Chapter-1

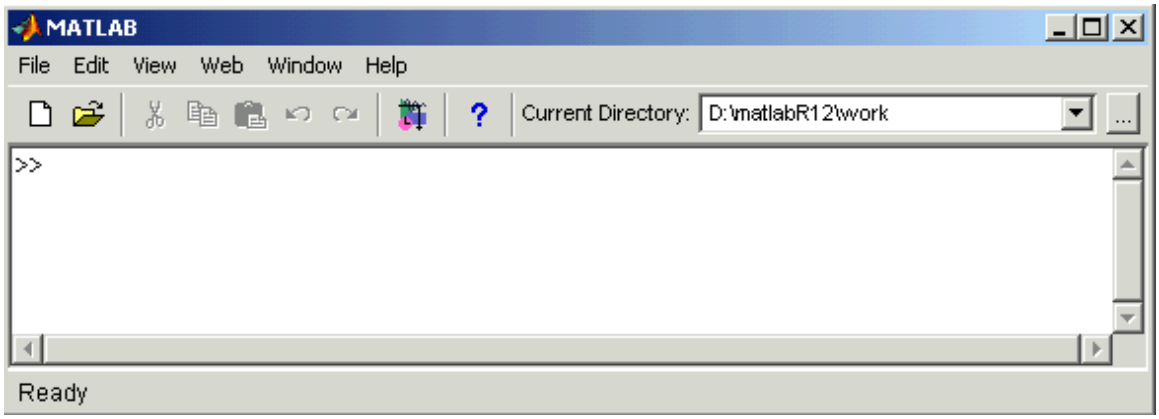
Introduction:

MATLAB, short for **MAT**rix **LAB**oratory, is a matrix-based computer program designed for performing scientific and engineering computation and data visualization. The MATLAB family of programs consists of the main program, namely, MATLAB, and add-on **toolboxes,** which extend the functionality of MATLAB. MATLAB is available in the School of Engineering on the PC-network. As of this writing the following toolboxes are supported.

- Simulink
- Signal processing
- Communications
- DSP blockset
- Image processing
- Fuzzy logic
- Neural networks
- Control
- Optimization
- Data acquisition
- Wavelets
- Real-time workshop
- Symbolic

Starting MATLAB:

Locate the MATLAB program icon on the desktop of your computer and double click it to launch the program. This action opens the **command window**, showing the prompt on the left corner (>> or EDU>>). Once MATLAB has been started, the program interpreter is ready to execute MATLAB commands.



A session may be terminated by simply typing **quit** or **exit** at the MATLAB prompt, followed by the "enter" key, i.e.,

>>quit <enter>

Evaluating Mathematical Expressions:

The simplest way to start with MATLAB is to use it for basic computations. You simply enter the expression much like a scientific calculator. Command lines are evaluated as soon as they have been concluded by pressing <enter>.

Example:

>>7/3 <enter>

To which MATLAB responds with

ans=
2.3333

Since no variable was defined, MATLAB assigns the result to the generic variable **ans** that stands for "answer".
All computations in MATLAB are done in double precision (8 bytes to represent a number). However, the screen output can be displayed in several formats. The command **format** provides control over the display of the answers. By default, MATLAB displays numerical data with four digits after the decimal point. To display the answer with more significant figures, use the **format long** command. Thus,

>>format long <enter>
>>7/3 <enter>

MATLAB returns

ans=
2.333333333333333
The single command **format** reverts the display to default.

>>format <enter>

The Primary Mathematical Operators:

In MATLAB, the standard arithmetic operations are denoted as follows:

Symbol	Meaning
+	Addition
-	Subtraction
*	Multiplication
/	Division
^	Exponentiation

MATLAB Variables:

Like most programming languages, MATLAB allows you to create variables and assign values to them. Variables can represent scalars, vectors, matrices, or strings. Variables in MATLAB can have any names **except reserved names** used for MATLAB functions. It is a good practice to

use variable names that describe the quantity they represent. The name must begin with a letter but may be followed by any combination of letters, digits or underscores (don't use space), and must contain at most 31 characters. Thus, xab, x12c, and x12_c are all legal names. Real scalars may be entered by a simple assignment of the form,

>>total= 9+11;

The statement above will cause the expression to the right of "=" to be evaluated. The result (in this case 20) is stored in the variable **total**. The semicolon at the end of the statement has the effect of suppressing the output so that nothing is printed on the screen. Without the semicolon, the result is printed out immediately. In general, when a statement is followed by a semicolon (;), the statement is executed but the result is not printed in the command window. The value of any variable is printed by simply typing its name, and hitting <enter>. Thus,

>>total <enter>

results in

total=
20

Note:

*All the variables created in any given session are stored in memory (in an area called the **workspace**). Once you exit MATLAB all values of the variables are lost.*

Character strings:

Strings are the form of data used in programming languages for storing and manipulating text, such as words, names, and sentences. An example of a string is,

>>s='Too much of any one thing becomes drudgery'

The single quotation marks are not part of the string. They are there to mark off the string. In MATLAB, string constants are surrounded by single quotation marks; this is how MATLAB recognizes a string. To insert an apostrophe inside a string a double apostrophe must be used. There are two useful commands in string treatment, namely, **strcmp** and **findstr**. The first one is a logical operator.

Syntax:

>>strcmp(x,y)

returns 1 if the strings x and y are the same, 0 otherwise.

>>findstr(x,y)

returns the position of the string y into the string a.

Practice:

```
>>x='Programming with MATLAB is fun';
>>y='Programming with MATLAB is simple';
>>strcmp(x,y)

ans =

    0

>>findstr(x,'u')

ans =

   29
```

Command	Meaning
int2str(a)	converts the integer 'a' into a character string
num2str(a)	converts the value 'a' into a character string
str2num(s)	converts the string 's' into the corresponding numerical value
str2mat	groups different strings into a matrix

Case Sensitivity:

As in C programming language, MATLAB is case (upper and lower case) sensitive (upper and lowercase letters are not interchangeable). In other words, **student**, **Student**, and **STUDENT** are three distinct variables. If this proves to be an annoyance, the command **casesen** will toggle the case sensitivity off and on. Always type commands in lowercase since all command and function names are in lowercase.

Precedence of Operators:

All operators in MATLAB are ranked according to their precedence. Exponentiation has the highest precedence, followed by multiplication and division, and finally addition and subtraction. Operations are evaluated left to right. If the order of operations is to be modified, parentheses must be used.

Comments:

Every computer language provides a facility for documenting a program. This optional facility lets you describe statements in the source program to make it clear to the reader what is going on. Your code must be commented and it should be written in such a way as if someone else is going to have to understand the program without your help. Include comments that clearly explain the logic of what you are doing. There are several ways to include comments. Any statement that begins with a percent sign (%) is considered to be a comment and ignored by MATLAB. Comments could either start at the beginning or anywhere in a line. Here is an example:

```
>>% This line is a comment
```

Second, you can add a comment to the end of a statement by prefacing the comment with a percent sign (%). Here is an example:

```
>>[z,p,k]=buttap(4);                %Here is a comment
```

Typical Mathematical Functions:

MATLAB has a very large library of built-in functions for mathematical and scientific computations. Here is a summary of some relevant functions.

Symbol	Meaning
sin(x)	sine of x
cos(x)	cosine of x
tan(x)	tangent of x
acos(x)	arccosine of x
asin(x)	arcsine of x
atan(x)	2-quadrant arctangent of x
asinh(x)	inverse hyperbolic sine of x
acosh(x)	inverse hyperbolic cosine of x
atan2(x(	four quadrants inverse tangent of x
tanh(x)	hyperbolic tangent of x
sec(x)	secant of x
csc(x)	cosecant of x
cot(x)	cotangent of x
asec(x)	inverse secant of x
acsc(x)	inverse cosecant of x
acot(x)	inverse cotangent of x
sech(x)	hyperbolic secant of x
csch(x)	hyperbolic cosecant of x
coth(x)	hyperbolic cotangent of x

asech(x)	inverse hyperbolic secant
acsh(x)	hyperbolic cosecant of x
acoth(x)	inverse hyperbolic cotangent of x
log(x)	natural logarithm of x
log10(x)	natural logarithm of x
log2(x)	logarithm base 2 of x
sqrt(x)	square root of x
exp(x)	exponential of x
abs(x)	magnitude of x
square(x)	generate a square wave with period 2π
sawtooth(x)	generate a sawtooth wave with period 2π
sign(x)	signum function of x
rem(x,y)	remainder when x is divided by y
sinc(x)	$\sin(\pi x)/\pi x$
erf(x)	error function of x
erfc(x)	complementary error function of x
erfinv(x)	inverse error function of x

Predefined variables:

Symbol	Meaning
pi	π
Inf	∞
NaN	Not-a-Number,e.g., $\frac{\infty}{\infty}, \frac{0}{0}, -\infty+\infty$
i,j	$\sqrt{-1}$

Practice:

Use MATLAB to evaluate the following expressions:

1. (7+3)+5 <enter>
2. (9-5)*6 <enter>
3. 3*cos(3*pi/4) <enter>
4. 3^2 <enter>
5. sqrt(5) <enter>
6. exp(5) <enter>
7. log(exp(2)) <enter>
8. 15/2 <enter>
9. 2\15 <enter>
10. atan(pi/4) <enter>
11. log10(100)
12. 3+sqrt(7)

Practice:

Evaluate the following expression:

$$c^3 - \sqrt{rA} - 5B$$

>>c=2.3; r=5.1; A=3.4; B=1.5;
>>c^3-sqrt(r*A)-5*B <enter>

A complete list of functions designed for rounding numbers to integers is given below:

Symbol	**Meaning**
floor(x)	Largest integer less than or equal to x
ceil(x)	Smallest integer greater than or equal to x
round(x)	Round x to the closest integer
fix(x)	Round x toward zero

Practice:

1. What is the integer closest to $\sqrt{173}$?

>>x=sqrt(173); <enter>
>>round(x) <enter>

2. Between what consecutive integers does $\left(\pi^2+1\right)^5$ lie?

>>x=(pi^2+1)^5; <enter>

>>lbound=floor(x) <enter>
>>ubound=ceil(x) <enter>
answer: $lbound < x < ubound$

Base conversions:

It is often the case in computer engineering to convert numbers from one base to another. MATLAB has a number of functions tailored for that purpose. These functions are **bin2dec**, **dec2bin**, **hex2dec**, **dec2hex**, **dec2base**, and **oct2dec**. Table below provides a summary of these functions.

Function	meaning
dec2bin	Convert decimal to a binary string
bin2dec	Convert binary string to decimal integer
dec2hex	Convert decimal to hexadecimal
hex2dec	Convert hexadecimal to decimal
dec2base	Convert dec numbers to octal numbers
oct2dec	Convert octal numbers to decimal numbers

Practice:

Make the following base conversions:

1. $(723542)_8$ to decimal
2. $(8451)_{10}$ to binary
3. $(4E52B)_{16}$ to binary
4. $(5C52B)_{16}$ to octal
5. $(1001011)_2$ to decimal

>>oct2dec(723542)
ans: 239458
>>dec2bin(8451)
ans: 10000100000011
>>dec2bin(hex2dec('4E52B')
ans: 1001110010100101011
>>dec2base(hex2dec('5C52B'),8)
ans: 1342453
>>bin2dec('1001011')

ans: 75

Basic commands:

The **who** command lists all the variables currently in workspace, and the **whos** command list the variables in workspace and gives extra information regarding variable dimension, type, and size in bytes. Entering the **clear** command without arguments removes all the variables in the current workspace and **clear** followed by the name of any variable deletes only that variable in workspace. The **clc** command clears the command window and resets the command prompt at the top of the screen.

Practice:

1. Use MATLAB to find the area of a circle of radius equal to3.5.

```
>>% Evaluation of the area of a circle
>>radius=3.5;                    %set radius  to 3.5
>>area=pi*r^2  <enter>           %compute the area of the circle
```

2. Create three variables **x**, **y**, and **z**, then use the **who**, and **whos** commands to display the variables in workspace. Afterwards clear all the variables and the MATLAB command window.

```
>>x=2*cos(pi/6); <enter>         %define variable x
>>y=5*sin(pi/4);  <enter>        %define variable y
>>z=exp(pi*sqrt(23)) <enter>     %define variable z
>>who <enter>                    %display the list of variables in workspace
>>whos <enter>                   %give list of variables with additional attributes
>>clear x <enter>                %clear variable x
>>clear  <enter>                 %clear all remaining variables
>>clc  <enter>                   %clear command line window
```

Note:

If a statement does not fit in the 80 spaces available on a line, you can split it over two (or more) lines by placing an ellipsis (three periods) at the end of the line and resume typing on the next line.

```
>>x=sin(2*pi*3*t)+2*sin(2*pi*6*t)+7*sin(2*pi*9*t)+…
      3*sin(2*pi*12*t);
```

On-screen help:

There are many sources of help in MATLAB. If you know the name of the command you want help on, you can use the MATLAB **help** command followed by the name of the command to determine its syntax.

```
>>help command name <enter>
>>help sin <enter>               %provide the syntax for the sine function
```

If you are unsure about the spelling or existence of a command, you can try to find it using the **lookfor** command. The lookfor command searches the MATLAB files and returns the names containing a specific keyword.

```
>>lookfor hilbert <enter>          %retrieve all commands containing the keyword Hilbert
```

As soon as the command name is found, use the **help** command to retrieve its syntax.

If you type **help** with no parameters a list of the main MATLAB topics appear on the screen, while **help** *topic_name* returns all available commands on the specified topic.

```
>>help <enter>                    %return a list of the main MATLAB topics
>>help signal  <enter>            %return a list of functions of the signal processing toolbox
```

Generation of vectors:

A straightforward way to generate a **row vector** is to list its elements, surrounded by square brackets [ ]. Either commas or blanks may separate the elements of a vector. For example, to create a vector having as elements 3, 5, 7, 9, and 11, just enter:

```
>>x=[3  5  7  9  11]   <enter>          %define a row vector
```

MATLAB should return

```
x=
        3   5    7   9   11
```

Column vectors have similar constructs to row vectors, but semicolons separate the entries.

```
>>x= [3;  5;  7;  9;  11]  <enter>      %define a column vector
```

It is possible to turn a row vector into a column vector (and vice versa) via a process called transposing and defined using the prime operator (apostrophe), [‘].

```
>>x=[3  5  7  9  11]; <enter>           %specify a row vector
>>x’ <enter>                           %convert a row vector into a column vector
```

This way of defining vectors becomes awkward for large data sets (this can be time consuming), moreover, common vectors are those of equally spaced numbers. MATLAB provides a more flexible way of constructing vectors of evenly spaced values over a given range. The colon operator [:] is used for this purpose. The colon will be used most often to generate vectors for creating x-y plots. The general form of the statement is:

```
>>x = start: step: end;
```

where **start** and **end** are the lower and upper bounds of the interval and **step (increment)** is the step size.

Practice:

```
>>x=0: 0.1: 1  <enter>   %generate 11 data pts from 0 through 1 in increments of 0.1
```

x=

0 0.1 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1

You can reference individual items within the vector. To change the sixth element in the **x** vector, proceed as follows:

>>x(6)=0.45;

Note:

It is just as easy to use negative increments. If the step size is omitted, a value of 1 is used.

```
>>x=7:-1:2      <enter>      %generate an array with negative step size
>>x= 0: 5  <enter>          %generate an array with step size of 1
```

Practice:

Compute the sum of the finite geometric series

$$s = 1 + r + r^2 + \ldots + r^n$$

where the common ratio is r=0.6 and n=10.

```
>>n=0:10;                   %define the running index n
>>r=0.6;                    %specify the ratio of the geometric series
>>s=sum(r.*n)  <enter>      %evaluate the sum
```

Practice:

We are given a vector x=[0:0.2:3].

1. Determine the seventh component of x
2. Determine the length of x

```
>>x=[0:0.2:3];              %specify vector x
>>x(7)  <enter>             %specify the seventh component of x
>>length(x) <enter>         %return the length of the vector x
```

note:

In MATLAB, all arrays are indexed starting with 1, i.e., x(1) is the first element of the array x. The notation **x(1:12)** *means the first 12 elements of the vector* **x**.

Practice:

Compute the dot product of the following vectors:

>>x=[1 2 3];

```
>>y=[4 5 6];
>>x*y' <enter>
```

MATLAB has two built-in functions to generate vectors. The **linspace** function creates linearly spaced vectors of length **n** over the range from **start** to **end** (if the length is omitted, MATLAB assumes 100 points). The command structure is as follows:

```
>>x=linspace(start, end, n);
```

Practice:

Write a piece of code to convert temperatures from degrees Fahrenheit to degrees centigrade

```
>>F=linspace(0,9,10); <enter>        %specify evenly spaced temperatures
>>C=(F-32)*5/9;  <enter>             %Fahrenheit to Centigrade conversion
>>[F' C']  <enter>                   %display both temperatures as column vectors
```

```
    0.0    -17.22
    1.0    –17.22
    2.0    –16.67
    3.0    –16.11
    4.0    –15.56
    5.0    –15.00
    6.0    –14.44
    7.0    –13.89
    8.0    –13.33
    9.0    –12.78
```

Lastly, the function **logspace** generates a logarithmically spaced vector of length n ranging from 10^{start} to 10^{end}. The command structure is as follows:

```
>>x=logspace(start,end,n);
```

Practice:

```
>>x=logspace(0,2,5) <enter>          %create a vector of length 5 ranging from 1 to 100
```

Term-by-term operations:

MATLAB has special operators, to carry out term-by-term multiplication, division, and exponentiation. An operator preceded by a dot (or period) causes the operation to be performed term-by-term. These operators are shown in the following table:

Symbol	Term-by-term operation
.*	Multiplication
./	Division
.^	Exponentiation

Practice:

```
>>% Term-by-term multiplication
>>x=[1  2  3];                    %specify vector x
>>y=[2  4  1];                    %specify vector y
>>z=x.*y  <enter>                 %compute the term by term product

>>%Term-by-term division
>>x=[1  2  3];                    %specify vector x
>>y=[2  4  1];                    %specify vector y
>>z=x./y  <enter>                 %compute the term by term division

>>%Term-by-term exponentiation
>>x=[1  2  3];                    %specify vector x
>>y=[2  4  1];                    %specify vector y
>>z=x.^y  <enter>                 %compute the term by term exponentiation
```

Complex numbers:

MATLAB can handle both real as well as complex data. In this section we shall explore the use of MATLAB for doing complex arithmetic and algebra.

The number, $\sqrt{-1}$, is identified in MATLAB by the variables **i** or **j.** Using **j** (**i** is typically dedicated to electrical current), one can generate complex numbers. Therefore, a complex number, such as z=3+5j, may be input as z=3+7j or z=3+7*j. MATLAB always displays the imaginary unit as **i.**

Practice:

```
>>z=2+3j;                         %define a complex number z
```

MATLAB provides several built-in functions to work with complex numbers. We can extract the real and imaginary parts of an arbitrary complex number by the functions **real(z)** and **imag(z).**

Practice:

```
>>z=3 + 5j;  <enter>              %define a complex number z
>>x=real(z)  <enter>              %extract the real part of z and store the result in x
>>y=imag(z)  <enter>              %extract the imaginary part of z and store the result in y
```

To convert to polar notation, the function **abs(z)** and **angle(z)** ($-\pi < angle(z) \le \pi$)**,** compute the modulus (magnitude) of the complex number and its phase in radians, respectively. Lastly, **conj(z)** returns the complex conjugate of the complex number z.

Practice:

```
>>z=5+3j;                         %define a complex number z
>>mag=abs(z) <enter>              %compute the magnitude of z
>>phase=angle(z)  <enter>         %compute the phase in radians
>>phase=angle(z)*180/pi <enter>   %compute the phase in degrees
```

>>zbar=conj(z) <enter> %compute the complex conjugate of z

It is often the case to convert a complex number from a cartesian form to polar form and vice versa. MATLAB has built-in functions **cart2pol** and **pol2cart** that perform conversion from cartesian to polar and polar to cartesian, respectively.

Function synopsis:

```
>>z1=x+j*y;                    %define a complex number in Cartesian form
>>z2=mag*exp(j*theta);         %define a complex number in polar form
>>[theta, mag]=cart2pol(x,y);  %conversion from cartesian to polar
>>[x,y]=pol2cart(theta,mag);   %conversion from polar to Cartesian
```

Practice:

Express the given complex number in polar form

```
>>z=-2+0.5j;                   %define a complex number in Cartesian form
>>[theta, mag]=cart2pol(-2, 0.5)  %provide polar form of z
```
answer: theta=2.8966; mag=2.0616

$\therefore z = -2 + 0.5j = 2.061e^{j2.8966}$

Practice:

1. Use MATLAB to evaluate the magnitude and phase of the given complex numbers

```
>>z1=2+3j;
>>z2=-2+j;
>>z3=-2-3j;
>>z4=1-3j;
```

2. Express the numbers defined in part (1) in polar form
3. Determine z1*z2, and z1/z2
4. Determine z3+z4, and z4-z3
5. Determine the real part of $z1^2 \times z2^2$
6. Determine the imaginary part of $z1^4 / z2^3$
7. Plot z1 using plot(z1,'x'). This command will plot the imaginary part versus the real part.

Practice:

Check the following identities:

1. $e^{j\frac{\pi}{2}} = j$
2. $e^{-j\frac{\pi}{2}} = -j$
3. $e^{j\pi} = -1$

```
>>exp(j*pi/2)
>>exp(-j*pi/2)
>>exp(j*pi)
```

Practice:

Simplify the following expressions:

1. $z = (1-j)^5$
2. $z = je^{j\frac{\pi}{3}}$
3. $z = \dfrac{(2+3j)(4-9j)}{(1+5j)(7-6j)}$
4. $z = e^{j\frac{\pi}{2}} + e^{-j\frac{\pi}{3}}$
5. $z = (1+j)e^{-j\frac{\pi}{3}}$

```
>>z=(1-j)^5 <enter>
>>z=j*exp(j*7*pi/3)  <enter>
>>z=((2+3j)*(4-j))/((1+5j)*(7-6j))  <enter>
>>z=exp(j*pi/2)+exp(-j*pi/3); <enter>
>>z=(1+j)*exp(-j*pi/3) <enter>
```

Practice:

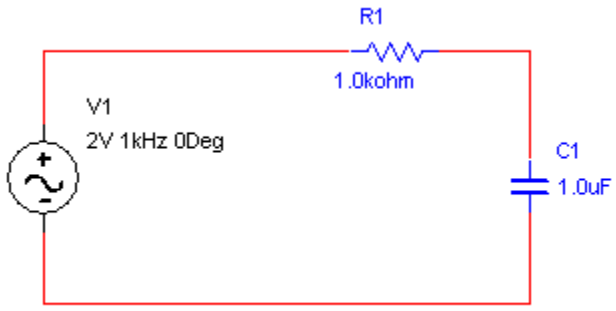
Simplify the following complex-valued expressions and give the answers in both Cartesian form and polar form.

1. $3e^{j\frac{2\pi}{3}} + 5e^{-j\frac{3\pi}{4}}$
2. $\left(\sqrt{7} + j5\right)^4$
3. $\left(\sqrt{5} - j7\right)^{-2}$
4. $\mathrm{Im}\left(je^{-j\frac{\pi}{7}} + e^{j\frac{2\pi}{7}} \right)$
5. $\mathrm{Re}\left(je^{-j\frac{\pi}{5}} - e^{j\frac{2\pi}{3}} \right)$

Practice:

The following circuit is driven by a source delivering a voltage of 2v with a frequency of 1kHz.

1. Determine the impedance of the circuit
2. Find the current through the circuit
3. Find the voltage across the resistor
4. Find the voltage across the capacitor



Solution:

```
>>% Specify the values of components
>>V=2; R=1e+3; C=1e-6; omega=2*pi1e+3;
>>Z_C=-j/(C*omega);
>>Z=R+Z_C;                    %impedance of the circuit
>>I=V/Z;                      %current through the circuit
>>V_R=I*R;                    %voltage across the resistor
>>V_C=I*Z_C;                  %voltage across the capacitor
```

Polynomials:

Polynomials are quite common in electrical engineering. Transfer functions characterizing linear systems are typically ratios of two polynomials (rational functions). MATLAB represents polynomials as row vectors containing the coefficients of the powers in descending order. For instance, the polynomial $P(s) = 2s^2 + 4s + 5$ can be expressed as a vector by entering the statement P=[2 4 5], where the variable P is the name we have assigned to the polynomial. MATLAB can interpret a vector of length (n+1) as an n-th order polynomial. Missing coefficients must be entered as zero. MATLAB provides functions for standard polynomial operations, such as polynomial roots, evaluation and differentiation.

The **roots** function extracts the roots of polynomials. If **p** is a row vector containing the coefficients of a polynomial, **roots(p)** returns a column vector whose elements are the roots of the polynomial.

Practice:

Find the roots of the polynomial $p(s) = s^3 + 2s^2 + 3s + 4 \Leftrightarrow [1\ 2\ 3\ 4]$

```
>>p=[1  2  3  4];             %specify polynomial p(s)
>>roots(p)  <enter>          %provide the roots of the polynomial p(s)
```

ans=

```
-1.6506
-0.1747+1.5469j
-0.1747-1.5469j
```

The **poly** command is used to recover a polynomial from its roots. If **r** is a vector containing the roots of a polynomial, **poly(r)** returns a row vector whose elements are the coefficients of the polynomial.
The **polyval** command evaluates a polynomial at a specified value. If **p** is a row vector containing the coefficients of a polynomial, **polyval(p,s)** returns the value of the polynomial at the specified value s.

Practice:

The roots of a polynomial are –1, -2, $-3 \pm j4$. Determine the polynomial equation

```
>>r=[-1 –2 –3+4*j  -3-4*j];      %define the roots of a polynomial
>>p=poly(r) <enter>              %extract the polynomial p from its roots
```

p=

$$1 \;\; 9 \;\; 45 \;\; 87 \;\; 50 \Leftrightarrow p(s) = s^4 + 9s^3 + 45s^2 + 87s + 50$$

```
>>% Evaluation of polynomials
>>p=[1  2  3  4];                %define a polynomial p(s)
>>val=polyval(p,1) <enter>       %evaluate the polynomial p(s) at s=1
```

Practice:

A linear time-invariant (LTI) system is specified by its transfer function given by

$$H(s) = \frac{s^3 + 3s^2 + 2s + 5}{s^4 + 2s^3 + 5s^2 + 3s + 1}$$

1. Use MATLAB to evaluate its poles and zeros
2. Evaluate H(s) at s=2j
3. Find the magnitude of H(2j)
4. Find the phase of H(2j)

Solution:

```
>>num=[1  3  2  5];                      %specify numerator of H(s)
>>zero=roots(num);                       %determine the zeros of H(s)
>>den=[1  2  5  3  1];                   %specify denominator of H(s)
>>pole=roots(den);                       %provide the poles of H(s)
>>H=polyval(num,2j)/polyval(den,2j);     %evaluate H(s) at s=2j
>>mag=abs(H);                            %specify the magnitude
>>phase=angle(H)*180/pi;                 %specify the phase in degrees
```

The zeros, poles, and gain of a transfer function can also be found via **tf2zp** command, as illustrated below.

Practice:

```
>>num=[1  3  2  5];                      %specify numerator of H(s)
>>den=[1  2  5  3  1];                   %specify the denominator of H(s)
```

```
>>[z,p,k]=tf2zp(num,den);          %extract zeros, poles and gain of H(s)
```

note:

z=zeros
p=poles
k=gain

To find the numerator and denominator polynomials of a transfer function H(s) from the zeros (z), poles(p), and gain(k), we use the command **zp2tf.**

Practice:

```
>>z=[1+2j; 1-2j];                  %zeros as a column vector
>>p=[-3; -2+5j; -2-5j];            %poles as column vector
>>k=1;                             %gain set equal to unity
>>[num,den]=zp2tf(z,p,k);          %provide the transfer function
```

Practice:

A system has zeros at –6, -5, 0 and poles at $-3 \pm j4$, -2, -1, and a gain of unity. Determine the system transfer function.

```
>>z=[-6; -5; 0];                   %specify zeros
>>k=1;                             %specify the gain
>>p=[-3+4*j; -3-4*j; -2; 1];       %specify poles
>>[num,den]=zp2tf(z,p,k) <enter>   %numerator & denominator of transfer function

num=
          0    1  11  30  0
den=
          1    9  45  87  50

>>sys=tf(num,den) <enter>          %print the transfer function of the system


Transfer function:
     s^3 + 11 s^2 + 30 s
--------------------------------
s^4 + 9 s^3 + 45 s^2 + 87 s + 50
```

Differentiation of polynomials is a straightforward procedure, one that MATLAB implements with the function **polyder.**

Function synopsis:

```
>>s=polyder(p);                    %return the derivative of polynomial
>>s=polyder(p,q);                  %give the derivative of the product p(x).q(x)
```

Polynomial multiplication:

The product of two polynomials p(x) and q(x) is found by taking the convolution of their coefficients. MATLAB makes use of the **conv** function to obtain the coefficients of the required polynomial product. The coefficients should be in the order of decreasing powers. Multiplication of more than two polynomials requires repeated use of **conv.**

Practice:

Consider the following two polynomials,

$$p(x) = 2x^2 + 3x + 2$$
$$q(x) = 4x^3 + 5x^2 + 7x + 1$$

Find the coefficients of the product polynomial $y(x) = p(x) \times q(x)$

```
>>p=[2  3  2];                %define p(x) in vector form
>>q=[4  5  7  1];            %define q(x) in vector form
>>y=conv(p,q)                %compute the product polynomial in vector form


y=
        8        22        37        33        17         2
```

The screen output displays the coefficients of the resultant product polynomial in descending order. This means that the product polynomial is given by

$$\therefore y(x) = 8x^5 + 22x^4 + 37x^3 + 33x^2 + 17x + 2$$

Practice:

Find the product of the following three polynomials

$$p(x) = x + 5$$
$$q(x) = 2x + 3$$
$$r(x) = 7x + 8$$

```
>>p=[1 5];
>>q=[2 3];
>>r=[7 8];
>>product=conv(r,conv(p,q))

product =

                14   107  209  120
```

$$\therefore \text{product} = 14x^3 + 107x^2 + 209x + 120$$

Polynomial Division:

Division of polynomials is achieved by the deconvolution function **deconv**. The **deconv** function will return the remainder as well as the result.

Function Synopsis:

>>[Q,R]=deconv(num,den);

This function returns two polynomials Q(s) (Quotient), and R(s) (remainder) such that num(s)=Q(s) den(s)+ R(s).

Practice:

Consider the following improper rational function,

$$D(x)=\frac{B(x)}{A(x)}=\frac{x^3+3x-5}{x^2+4x-3}$$

which can be written as,

$$D(x)=Q(x)+\frac{R(x)}{A(x)}$$

where Q(x) is returned as zero if the order of B(x) is less than the order of A(x)

```
>>B=[1  0  3  -5];          %specify the polynomial B(x) in vector form
>>A=[1  4  -3];            %specify the polynomial A(x) in vector form
>>[Q,R]=deconv(B,A)        %perform division
```

Q=

1 -4

R=

0 0 22 -17

$$\therefore D(x)=\frac{x^3+3x-5}{x^2+4x-3}=(x-4)+\frac{22x-17}{x^2+4x-3}$$

Plotting and Graphics:

The graph of a function provides a tremendous insight into the function's behavior and can be of great help in the solution of a problem. MATLAB is capable of generating a wide range of graphics, from simple plot to 3-D plots. We shall focus on the most fundamental and most widely used of the MATLAB plotting capabilities. The basic functions are **plot**, **semilogx**, **semilogy, loglog**, and **stem.** These commands have similar basic form. The **plot(x,y)** command generates a plot of the values in the vector **y** versus the values in the vector **x** on a linear scales. The **x** values will appear on the horizontal axis and the **y** values on the vertical axis. The **semilogx** (**semilogy**), indicates that the x-axis (y-axis) is logarithmic, and the other axis is linear. In the **loglog** function both axes are logarithmic. The **polar** uses polar coordinates, and **stem** works just like the **plot** command except that the plot created will have a vertical line at each value rather than a smooth

curve, a type of plot that is very often used in signal processing for visualizing sequences. The **plotyy** function creates graphs with y-axes on both left and right side.

Syntax:

>>plotyy(t1,y1,t2,y2)

Plots y1 versus t1 with y-axis labeling on the left and y2 versus t2 with y-axis labeling on the right.

>>plotyy(t1,y1,t2,y2,'function')

Uses the plotting function specified by the string 'function' instead of **plot** to produce each graph. The string 'function' can be plot, semilogx, semilogy, loglog, or stem.

All plots generated by the plotting commands appear in a **figure window**.

Practice:

```
>>t=0:pi/100:2*pi;
>>y1=sin(t);
>>y2=0.5*sin(t-1.5);
>>plotyy(t,y1,t,y2,'stem')
```

Lines, Marks and Colors:

When plotting multiple curves, it is desirable to vary the colors, plot symbols and line styles (dashed, dotted,etc.) associated with each line. This feature is accomplished by adding another argument to the plot command.

***Note**: Line styles and markers allow you to discriminate different data sets on the same plot when color is not available.*

Syntax:

>>plot(x,y, 'linestyle_mark_color');

with no separators between the options. The options can be in any order.

Practice:

```
>>plot(t,y,':');                 %plot y versus t using a dotted line
>>plot(t,y,'r:');                %plot y versus t using a dotted line in red
>>plot(t,y,'-.ro');              %plot y versus t using a dash-dot line (-.), colored red (r) and
>>%and places circular markers (o) at the data points
```

The line styles and colors consist of character string whose first character specifies the color (optional) and the second the line style, enclosed in single quotes. The options for line styles, marks, and colors are depicted below.

Line	Symbol
Dash	--
Dashdot	-.
Dotted	:
Solid	-(default)

Mark	Symbol
Circle	O
Point	.
Plus	+
Star	*
X-mark	x
Square	s
Diamond	d
Pentagram	p
Hexagram	h

Color	Symbol
Blue	b
Black	k
Cyan	c
Green	g
Magenta	m
Red	r
White	w
Yellow	y

Practice:

```
>>t=0:0.01:2                    %define a time vector
>>y=cos(2*pi*4*t)               %define a vector y
>>plot(t,y,'*r')                %plot y versus t by (*) marks in red color
```

When the plot command is executed, a graphics window appears automatically. It is possible to open as many figure windows as memory permits. To create a new window use the command **figure(n).** MATLAB numbers figure windows starting at 1.

```
>>figure(2);                    %pop up a new graphics window
```

Figures can be cleared using the **clf** command, and closed by entering **close(n)** when **n** is the number of the window to close.

Overlaying plots:

Often it is desirable to overlay two plots on the same set of axes. To overlay plots, you tell MATLAB to hold the previous plot using **hold on** and subsequent graphs will be on the same axes. The **hold** command will remain active until it is turned off, by entering **hold off.**

Practice:

```
>>t=0:0.01:2;                   %define a time vector
>>y=cos(2*pi*4*t);              %define vector y
>>plot(t,y);                    %plot y versus t
>>z=sin(2*pi*3*t);              %define vector z
>>hold on                       %hold the previous plot
>>plot(t,z)                     %superimpose this plot with the first
>>hold off                      %turn off the hold function
```

Similarly, several signals with equal number of data points may be displayed in the same frame against the same axis as follows:

```
>>t=0:0.01:2;                   %define a time vector
>>x1=sin(2*pi*3*t);             %define vector x1
>>x2=cos(2*pi*2*t);             %define vector x2
>>x3=abs(x2);                   %define vector x3
>>x=[x1;x2;x3];                 %matrix of data
>>plot(t,x);                    %plot 3 signals against time
```

If, on the other hand, the curves are plotted against different vectors, we use,

```
>>plot(t1,x1,t2,x2,t3,x3)
```

This command plots x1 versus t1, x2 versus t2, and x3 versus t3. In this case, t1,t2, and t3 may be of different sizes, provided that x1,x2, and x3 are of the same size as their corresponding time vectors t1, t2, and t3, respectively.

```
>>plot(t1,x1,'r',t2,x2,'g')     %plot x1 in red and x2 in green
```

Practice:

Plot the discrete-time signal specified by $x[n] = \cos\left(2\frac{\pi}{13}n\right)$

```
>>n=0:1:24;                     %define a vector n
```

```
>>x=cos(2*pi*n/13);          %define vector x
>>stem(n,x)                  %plot x versus n
```

Practice:

We shall try now semilog plots.

```
>>t=linspace(0,2*pi,200);   %generate 200 linearly spaced points in [0,2π].
>>x=exp(-2*t);              %define the function x(t)
>>y=t;                      %define the function y(t)
>>semilogx(x,y); grid       %provide a semilog plot of y versus x
```

Practice:

The plot command, which directly plots vectors of magnitude and angle, is **polar**.

The equation of a cordioid in polar form, with parameter a is given by

$$r = a\left(1+\cos\left(\theta\right)\right), \qquad 0 \le \theta \le 2\pi$$

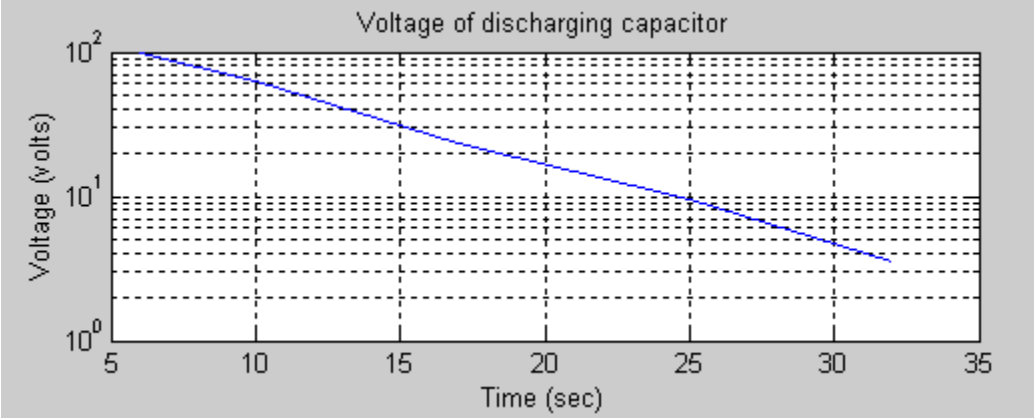
```
>>a=1;
>>theta=0:2*pi/200:2*pi;
>>r=1+cos(theta);
>>polar(theta,r)
```

Practice:

The voltage across a capacitor during discharge was recorded as a function of time.

Time (s)	6	10	17	25	32
Voltage (volts)	98	62	23	9.5	3.5

```
>>time=[6  10  17  25  32];              %time vector
>>voltage=[98  62  23  9.5  3.5];        %capacitor voltage
>>semilogy(time,voltage); grid           %plot voltage versus time
>>title('Voltage of discharging capacitor')
>>xlabel('Time (sec)')
>>ylabel('Voltage (volts)')
```



Subplots:

MATLAB graphics window accommodates a single plot by default, but multiple plots can be placed in the same graphics window using the command **subplot**. The subplot command allows a given figure window to be broken into a rectangular array of plots, each addressed with the standard plot commands.

>>subplot(r,c,w)

The arguments r and c are the number of rows and columns into which the graphics window is divided, respectively. The w designates which of the windows are to be used. Windows are numbered from left to right and top to bottom within the figure. For example, subplot(2,1,1) partition the graphics window into two rows in a single column and fits the plot on the top cell. Figure 1 depicts two possible subplots arrangements.

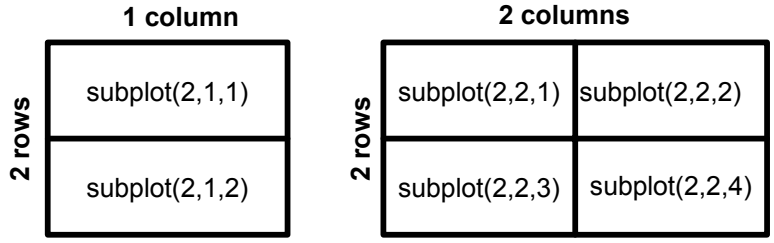


Figure 1: Subplots

Customizing plots:

MATLAB provides means to improve the appearance and clarity of the plots. Once a plot is on the screen, it may be given a title, axes labeled and text placed within the graph. The **title** command is used to place a title above the plot, **xlabel** writes text beneath the x-axis, and **ylabel** writes a text besides the y-axis of a plot. They each take a string variable, which must be in single quotes. The **grid** command toggles a grid on and off in the current figure, the **legend** command adds a legend to an existing graph (movable with the mouse) that automatically uses

the right symbols and colors and sticks the description in the legend command after them, and the **text** command allows a string of text to be placed at a particular x-y position on the graph.

Syntax:

```
>>xlabel('label');                    %write label beneath the x-axis
>>ylabel('label');                    %write label besides the y-axis
>>title('label');                     %place a title above the plot
>>text(x,y,'label');                  %write label at the location (x,y)
>>grid                                %draw a grid on the graph area
>>legend('first plot', 'second plot'); %place a legend within a graphics window
```

Note:

It is very important to always label your axes with units. This is engineering, not mathematics—we deal with physical quantities.

Practice:

```
>>t= - 2*pi: 0.02: 2*pi;      %define a time vector
>>y=sin(t).*cos(t).^2;        %define a dependent vector y
>>plot(t,y);grid;             %plot y versus t
>>xlabel('time, [s]')         %annotate the t-axis
>>ylabel('Amplitude, [v]');   %annotate the y-axis
>>legend('trig function')     %add a legend to plot
```

The **gtext** command provides interactive labeling. After generating the plot, enter the following command:

```
>>getext('label')
```

This command places text on the graph by showing a crosshair on the graphics window. After the crosshair is positioned where you want the text to appear, press the mouse button. The **ginput** command determines the coordinates of points on a graph.

```
>>[x,y]=ginput(n);            %provide coordinates of n points on a graph
```

Position the mouse cursor on a point of a graph for which you want to know the coordinates, and click the mouse button, then repeat the process for the remaining (n-1) points. When done, hit the carriage return (enter key), and the n-coordinates will be shown on the command window. MATLAB automatically selects the appropriate ranges and tick marks for the graph, but it is often necessary to redefine it. The **axis** command manually sets the axis limits. This command is implemented as follows:

```
>>axis([xmin  xmax  ymin  ymax])
```

where **xmin xmax ymin ymax** are the desired maximum and minimum values for the x and y axes, respectively.

The command **axis('square')** ensures that the same scale is used on both axes. You can remove the axes from your graph and put them back via **axis off** and **axis on**, respectively.

```
>>axis off;                    %remove axes
>>axis on;                     %put axes back
```

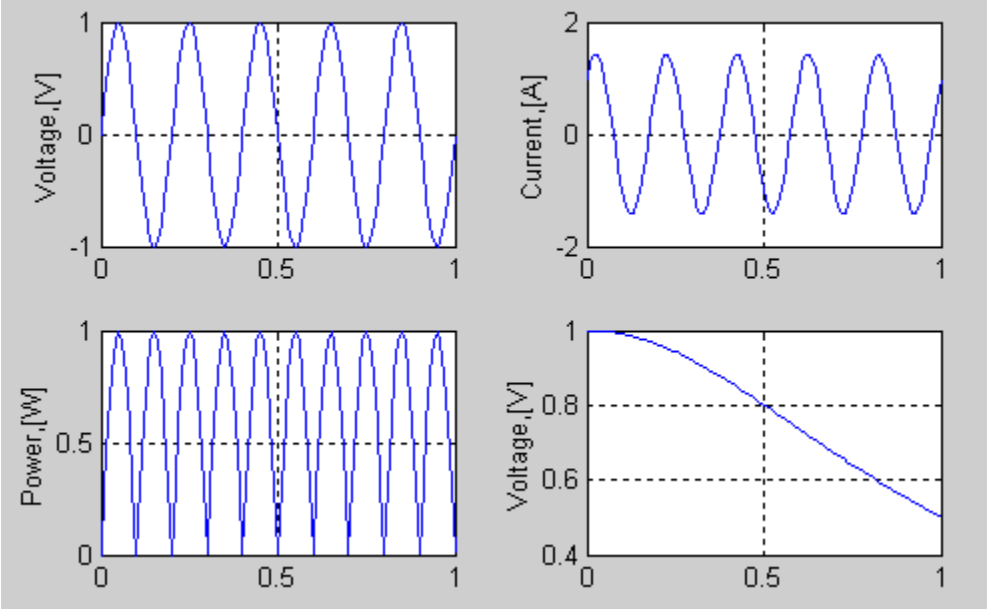
Practice:

Use the plot command to draw a circle.

```
>>t=0:pi/100:2*pi;            %time base
>>plot(sin(t),cos(t));        %draw circle
>>axis('square')              %use same scale on both axes
```

Practice:

```
>>t=0:0.01:1;                 %generate a time vector t
>>y=sin(2*pi*5*t);            %define the dependent vector y
>>x=y+cos(2*pi*5*t);          %define the dependent vector x
>>z=abs(y);                   %define the dependent vector z
>>w=1./(1+t.^2);              %define the dependent vector w
>>subplot(2,2,1);plot(t,y);grid;   %split screen, plot y versus t, and apply grid lines
>>ylabel('Voltage,[V]');      %label the vertical axis
>>subplot(2,2,2); plot(t,x);grid;  %plot x versus t, and apply grid lines
>>ylabel('Current, [A]');     %label the vertical axis
>>subplot(2,2,3);plot(t,z);grid;   %plot z versus t, and apply grid lines
>>ylabel('Power,[W]');        %label the vertical axis
>>subplot(2,2,4); plot(t,w); grid;  %plot w versus t
>>ylabel('Voltage,[V]');      %label the vertical axis
```



Greek letters, subscripts, and superscripts:

When you add labels and titles on your plot, you may want to use Greek letters, subscripts and superscripts. To get Greek letters simply type their names preceded by a backslash, as follows:

\alpha	\beta	\gamma	\delta	\epsilon	\phi
\theta	\kappa	\lambda	\mu	\pi	\rho
\sigma	\tau	\xi	\zeta	\omega	

Practice:

>>ylabel('H(\omega)')

You can also use capital Greek letters, like this, \Gamma

To put a subscript on a character use the underscore character on the keyboard: μ_1 is coded by typing \mu_1. If the subscript is more than one character long, such as μ_{12}, use this: \mu_{12}. Superscript work the same way only use the ^ character: \theta^{10} to get θ^{10}.

MATLAB files: script files and function files

MATLAB operates in two modes:

- The interactive mode
- The batch mode

Thus far we considered only the command-driven mode (interactive mode). Under this mode MATLAB processes the statement and displays the result immediately. MATLAB is also able to execute (batch mode) programs that are saved in files. These files must be in ASCII format and have an extension **.m** (for example prog1.m). This is the reason why MATLAB files are called M-files. There are two types of M-files: script files and function files.

Script files:

A script file is an ordinary text file that contains a sequence of MATLAB commands. These files offer a more effective working environment and allow files to be saved for future use. To execute a script file, simply type the filename (without the extension) at the MATLAB command window.

To make a script file, I suggest you create a temporary sub-directory for all your work, like ***c:\myfiles***, start MATLAB and change its working directory to ***c:\myfiles***, via the **cd** command, as you would in DOS and UNIX. To use a floppy disk as the storage location, which is an excellent idea since you can take your work with you when you leave the computer lab, put a formatted floppy disk in the computer and type **cd a:** as follows:

```
>>cd a:\  <enter>          %change the current directory to a:
```

The following commands facilitate moving around directories:

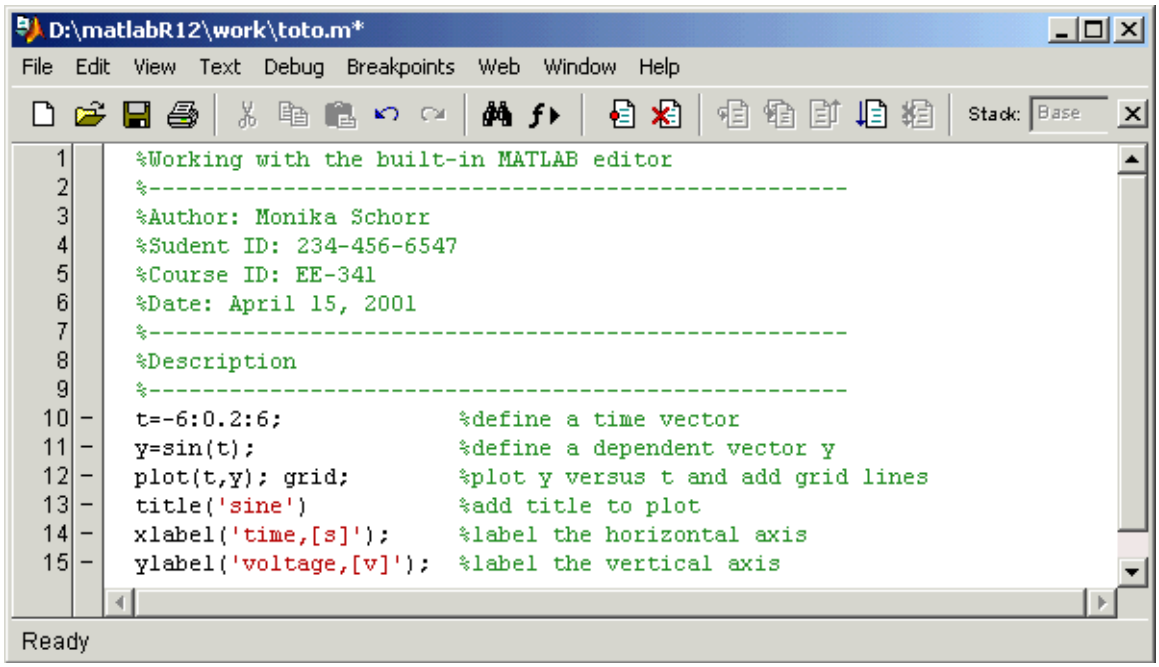
```
>>! mkdir c:\mlab          %create a sub-directory named mlab
>>!rmdir c:\mlab           %remove the sub-directory mlab
>>cd c:\mlab               %change the working directory to mlab
>>pwd                      %show current working directrory
```

>>dir	%list the contents of the current directory
>>what	%list only the M-files in the current directory
>>ls	%show a list of files in the working directory
>>delete *filename.m*	%delete a specified file
>>type *filename.m*	%print a specific file to the screen
>>which *filename.m*	%display the directory to which *filename.m* belongs
>>path	%find the current path

Note:

In the CAEC (or ECE labs) cluster, all directories on the hard disk are write protected, in order to avoid accumulation of files. The best practice is to use a floppy disk for your M-files.

As an example, let us create a script file named, **toto.m**. The script file can be created and edited using any ASCII editor, such as **notepad** or the built-in MATLAB editor, which color codes reserved words and other program elements. You bring up the MATLAB text editor window by clicking the editor icon on the toolbar (or choose **New,** then **M-file** under the **File** pull-down menu or launch it by typing **edit** from within MATLAB environment). Then enter the script file in the editor window, as follows:



After you have typed in the script file, you should save it in the newly created sub-directory. To do this, select **Save As** under the **File** menu item from the editor's menu bar. When the save dialog box opens, type in the name **toto.m** and click on save. Return to the MATLAB command window.

To run the script file, simply type,

>>toto <enter>

If there are errors, MATLAB will beep and display error messages in the command window.

Return to the MATLAB editor to debug the original script, save the changes and run it again. To open an existing M-file, choose **Open** under the **File** menu and select the file for editing.

Function files:

MATLAB has many powerful built-in functions. MATLAB also allows for user to write their own functions. Functions are identical to script files, except that variable values may be passed into or out of the function file. The function file starts with the keyword **function** and defines the function name and input and output variables. The format of the first statement for a function named **toto** is of the form

function [output1,output2,output3,…] = toto(input1,input2,input3,…)

Where the input variables are enclosed within parentheses while output variables are within square brackets if there is more than one output variable.

As an illustration, let us create the function **magphase.m**, which computes the magnitude and phase of a complex number z supplied by the user.

Invoke the built-in MATLAB editor and enter the following lines of code:

```
function  [m,p]=magphase(z)     %specify a file as a function file
% z is a complex number supplied by the user (input variable)
%m and p are output variables representing the magnitude and phase of z
%magphase is the function name
m=abs(z);                       %compute the magnitude of z
p=angle(z)*180/pi;              %compute the phase in degrees
```

Save this function as **magphase.m**, and then leave the editor to return to the command window. Be careful not to save your M-file with the same name as one of MATLAB's functions.

We are ready to run the created function file.

```
>>z=2 + 3j;                    %specify an arbitrary complex number
>>magphase(z)                  %provide the magnitude and phase of z.
```

note: *Functions have many advantages over scripts, therefore, I recommend that you always use functions over scripts*

Sub-functions:

A sub-function is local and visible only to other functions in the same file. Defining a new function with the **function** keyword, after the body of the preceding function, creates a subfunction.

Practice:

```
function [mn, stdev]=stat(x)
%returns the mean and standard deviation of a supplied data vector
%mn=mean
%stdev=standard deviation
```

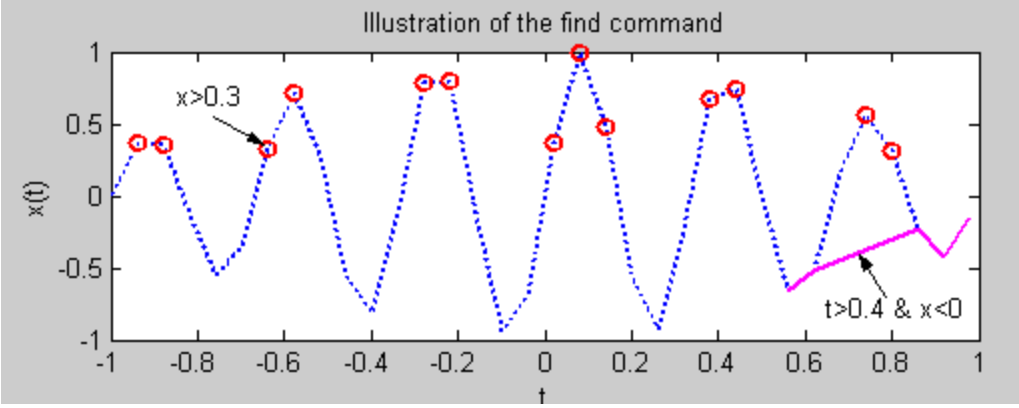
```
% x=data vector supplied by the user

n=length(x);
mn=avg(x,n)
stdev=sqrt(sum((x-avg(x,n)).^2)/(n-1))
function mn=avg(x,n)
mn=sum(x)/n;
```

Additional MATLAB commands:

There are some special functions that can be very helpful when included in M-files. The **echo** command display each command in your script on the MATLAB command window, as the script is being executed. The **pause** command causes a routine to stop executing. This last command gives you time to check your results. Striking any key will cause the script file to resume operating. The command **pause(n)** will pause execution for n seconds. The **input** command prompts the user for a numeric or string input data from the keyboard during program execution. The **disp** command displays scalar, vector, matrix or a string on the command window without variable name. The function **find** returns a list of indices of the elements of a vector or matrix that satisfy some condition. The **zoom** command provides a means to zoom on any part of a 2-D graph and see it enlarged in the plot window. The statement **zoom on** turns on the zoom mode. Then, to zoom in about a particular point on the graph, move the cursor to the point and click with the mouse. This action expands the plot by a factor of 2 centered on that point. To zoom out by a factor of 2, click the right mouse button. The command **zoom off** turns off the zoom mode.

Practice:

```
t=-1:0.06:1;                                          %time base
f= input('Enter the frequency of the sine wave: ');   %input from keyboard
disp(['frequency: ',intstr(f)])                       %print the value of frequency
x=sin(2*pi*f*t).*exp(-x.^2);                          %wave
plot(t,x, ':','LineWidth',2);                         %plot wave
disp('Press any key to continue')
pause;                                                %pause execution
hold on                                               %hold previous plot
k=find(x>0.3)                                         %find indices for which x>0.3
plot(t(k),x(k),'ro','LineWidth',2);                   %plot x(k) vs t(k)
disp('Press any key to continue')
pause                                                 %pause execution
m=find(t>0.4 & x<0)                                   %find m's such that t>0.4 & x<0
plot(t(m),x(m),'m-','LineWidth',2)                    %plot x(m) vs t(m)
xlabel('t')                                           %label horizontal axis
ylabel('x(t)')                                        %label the vertical axis
title('Illustration of the find function')            %add title
hold off
```



Note: A string input can be typed from the keyboard, as follows:

>>str=input('What is the capital of Belgium? ', 's');

The argument **s** specifies that the input from the keyboard is a string.

Formatted Outputs:

Output data can be written from the computer onto a standard output device using the function **fprintf**. The **fprintf** function has a unique format for printing constants and variables. The **fprintf** function is also vectorized. This enables printing of vectors and matrices with compact expressions.

Syntax:

>>fprintf(character string, arg1,arg2,…,argn)

The **character string** refers to a string that contains formatting information, and **arg1,arg2,…,argn** are arguments that represent the individual output data items. Note that **fprintf** function can have one or more arguments enclosed within parentheses. A comma separates these arguments. The first argument to the **fprintf** routine is always the **character string** to be displayed. However, along with the display of the character string we may frequently wish to have the value of certain program variables displayed as well.

fprintf('Programming in MATLAB is fun.\n')

What does the function **fprintf** do with the argument? Obviously, it looks at whatever lies between the single quotation marks and prints that on a terminal's screen. The characters **\n** included in the quotes does not get printed; it advances the screen position by one line.

num=1;
fprintf('My favorite number is **%d** because it is first.\n', **num**);

The **fprintf** function takes the value of the variable on the right of the comma and plugs it into the string on the left. Where does it plug it in? Where it finds a format specifier such as **%d**. Format specifier tells **fprintf** where to put a value and what format to use in printing the value. The **%d**

tells **fprintf** to print the value **1** as a decimal integer. Other specifiers could be used for the number **1**. For instance **%f** would cause the **1** to be printed as a floating-point number. In addition to specifying the type of conversion (e.g., %d, %f, %e) one can specify the width and precision of the result of the conversion.

Syntax:

%wd
%w.pe
%w.pf

w: the number of characters in the width of the final result
p: represents the number of digits to the right of the decimal point

Illustration:

%12.3f use floating-point format to convert a numerical value to a string 12 characters wide with 3 digits after the decimal point.

The **fprintf** function can also be used to write formatted output into a file:

>>fprintf('file', 'area=%4.2f\n', area)

The following table provides a list of the conversion characters.

Characters	**Description**
%s	format as a string
%d	format with no fractional part (integer format)
%f	format as a floating-point value
%e	format as a floating-point value in scientific notation
%g	format in the most compact form of either %f or %e
\n	insert newline in output string
\t	insert tab in output string

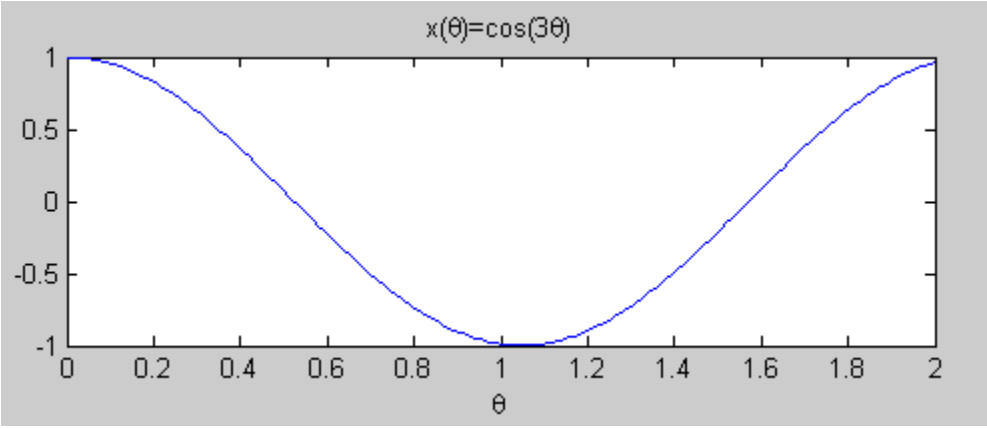
Practice:

```
>> A=[1 2 3; 4 5 6; 7 8 9];
>> fprintf('%8.2f   %8.2f   %8.2f\n',A)
   1.00      4.00      7.00
   2.00      5.00      8.00
   3.00      6.00      9.00
```

One can build labels and titles that contain numbers you have generated; simply use MATLAB's **sprintf** function, which works just like **fprinf** except that it writes into a string variable instead of to the screen. You can then use this string variable as the argument of the commands **xlabel**, **ylabel**, and **title**.

Practice:

```
>> theta=0:0.01:2;
>> x=cos(3*theta);
>> subplot(2,1,1);plot(theta,x)
>> s=sprintf('x(\\theta)=cos(%i\\theta)',3);
>> title(s)
>> xlabel('\\theta')
```



Handle graphics:

When using the plotting command, MATLAB draws the graph using a number of graphics objects, such as line, text, and surfaces. All graphics objects have a set of properties that control the appearance and behavior of the object. For example a line is an object with properties such as line style, color, and thickness. It is possible, under MATLAB, to access and modify these properties.

MATLAB assigns a **unique identifier** to every object in the figure window. This number is called the **handle** of the object. The **handle** of the figure is an integer, and all other handles are floating-point numbers. You can use this handle to access the object's properties. The commands **xlabel**, **ylabel**, **title**, and **text** return handles to the objects they create.

```
>>h1=plot(x,y,'mo');          %make a plot and return graphics object handle
>>h2=xlabel('time,[s]');      %label the horizontal axis and return handle
>>h3=ylabel('|(\omega)|');    %label the vertical axis and return handle
```

The variable h1, for example, holds information about the graph you generated and is called the handle graphics. You may view the list of properties and their values with command **get(handle).**

Practice:

```
>>t=0:0.01:2;                 %define the time vector
>>y=sin(2*pi*3*t);            %specify the corresponding y-vector
>>h1=plot(t,y);               %generate a plot and return handle
>>h2=xlabel('time,[s]');      %label the time axis and return handle
>>h3=ylabel('Amplitude,[v]'); %label the voltage axis and return handle
```

```
>>h4=title('Sine wave');          %add title and return handle
>>get(h2)                         %list all properties of h2 and their values

Color = [0 0 0]
EraseMode = normal
Editing = off
Extent = [0.87468 -1.35849 0.235294 0.169811]
FontAngle = normal
FontName = Helvetica
FontSize = [10]
FontUnits = points
FontWeight = normal
HorizontalAlignment = center
Position = [0.997436 -1.22275 17.3205]
Rotation = [0]
String = time,[s]
Units = data
Interpreter = tex
VerticalAlignment = cap

BeingDeleted = off
ButtonDownFcn =
Children = []
Clipping = off
CreateFcn =
DeleteFcn =
BusyAction = queue
HandleVisibility = off
HitTest = on
Interruptible = on
Parent = [100.001]
Selected = off
SelectionHighlight = on
Tag =
Type = text
UIContextMenu = []
UserData = []
Visible = on
```

There are several functions that are useful for accessing handles of current objects. These are:

```
gcf(get current figure)          %return the handle of current figure
gca(get current axis)            %return the handle of current axes
gco(get current object)          %return the handle of current object
```

Syntax:

```
>>h2=get(gca,'xlabel')           %provide handle of xlabel
>>h3=get(gca,'ylabel')           %provide handle of ylabel
>>h4=get(gca,'title')            %provide handle of title
```

The following commands provide the list of properties:

```
>>get(gcf)                    %list all properties of the figure
>>get(gca)                    %list all properties of the axes
>>get(gco)                    %list all properties of an object
```

The **set** function allows the setting of object's property by specifying the object's handle and any number of property name/property value pairs.

Syntax:

```
>>set(handle, 'property_name', property_value)
```

For instance, to change the color and width of the line, proceed as follows:

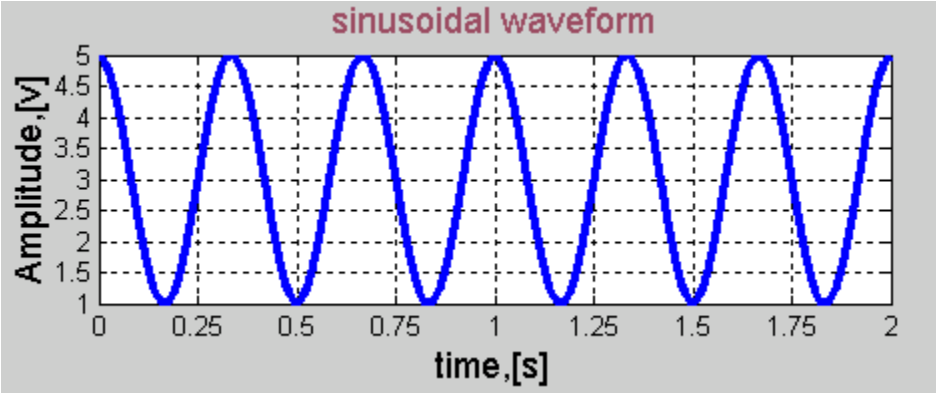
```
>>set(handle, 'color', [0 0.8 0.8], 'LineWidth', 3)
```

To obtain a list of all settable properties for a particular object, call **set** with the object's handle.

```
>>set(handle)
```

Practice:

```
>>t=0:0.01:2;                          %define time vector
>>x=3+2*cos(2*pi*3*t);                 %define the dependent vector x
>>h1=plot(t,x);                        %plot and get handle
>>set(h1,'LineWidth',3);               %set thickness to 3
>>h2=xlabel('time,[s]');               %label axis and get handle
>>set(h2,'FontSize',13);               %set the font size of x-label to 13
>>set(gca,'Xtick',0:0.25:2);           %set X-tick
>>h3=ylabel('Amplitude,[v]');          %label axis and get handle
>>set(gca,'Ytick',0:0.5:5);            %set Y-tick
>>set(h3,'FontSize',13);               %set font size of y-label to 13
>>h4=title('Sinusoidal waveform');     %add title and get handle
>>set(h4,'color',[0.6 0.3 0.4],'FontSize',13);   %set color and font size of title
>>grid                                 %add grid
```



Loops and control:

MATLAB has control statements similar to those found in most high-level computer languages. We shall begin with relational and logical operations. In this section you should think of 1 as **true** and 0 as **false**.

Relational operators:

<	less than
<=	less than or equal
>	greater than
>=	greater than or equal
= =	equal
~ =	not equal

We illustrate the use of these operators in the following example:

Practice:

```
>>A=[1  2  3];
>>B=[5  4  3];
>>A<B
```
answer: 1 1 0

```
>>A~=B
```
answer: 1 1 0

```
>>A>=B
```
answer: 0 0 1

Logical operators:

&	and
|	or
~	not
xor	logical exclusive or

Practice:

```
>>A=[1  0  1  1];
>>B=[0  1  0  0];
>>A & B
```
answer: 0 0 0 0

```
>>A | B
```
answer: 1 1 1 1

```
>>~A
```
answer: 0 1 0 0

```
>>xor(A,B)
```
answer: 1 1 1 1

Logical functions:

MATLAB offers several handy logical functions for analyzing the results of relational comparisons. These include **any** and **all**. The function **any** is used to determine if a matrix or vector has at least one nonzero entry, and the function **all** checks if all the entries are nonzero. The output of these two functions is boolean ('1' is true, and '0' is false).

Practice:

```
>>A=[0 0 0 0];
>>any(A)


ans =

    0

>>B=[1 1 1 1 1 1];
>>all(B)

ans =

    1
```

Loop constructs:

for loop:

It is often the case in programming that one wants to do something a fixed number of times. The **for** loop is ideally suited for this purpose. The form of a **for** loop that is most commonly used is:

```
>>for index = start : step : end
        command statements
  end
```

The index is increased from **start** to **end** in steps specified by **step.**

Practice:

```
>>% initializing a vector x
>>for k=1:10
        x(k)=0;
  end
```

This loop assigns the value 0 to the 10 elements of the array x.

Practice:

Find the sum of the following series

$s = 1 + 3 + 5 + 7 + ... + 99$

```
>>s=0.0;                    %initialize the sum
>>for k=1:2:99              %running index
        s=s+k;              %update sum
  end                       %end for
>>s  <enter>                %print value of sum
```

While loop:

The second loop structure available in MATLAB is the **while** loop. The **condition** is evaluated. If the result is true, **statements,** which immediately follow are executed. After execution of the **statements**, **condition** is once again evaluated. If the result of the evaluation is true, then **statements** are executed again. This cycle of test and execution is repeated until condition finally evaluates false, at which point the loop is terminated. Each cycle is called iteration. The general form of a **while** loop is:

```
>>while condition
        command statements
  end
>>
```

Practice:

```
>>k=0;
>>while k<5
        k=k+1;
   end
>>
```

Practice:

Enter and run the following MATLAB script file:

```
n=1;
while n<200
        x=n*0.05;
        y(n)=4.25*cos(x);
        z(n)=-7.2*sin(x);
        n=n+1;
end
```

Practice:

Calculate the squares of the integers from 1 to 20.

```
>>square=[];
>>k=1;
>>while k<=20
        square[k]=k^2;
        k=k+1;
```

```
end
>>
```

***Note**: As a rule it is best to avoid such loops (for & while), for they are not executed efficiently in MATLAB.*

Control of flow:

If statement:

Like most programming languages, MATLAB uses the keyword **if** to implement the basic decision making statement. The **if** statement itself will execute a single statement of a compound statement when the controlling condition is true. It does nothing when it is false.

Syntax:

```
if  condition
        Command statements
end
```

Practice:

```
>>count=0; sum=0;
>>a=0;
>>if a<10
        count=count+1;
        sum=sum+a;
        a=a+1;
end
>>
```

*The **else** clause:*

The **else** clause allows execution of one set of statements if a controlling condition is true and a different set if the controlling condition is false.

Syntax:

```
>>if  condition
        command statements
  else
        command statements
end

>>
```

*Muliple choice **elseif** clause:*

When we nest several levels of if-else, it may be difficult to determine which controlling condition must be true (false) to execute each set of statements. In this case, the elseif clause is often used to make the program logic clearer.

Syntax:

```
>>if      condition1
            command statements
   elseif  condition2
            command statements
   elseif   condition3
            command statements
end

>>
```

Practice:

Enter and run the following script file:

```
n=input('Enter a positive number:  ');
ff rem(n,3)==0
disp('The number is divisible by 3')
elseif rem(n,5)==0
disp('The number is divisible by 5')
else
disp('The number is neither divisible by 3 nor by 5')
end
```

*The **switch-case** construct:*

The **switch** statement is similar to the **elseif** construct but has more flexibility and a clearer format. It compares the input expression to each **case** value. Once the match is found it executes the associated commands.

Practice:

```
% Four-function calculator
num1=input('Enter a number:  ');
num2=input('Enter a number:  ');
op=input('Enter the operation:  ')
switch op
case '+'
        x=num1+num2
case '-'
        x=num1-num2
case '*'
        x=num1*num2
otherwise
        x=num1/num2
end
```

Here is a sample interaction with the script file:

```
Enter the first number:  34
Enter the second number:  24
```

Enter the operation: '+'

x = 58

Curve Fitting:

Sometimes we are given a set of measured data and we are told to look for a function that can be used to fit these measurements. Often such a function is called a model. MATLAB has a handy function called **polyfit** that finds the coefficients of a polynomial that fits a set of data in a least squares sense. A least squares fit is a unique curve with the property that the sum of the squares of the difference between the fitted curve and the given data at the data points is a minimum.

Practice:

Find the third-order least squares regression polynomial for these data and use the resulting model to predict the value of y for x=8.

x	1	2	3	4	5	6	7
y	2	8	26	50	140	224	350

```
>>x=[1  2  3  4  5  6  7];
>>y=[2  8  26  50  140  224  350];
>>p=polyfit(x,y,3)                    %third-order polynomial that fits the data

p =

   0.5000    6.6429  -23.8571   20.8571
```

$\therefore\ p = 0.5x^3 + 6.6429x^2 - 23.8571x + 20.8571$

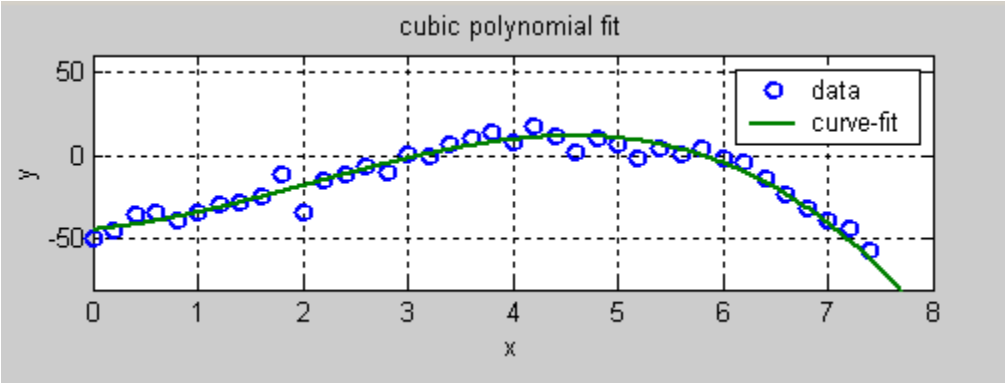
```
>>val=polyval(p,8)                    %predict the value of y using the given model

val =

  511.1429
```

Practice:

In this example we will generate the data from $y = -40 + 7x^2 - x^3$ with added random error. The random error has a gaussian distribution with zero mean and a standard deviation of unity. We will fit a cubic polynomial to the data, then plot the two functions on the same frame to see if the fit is any good.

```
x=linspace(0,8,41);
y=-40+7*x.^2-x.^3;
y=y+6*randn(size(x));
xp=0:0.02:8;
n=3;
p=polyfit(x,y,n);
```

```
yp=polyval(p,xp);
subplot(2,1,1);plot(x,y,'o',xp,yp,'LineWidth',2); grid
title('cubic polynomial fit')
ylabel('y')
xlabel('x')
axis([0 8 -80 60])
```



Interpolation:

MATLAB has a built-in interpolation routine **interp1**. Suppose you are given a set of data points $\{x, y\}$ and you have a different set of x-values $\{x_i\}$ for which you want to obtain the corresponding $\{y_i\}$ values by interpolating in the $\{x, y\}$ data set. You can accomplish this task by using one of these three flavors of the **interp1**. By default, MATLAB uses linear intepolation between data points.

```
>>yi=interp1(x,y,xi,'linear');      %linear interpolation
>>yi=interp1(x,y,xi,'cubic');       %quadratic interpolation
>>yi=interp1(x,y,xi,'spline');      %spline interpolation
```

Practice:

```
%data set
>>inc=pi/5;
>>x=0: inc: 2*pi;
>>y=sin(x);
>>xi=0:inc/20:2*pi;
>>%linear interpolation
>>yi=interp1(x,y,xi,yi,'linear');
>>subplot(2,1,1);plot(x,y,'b-',xi,yi,'r-');grid
>>%cubic interpolation
>>yi=interp1(x,y,xi,'cubic');
>>subplot(2,1,2);plot(x,y,'b-',xi,yi,'r-'); grid
```

Saving and Loading of Data:

Data file commands are used to save and load files in either standard ASCII text or the more compact MATLAB binary format which uses the ***.mat** extension. The binary **.mat** format is useful for files which will be used with MATLAB, while the ASCII format is useful when working with other programs (such as a word processor), or sharing data with others who may not have access to MATLAB.

Practice:

```
>>x=0:5;
>>y=rand(size(x));
>>[x' y']

ans =

         0    0.9501
    1.0000    0.2311
    2.0000    0.6068
    3.0000    0.4860
    4.0000    0.8913
    5.00      0.7621
```

The **save** command will save all of the user-generated variables:

```
>>save my_data  x  y;          %create the file my_data.mat
```

The use of ASCII format, **-ascii** or **/ascii** is appended after the variable names:

```
>>save my_data  x y /ascii;    %create the text file my_data.dat
```

To verify that these files are valid we first clear the MATLAB workspace and load the file back into the workspace.

The **load** command is used to restore the variables at a subsequent MATLAB session:

```
>>load my_data                 %load the .mat file
>>load my_data.dat             %load the ASCII file
```