.
clear all

% clc clears all input and output from the Command Window display,
% giving you a "clean screen."
clc

% 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,n) generates a row vector y of n points linearly
% spaced between and including a and b.
% 
% x=linspace(0,10*pi,1000);
The Colon Operator (:) is used to create a vector containing:

\[-2.0000 \ -1.8000 \ -1.6000 \ \ldots \ 1.6000 \ 1.8000 \ 2.0000\]

with 21 cells

\[x = [-2:0.2:2];\]
\[y = [-2:0.2:2];\]

meshgrid - Generates X and Y matrices for three-dimensional plots

\[\text{[X,Y]} = \text{meshgrid}(x,y)\]
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 \(y\).

For example, the \([X,Y] = \text{meshgrid}(1:3,10:14)\) are:
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\%
X =
%

\%
1 2 3
\%
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
\[ [X,Y] = \text{meshgrid}(x,y); \]

\% * operator is used to perform an element by element multiplication
\[ Z = X. \times \exp(-X.^2-Y.^2); \]

\text{subplot}(2,2,1)

\% mesh(X,Y,Z) draws a wireframe mesh with color determined by Z so color
\% is proportional to surface height.
\text{mesh}(X,Y,Z)
\text{title('Mesh Plot')}
\text{xlabel('x-axis')}
\text{ylabel('y-axis')}
\text{zlabel('z-axis')}

subplot(2,2,2)
% surf(X,Y,Z) creates a shaded surface using Z for the color data as well
% as surface height.
surf(X,Y,Z)
title('Surface Plot')
xlabel('x-axis')
ylabel('y-axis')
zlabel('z-axis')

subplot(2,2,3)
% contour(X,Y,Z) draws contour plot of Z
contour(X,Y,Z)
title('Contour Plot')
xlabel('x-axis')
ylabel('y-axis')
zlabel('z-axis')
subplot(2,2,4)
% surfc(...) draws a contour plot beneath the surface.
surfc(X,Y,Z)
title('Combination Surface and Contour Plot')
xlabel('x-axis')
ylabel('y-axis')
zlabel('z-axis')
M-file function

Syntax

\[ \text{function } \left[ \text{out}_1, \text{out}_2, \ldots \right] = \text{funname}(\text{in}_1, \text{in}_2, \ldots) \]

\[ \text{function } \left[ \text{out}_1, \text{out}_2, \ldots \right] = \text{funname}(\text{in}_1, \text{in}_2, \ldots) \text{ defines function funname that accepts inputs } \text{in}_1, \text{in}_2, \text{etc. and returns outputs } \text{out}_1, \text{out}_2, \text{etc.} \]
Multiple functions within an M-File

MATLAB allows multiple subfunctions within a M-File

These subfunctions are not visible to other functions in the other M-Files

A function is terminated using an end statement or use a return statement to force an early return

Local variables

The variables within the body of the function are all local variables
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.

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.
Example

M-File Name: stat.m
Input: vector x
Output: mean and stdev

function [mean, stdev] = stat(x)
    n = length(x);
    mean = sum(x)/n;
    stdev = sqrt(sum((x-mean).^2)/n);
end
Function handle is used to call functions indirectly

Syntax
handle = @functionname

handle = @functionname returns a handle to the specified MATLAB function
Function handle

A function handle is a MATLAB value that provides a means of calling a function indirectly.
M-Files

rosenbrock.m function
test.m script
minimize.m function

Test calls minimize function, function Handle to rosenbrock function is passed as parameter to minimize function
% Partial example

function y = rosenbrock()
    % Rosenbrock banana function
    % The minimum is at (1,1), (y=8.1777e-010).
    % The traditional starting point is (-1.2,1).

    y = 100 * (x(2)-x(1)^2)^2 + (1-x(1))^2;

end
% MatLab Script
% File name: Test

x=[-1.2 1];
[x, y, history] = minimize(@rosenbrock, x);
x
y

history
m1=min(history(:,1));
m2=max(history(:,1));
m3=min(history(:,2));
m4=max(history(:,2));
m1, m2, m3, m4

.......
% File Name: minimize.m

function [x, y, history] = minimize(functionHandle, x_init)

    history = [];
    options = optimset('OutputFcn', @myoutput);
    [x y] = fminsearch(functionHandle, x_init, options);
    function stop = myoutput(x, optimvalues, state);
        stop = [];
        if state == 'iter'
            history = [history; x];
        end
    end
end
end
% MatLab Script – Example

x = [-2:0.2:2];
y = [-2:0.2:2];
[X,Y] = meshgrid(x,y);
Z = 100*(Y-X.^2).^2+(1-X).^2;
subplot(2,2,1)

% mesh(X,Y,Z) draws a wireframe mesh with color determined by Z so color
% is proportional to surface height.
mesh(X,Y,Z)
title('Mesh Plot')
xlabel('x-axis')
ylabel('y-axis')
zlabel('z-axis')
subplot(2,2,2)
% MatLab Script
% surf(X,Y,Z) creates a shaded surface using Z for the color data as well % as surface height.
surf(X,Y,Z)
title('Surface Plot')
xlabel('x-axis')
ylabel('y-axis')
zlabel('z-axis')

subplot(2,2,3)
% contour(X,Y,Z) draws contour plot of Z
contour(X,Y,Z)
title('Contour Plot')
xlabel('x-axis')
ylabel('y-axis')
zlabel('z-axis')
% MatLab Script
% File name: minimizeTest

subplot(2,2,4)
% surfc(...) draws a contour plot beneath the surface.
surfc(X,Y,Z)
title('Combination Surface and Contour Plot')
xlabel('x-axis')
ylabel('y-axis')
zlabel('z-axis')

close all; % close all previously drawn graphs
figure; % create a new figure/plot
grid on;
title('History points')
xlabel('x(1)');
ylabel('x(2)');
plot(history(:,1),history(:,2), '--rs', 'LineWidth',2, 'MarkerEdgeColor',
    'k', 'MarkerFaceColor','g', 'MarkerSize',2)
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Figure No. 1

Mesh Plot

Surface Plot

Contour Plot

Combination Surface and Contour Plot
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\textbf{The first 300,000 digits of \pi}

Pi with million digits:

\[ \pi = 3.141592653589793238462643383279502884197169399375105820974944592230781640628620899862803482534232177\ldots \]

0.00056812714526356082778577134275778960917363717872114648409012249534301465495853710507922796892589235
42019956112129021960860434811598136297477130969601870721134999998729780499515973173281609631859
5024459455346908302642522308253446850352649313188181711010031312368375288685753320388342061717769147303
59825354902875546873115956268386235238753971955778185778035217122686601300192786761119599091642021989
3809525702016548563278866361553818279662303019520353018526989577362259941389124972177528347913151
5574857242451506959082953311861617278558890750988317564376493931925506040927701671119309848240212
8583610365370766010471081894299556918906768734749447537977472687410404753466260840666847590694912
9331367702898915210475621020569662040580381501935125338243003558764024794674732693914992726042692279
6782354816309394143716214219925861350289969503574945818508498869269956097271079579009302955
321165344987202755960236480665499119881834797753566369807426542527862551818417547672890977727938000
8167460010145249192172172477320501414419137658684816136157352551233475741849648345232329037914333
454776241686252189835648586520992192221844172255025425688671790496016534668094988627237297178605878483
82796796681454100953883783609560866042521250151739284860841284862694560424916525802210611863
06744276640950925495071231378690695363473197127876764645757396241389086583264595981539047802759009
9465764078512694638935325597098256220524284072767194728628401476909026041363943475530568203
4962542517493965914132490819065920397721669641515079588387410597858957729754989301617539284681328
68683868942774155991855925459593941024997252468084508727364649584653836376326226209912460805124388
4390512441365497627807797716591435997001296160894416948685558478406354342202722582884864815456208506
016842739426627467678895252138522549546467278239665659611635486862305745646083055936345681743421125
1507806694794510596590904025228879108931456961368677287489040610150330861729860902078476091782493858
9090194906759852613654978113279848216898299848276580408575640142074077555132379641451523764323464
5428584447952565867821051143537435739523113427166102135965362314429524893178011070457645035920799344
0374200731057853906219838744780847849683321445713868751943506430218453190104848100537061468067491927
% Utility program to group digits of Pi
% (group of 1, 10 and 15 digits) –
% Use the first 300000 digits of Pi
fid = fopen('PI.txt');
a = fscanf(fid,'%s');  % It has two rows now.

b=[];
for d=1:300000
    if(a(l , d)>'0' && a(l , d)<='9')
        a(1,d);
        b=[b,a(1,d)];
    end
end

size(b);
k=10;  l=1; m=15;
 fid1 = fopen('PI10Out-150000.txt','w');
 fid2 = fopen('PI15Out-150000.txt','w');
 fid3 = fopen('PI1Out-150000.txt','w');

% group of 15, 5 groups per row
for d=1:20000
    ac1=b(l:m);  l=l+15; m=m+15;
    ac2=b(l:m);  l=l+15; m=m+15;
    ac3=b(l:m);  l=l+15; m=m+15;
    ac4=b(l:m);  l=l+15; m=m+15;
    ac5=b(l:m);  l=l+15; m=m+15;
    fprintf(fid2,'%15s %15s %15s %15s ...
        %15s\n',ac1,ac2,ac3,ac4,ac5);
end
% group of 10, 5 groups per row
for d=1:30000
    ab1=b(j:k); j=j+10; k=k+10;
    ab2=b(j:k); j=j+10; k=k+10;
    ab3=b(j:k); j=j+10; k=k+10;
    ab4=b(j:k); j=j+10; k=k+10;
    ab5=b(j:k); j=j+10; k=k+10;
    fprintf(fid1,'%s %10s %10s %10s %10s
',ab1, ab2, ab3 ,ab4 ,ab5);
End

% group of 1, 75 groups per row
j=1; k=1;
for d=1:2000
    b1=[];
    for b2=1:75
        b1=[b1,b(j:k)];
        b1=[b1,' '];
        j=j+1; k=k+1;
    end
    fprintf(fid3,'%s\n',b1);
End
fclose(fid); fclose(fid1); fclose(fid2); fclose(fid3);
% The first 300,000 digits of pi

Pi with million digits: \[ \pi = 3.14159265358979323846264338327950288419716939937510582097494459223078164062862089896828034825342117067982148086513282306647093846049550822342753594780481117450284102701938521105559644622948954930381964428810975965693334614284756482337867831652712019091454856869932463048610454326648213393607620249912737245870066031558817488152092096282954091715364376892590360011330530548820466521384146951941511609433057702656765959195029128616117819326117910511058480746627349567351885752724892271298381301911298336733624406566430860213944936522473719070217989069437027705392171762759738467481846766940513200005681271452435608277877134275778690917363717872714684409012249534301465495853710507927299882589235420199561112129021608640344181598136297747771309996051870727113499999983729780499510597317328160963185950244594553469030264252230825334468505326193118817110100003137838752886587533208381420611717669147303598253490426875546873115195626836832353787597351957781857745032112260686310019217876761119590921640219893809552701065485863278865936135338128719682832031952035301852969957736225994138912497217752834791315574587524245415069590502953111686171738585890750938175467446493919225056040900277016711390098488240128583610635637076610471018194295559619994667837449448255379774726847104074575346462804064684259069412933136702898915210475712065696204580831501935112533824030355876402479964732639141992726042699227678254871363009341712614112945863150302861829745557067498385054945885869629956909272110775909302955321163449872027559023648066549911988138479775356363698074265425278625518184175476427889077772793800816470601614524921732172477350414197153685416316315735252133477418498463845523323907394143334547762416862518935694855620992192224726725502542568876719701994904616346680498862723279717860587843882797696681451401095383873863906806064251252501173929849860841284886264945604249169552850222106611863674427862609194642712357166972767467465375396261438908658326459958131339047802759009465670487915269483893525957098285226052428490727619742768268426017469090902401639443745530568203962562517499393914213890896529039722169646411517500858374610598785959729754989301617539284681382668386894277415159918559254595399341049977252468084585072736446958465386367362262609912468085124388439045124413654976278079771569143599700129616089441649685558484063534220722258284886481584560285061068427394526274676788952521358252549954666727283986456596161354866230577454890355953634568174324112510576694754565960925022887083913456691368672287489045061015033068172868092087476091782493858909917499675985261365549781893179784821682998478226588048575640142704775551323796414515237462343645428584447952658687820510511413457379532134716610213996593623144295248939718711014576540539027993440374200731057853906219838744780848489683321445713868751934506430218453319104841005376061468067491927
% Utility Program to count digits 0 - 9 in the first 300000 digits of Pi

fid = fopen('PI.txt');
b = fscanf(fid,'%s'); % It has two rows now.

d1 = 0; d2 = 0; d3 = 0; d4 = 0; d5 = 0; d6 = 0; d7 = 0; d8 = 0; d9 = 0; d0 = 0;

a = [];

for d = 1:300000
    if(b(1,d) >= '0' && b(1,d) <= '9')
        a = [a,b(1,d)];
    end
end

size(b)
% Change 300000 to a desire count
%
% Program utility to count 0 – 9 in the first 300000 digits of Pi
% inside 'file name'

fid = fopen('Pi.txt');

b = fscanf(fid,'%s'); % It has two rows now.

d1=0; d2=0; d3=0; d4=0; d5=0; d6=0; d7=0; d8=0; d9=0; d0=0;

a=[];

for d=1:300000
    if(b(1,d)=='0' && b(1,d) <= '9')
        a=[a,b(1,d)];
    end
end

size(b)
% Change 300000 to a desire count
% for d=1:300000
for d=1:300000
    if a(1,d) == '1'  d1=d1+1;
    elseif a(1,d) == '2' d2=d2+1;
    elseif a(1,d) == '3' d3=d3+1;
    elseif a(1,d) == '4' d4=d4+1;
    elseif a(1,d) == '5' d5=d5+1;
    elseif a(1,d) == '6' d6=d6+1;
    elseif a(1,d) == '7' d7=d7+1;
    elseif a(1,d) == '8' d8=d8+1;
    elseif a(1,d) == '9' d9=d9+1;
    elseif a(1,d) == '0' d0=d0+1;
    else
        a(1,d)
    end
end
fclose(fid);
% show counts of digits 0-9
d0, d1, d2, d3, d4, d5, d6, d7, d8, d9
Thank you!