3.1 Script M-Files

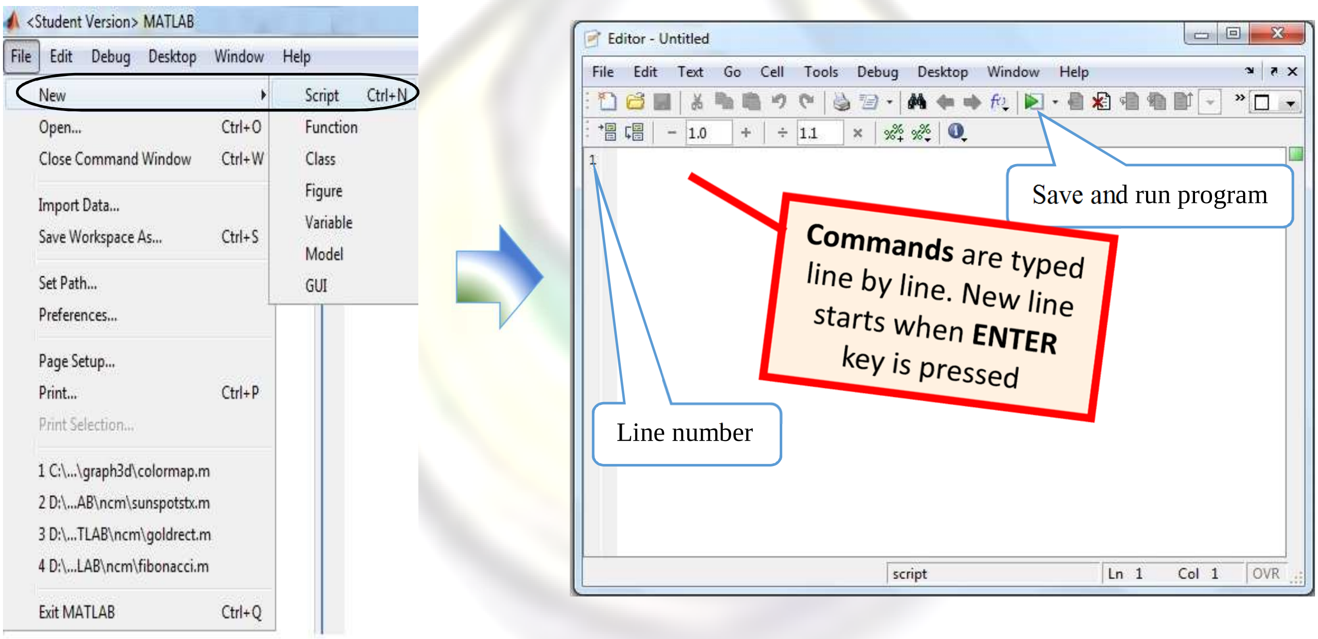
For simple problems, entering commands at the MATLAB prompt in the Command window is simple and efficient. However, when the number of commands increases, or you want to change the value of one or more variables, reevaluate a number of commands, typing at the MATLAB becomes tedious. You will find that for most uses of MATLAB, you will want to prepare a ***script***, which is a sequence of commands written to a file. Then, by simply typing the script file name at a MATLAB prompt, each command in the script file is executed as if it were entered at the prompt.

Script File**:** Group of MATLAB commands placed in a text file with a text editor. MATLAB can open and execute the commands exactly as if they were entered at the MATLAB prompt. The term "*script*" indicates that MATLAB reads from the "script" found in the file. Also called "*M-files*," as the filenames must end with the extension ***'.m'***, e.g. *example1.m*.

M-files are text files and may be created and modified with any text editor. The steps to create a script are:

1) Click on  icon on the MATLAB toolbar.
2) Press keys (***Ctrl*** + ***N***)
3) Form (***File*** → ***New*** → ***Script***)

- A new window will activate called ***the Editor*** as shown.



- When finished, save the file using ***File*** → ***Save*** or click on  icon. The rules for filenames are the same as for variables (they must start with a letter, after that there can be letters, digits, or the underscore, etc.). By default, scripts will be saved in the ***Work Directory***. If you want to save the file in a different directory, the *Current Directory* can be changed.

Example 3.1: Write a program (m-file) and named it "Qroots.m" to find the quadratic equation roots:

$$2x^2 - 5x + 3 = 0$$

Sol:

```
a=2;
b=-5;
c=3;
r1=(-b+sqrt(b^2-4*a*c))/(2*a)
r2=(-b-sqrt(b^2-4*a*c))/(2*a)
```

To execute the script M-file, simply type the name of the script file **Qroots** at the MATLAB prompt.

```
>> Qroots
r1 =
   1.5000
r2 =
    1
```

***Notes* :**

- When file is executed, All its variables are displayed in workspace window
- It is useful to use functions such as (clc , clear , format ,…) in script file to improve the results.

Example 3.2: write a program (vector.m) to generate a vector with 12 random elements and find:

a. The largest element and its position.
b. The smallest element and its position.

Sol:

```
clear                 % clear variable from memory
clc                   % clear the commands windows
format bank           % real number with 2 digits
V=rand(1,12)          % generate row vector
[Vmax,Pmax]=max(V)    % find the maximum element and its position
[Vmin Pmin]=min(V)    % find the minimum element and its position
```

```
>> vector
V =
  Columns 1 through 6
        0.75        0.26        0.51        0.70        0.89        0.96
  Columns 7 through 12
```

```
        0.55    0.14    0.15    0.26    0.84    0.25
Vmax =
        0.96
Pmax =
        6.00
Vmin =
        0.14
Pmin =
        8.00
```

3.2 Input and Output Statements

The script would be much more useful if it were more general; for example, if the value of the *radius* could be read from an external source rather than being assigned in the script. Also, it would be better to have the script print the output in a nice, informative way. Statements that accomplish these tasks are called ***input/output*** statements, or ***I/O*** for short. With examples of input and output statements will be shown here from the Command Window, these statements will make the most sense in scripts.

3.2.1 input Function

The simplest input function in MATLAB is called **input**. The **input** function is used in an assignment statement. To call it, a string is passed, which is the prompt that will appear on the screen, and whatever the user types will be stored in the variable named on the left of the assignment statement. To make it easier to read the prompt, put a ***colon*** (:) and then a ***space*** after the prompt. For example:

```
>> r = input ('Enter the radius: ')
Enter the radius: 7
r =
    7
```

If character or string input is desired, ***'s'*** must be added after the prompt:

```
>> name = input ('Enter your Name: ', 's' )
Enter your Name: Ahmed
name =
Ahmed
```

MATLAB gave an ***error message*** and repeated the prompt. However, if the *input function* is used to enter number *but* the user instead enters a letter or vice versa

```
>> n = input ('Enter your Age: ')
Enter your Age: k
??? Error using ==> input
Undefined function or variable 'k'.
```

Enter your Age: 21
n =
    21

Separate **input** statements are necessary if more than one input is desired. For example

>> T = input('Enter the temperature: ');
Enter the temperature: **37**
>> s = input('Is it "C" or "F" ?','s');
Is it "C" or "F" ?**C**

3.2.2 Output Statements (disp and fprintf) functions

The simplest output function in MATLAB is **disp**, which is used to display the result of an expression or a string *without* assigning any value to the default variable *ans*. However, **disp** does *not* allow *formatting*. For examples:

>> disp ('Hello') % displays string
Hello

>> disp (6^4) % displays numeric expression
    1296

>> disp ([2:8]) % displays vector
    2 3 4 5 6 7 8

>> disp ([1:5 ; 5:5:25]) % displays matrix
    1 2 3 4 5
    5 10 15 20 25

>> disp('   Col.{1}   Col.{2}   Col.{3}') , disp(rand(5,3)) % displays as table

```
    Col.{1}    Col.{2}    Col.{3}
    0.3181     0.6393     0.5225
    0.1192     0.5447     0.9937
    0.9398     0.6473     0.2187
    0.6456     0.5439     0.1058
    0.4795     0.7210     0.1097
```

Formatted output can be printed to the screen using the **fprintf** function. For example:

>> fprintf ('The 7! value is %d\n' , factorial(7))
The 7! value is 5040

The ***fprintf*** function, first a string (called the ***format string***) is passed, which contains any text to be printed as well as formatting information for the expressions to be printed. In this example, the **%d** is an example of format information. The **%d** is sometimes called a ***placeholder***; it specifies where the value of the expression that is after the string is to be *printed*. The character in the placeholder is called the ***conversion character***, and it specifies the *type of value* that is being printed. There are others of the simple placeholders:

Placeholder (character)	Description	Example
%d	Format as a *integer*	**>> fprintf ('%d', 4^5)** **1024>>**
%f	Format as a *floating point* value	**>> fprintf ('%f', sqrt(90.25))** **9.500000>>**
%g	Format as the *most compact* form (*no trailing zero*)	**>> fprintf ('%g', sqrt(90.25))** **9.5>>**
%e	Format as a floating point value in *scientific* notation	**>> fprintf ('%e', pi)** **3.141593e+000>>**
%s	Format as a *string*	**>> fprintf ('%s', '3*8/2')** **3*8/2>>**
\n	Insert a *new line* in the output string	**>> fprintf ('Welcome! \n this is MATLAB')** **Welcome!** **this is MATLAB>>**
\t	Insert a *tab* in the output string	**>> fprintf ('Welcome! \t this is MATLAB')** **Welcome! this is MATLAB>>**

***Notes* :**

- It's important adding the character \n at the *end* of output string in order to *avoid* the prompt (>>) from *stick* to the result as shown before.

- The character \n can also use in *input* function, for example:

```
>> h = input ('Enter \n The shape height :')
Enter
 The shape height :
```

- The character \n in form '\n\n' use to get blank line in output, for example:

```
>> fprintf ('Hello \n\n This is MATLAB \n')
Hello

 This is MATLAB
```

- A ***field width*** can also be included in the placeholder in **fprintf**, which specifies how many characters total are to be used in printing. For example, %5d would indicate a field width of 5 for printing an integer and %10s would indicate a field width of 10 for a string. For floats, the number of decimal places can also be specified; for example, *%6.2f* means a field width of 6 (including the decimal point and the decimal places) with two decimal places. For floats, just the number of decimal places can also be specified; for example, *%.3f* indicates three decimal places.

```
>> fprintf ('The integer is %3d and the float is %6.2f \n', 56 , 42.95897)
The integer is  56 and the float is  42.96
```

*Note that if the field width is wider than necessary, **leading** blanks are printed, and if more decimal places are specified than necessary, **trailing** zeros are printed.*

- For a **vector**, if a conversion character (%d, %f …) and the **\n** character are in the format string, it will print in a *column* regardless of whether the vector itself is a row vector or a column vector. For examples:

```
>> v=1:5;
>>fprintf ('%d', v) , fprintf ('\n')
12345

>> fprintf ( '%d\n', v)
1
2
3
4
5
```

- For **matrices**, Specifying one conversion character and then the \n character will print the elements from the matrix in one column. The first values printed are from the first column, then the second column, and so on. For examples:

```
>> mat=[1 2 3;4 0 6;7 9 8]          % create (3 x 3) matrix
mat =
        1        2        3
        4        0        6
        7        9        8

>>fprintf ('%d\n', mat)
1
4
7
2
0
9
3
6
8
```

To *reshape* the matrix to (**3 x 3**), three of **%d** characters are specified, the **fprintf** will print *three* numbers across on each *line* of output and so on.

```
>> fprintf ('%d %d %d \n', mat)
1 4 7
2 0 9
3 6 8
```

Example 3.3: write a program to find the cosine of angles *(0,15,45,60,75,90)* and format the output result as : “**The cosine of angle X is : Y** “, named file “**AngleCosine**”

Sol

```
clc
clear
theta=0:15:90;                  % generate angles (0-90) steps 15
cosine=cosd(theta);             % find the cosine of angle
result= [theta ; cosine];       % merge the vectors to produce a matrix
fprintf('The cosine of angle %d is :%4.3f \n',result)
```

```
>> AngleCosine
The cosine of angle 0 is :1.000
The cosine of angle 15 is :0.966
The cosine of angle 30 is :0.866
The cosine of angle 45 is :0.707
The cosine of angle 60 is :0.500
The cosine of angle 75 is :0.259
The cosine of angle 90 is :-0.000
```

Example 3.4: How many years **(Y)** needs to be a *millionaire* **(Fv)** when you investment an amount of **(N)$** with annual interest rate (**R**)**%**, write a program *based on* equation: (using I/O statements and named file “investment”)

$$Fv = N(1+R)^Y$$

Sol :

1) Redefine the equation in terms of **Y**

$$Y = \frac{\ln \frac{Fv}{N}}{\ln(1+R)}$$

2) Write & run a program

```
clear
clc
N=input('The amount of Investment :');
R=input('The interest rate{%} :');
Fv=1000000;
Y=log(Fv/N)/log(1+R);
fprintf('\n The No. of years are :\t %0.2f \n',Y)
fprintf('\n Which is approximately :\t %d years \n',ceil(Y))
```

```
>> investment
The amount of Investment :80000
The interest rate{%} :0.12

 The No. of years are :      22.29

 Which is approximately :     23 years
```

3.3 Relational and logical Operators

In MATLAB the result of a **logical** operation is **1** if it is ***true*** and **0** if it is ***false***. The relational operators (<, <=, >, >=, == and ~=) can be used to compare two matrices of the *same size* or a vector with scalar. For examples:

Relational Operator	Description
<	Less than
>	Greater than
<=	Less than or equal to
>=	Greater than or equal to
= =	Equal to
~=	Not equal to

```
>> 3>8                    % checks if 3 is greater than 8
ans =
    0

>> x= 4<=7                % checks if 4 less or equal 7 and assigns answer to x
x =
    1

>> y=(5>4)+(2<7)+(4*3==36/3)  % sums the result of checking each parenthesis
y =
    3

>> A=[1 0 8 2 -5]; B=[9 0 -4 1 2];  % create vectors A and B with same length
>> C=A>=B                 % check if A elements is greater or equal to B elements
C =
    0    1    1    1    0

>> D=B~=C                 % checks which of B elements is not equal to C elements
D
   1    1    1    0    1

>> E=B-A>0                % subtracts A from B and checks which element is greater than zero
```

```
E =
    1    0    0    0    1

>> M = [9 5 1 0;3 6 -5 7;8 10 -6 -4]        % creates (3x4) matrix
M =
         9     5     1     0
         3     6    -5     7
         8    10    -6    -4

>> H = M<5        % checks M elements if less than 5 and assigns results to matrix H
H =
         0     0     1     1
         1     0     1     0
         0     0     1     1
```

***Notes* :**

- The vector with values of ***0s*** and ***1s*** which is the result of relational operation are called ***logical vector***. The real power of logical vectors is that they can be used as *on-off* subscripts in vector expressions. Suppose that the problem is not just to find out how many negative numbers are in the vector, but to extract them for future use:

```
>> v=[-2 3 4 -1 -6 2 8 9 -7 0 -5]        % create a vector v
v =
   -2    3    4   -1   -6    2    8    9   -7    0   -5

>> Vn = v<0        % checks which v elements less than zero and assign to logical
Vn =               vector Vn with 1s at positions where v elements are negative
    1    0    0    1    1    0    0    0    1    0    1

>> Vneg= v(Vn)    % extracts the negative elements of v using Vn vector and assign to Vneg
Vneg =
   -2   -1   -6   -7   -5

>> Vneg=v(v<0)    % the same result is done in one step
Vneg =
   -2   -1   -6   -7   -5
```

- **The order of precedence** in mathematical expression, the arithmetic operators (+, -, *, /, \, ^) is higher than relational operators, whereas the relational operators have the equal precedence and are evaluated from left to right, parenthesis used to overcome the precedence. For examples:

```
>> 6+1 <= 18/3    % the / and + executes first and then relational operator <=
```

```
ans =
    0

>> 6+ (1<=18) /3     % the parenthesis executes first
ans =
   6.3333
```

- The relational operators can also uses with characters based on **ASCII code**. For examples:

```
>> 'n' > 'z'
ans =
    0

>> 'n' > 'Z'     % the ASCII code of 'n' is greater than 'Z'
ans =
    1

>> 'Not' >= 'not'     % check each character in both strings(must have same length)
ans =
    0     1     1

>> 'MatLab'  <  'matlab'
ans =
    1     0     0     1     0     0
```

The **logical** operators (**&**, **|** and **~**) allow for the logical combination or negation of relational operators. For examples:

Logical operator	Name	Description
&	AND	**Compares** between two operands(A,B) if *both* are **true**, the result is **true**(1) ;otherwise its **false**(0)
|	OR	**Compares** between two operands(A,B) if *either one* or *both* are **true**, the result is **true**(1) ;otherwise its **false**(0)
~	NOT	**Checks** one operand (A), if it is **true** (1), the result is **false**(0), or vice versa.

```
>> 8 & -1       % 8 AND -1 (both operands are nonzero)
ans =
    1

>> 9 | 0        % 9 OR 0
ans =
     1
```

```
>> ~12                          % NOT 12 (which is returning zero)
ans =
    0

>> R=10*((1&-2) - (0|3) + (~0))      % using logical operators in math expression
R =
   10
>> X=[9 5 -4 0 6] ; Y=[1 0 7 -3 11];  % creates vectors X and Y (must have same length)
>> Z=X&Y                        % compares X elements with Y elements using logical AND
Z =
    1    0    1    0    1

>> Z= 0 | Y                     % compares scalar 0 with Y elements using logical OR
Z =
    1    0    1    1    1

>> W= ~(X .* Y)                 % logical NOT checks the results of multiplying element by
W =                             element of X with Y vectors
    0    1    0    1    0
```

<u>Notes</u>:

- **The order of precedence** for logical operator **NOT** is *<u>higher</u>* than both arithmetic and relational operations, whereas the logical **AND** and **OR** are *<u>equal</u>* and *<u>lower</u>* than both arithmetic and relational operations, if two or more operators have the same precedence is executed <u>from left to right</u>. For examples:

```
>>  x = -1 ; y = 4;         % defines variables x and y
>> -2 < x < 0               % executes (-2<x) first, then (result < 0)
ans =
    0

>> -2<x & x<0   % executes < operators first, then compares their results with AND operator
ans =
    1

>> ~ (y>=1)                 % executes parenthesis first, then logical NOT
ans =
    0

>> ~y<=1                    % executes logical NOT first, then chicks result with <=
ans =
    1
```

```
>> ~ ((x<-2) | (y>=4))      % executes parentheses first, then compares results with OR and finally uses logical NOT
ans =
    0

>> ~ (x<-2) | (y>=4)        % executes parentheses first, then uses logical NOT and finally compares results with OR
ans =
    1
```

- MATLAB provides additional built-in logical functions:

Function	Description	Example
all(A)	Determine whether ***all*** array elements are **nonzero** or **true**	**>> X=[3 4 1] ; Y=[8 0 7 5]; >> all(X) , all(Y) ans = 1 ans = 0**
any(A)	Determine whether ***any*** array elements are **nonzero**	**>> X=[0 0 0] ; Y=[6 0 5]; >> any(X) , any(Y) ans = 0 ans = 1**
Find(A)	Find ***indices*** and values of **nonzero** elements	**>> X=[0 9 1 0 3 0 5 7]; >> find(X) ans = 2 3 5 7 8**
Find(A>K)	Find ***indices*** of elements that returns ***true*** of relational operators	**>> X=[0 9 1 0 3 0 5 7]; >> find(X>5) ans = 2 8**

Example 3.5: Write a program to test the degrees of **40** students and find: (named file "students")

1) The number of students those degrees *above* **80**
2) The number of students those degrees *between* **60** and **79**
3) The number of students those ***failed*** *and* ***their degrees***

Sol:

```
clear
clc
Degree= randi([25,100],1,40)  % generate the degrees of 40 students their range (25-100)
DegreeAbove80=sum(Degree>80);  % find no. of students which degree>80 using sum function
Degree60to79=sum(Degree>=60 & Degree<80);  % find no. of students which 60<degree<80
Failures=sum(Degree<50);  % find no. of failures students
fprintf('\n')            % format output results
disp('---------------------------------------------')
fprintf('The no. of students with degree above 80 :
%d\n',DegreeAbove80)
```

```
fprintf('The no. of students with degrees 60 to 79 :
%d\n',Degree60to79)
fprintf('The no. of failures students: %d\n',Failures)
fprintf('And their degrees are :\n')
disp(Degree(Degree<50))        % display the degrees which are less than 50
```

>> students

Degree =

Columns 1 through 15

61 85 42 62 93 68 89 81 69 43 75 31 72 75 80

Columns 16 through 30

92 99 83 69 95 69 26 34 90 61 89 40 66 72 27

Columns 31 through 40

71 52 28 62 39 34 40 36 39 28

The no. of students with degree above 80 : **10**
The no. of students with degrees 60 to 79 : **14**
The no. of failures students: **14**
And their degrees are :

42 43 31 26 34 40 27 28 39 34 40 36 39 28

3.4 Flow Control

Selection statements that test the results of relational or logical functions or operators are the decision-making structures that allow the flow of command execution to be controlled.

MATLAB has two basic statements that allow *choices*: the **if** statement and the **switch** statement. The **if** statement has optional **else** and **elseif** clauses for branching. The **if** statement uses expressions that are logically true or false.

There are two different *loop* statements in MATLAB: the **for** statement and the **while** statement. In practice, the **for** statement usually is used as the *counted loop*, and the **while** is used as the *conditional loop*.

3.4.1 The {if – elseif – else – end} statement

An **if** statement can be followed by an (or more) optional **elseif**... and an **else** statement, which is very useful to test various condition. When using **if... elseif...else** statements, there are few points to be considered:

- The **if - end** uses with *one* condition, the **if – else – end** uses with *two* conditions and for more than two uses **if – elseif – else – end.**
- An **if** can have *zero or one* **else** and it must come *after* any **elseif**.
- An **if** can have *zero to many* **elseif** and they must come *before* the **else**.
- The *nested* **if** statements can use one **if** or **elseif** statement inside another **if** or **elseif** statement(s). The *syntax* of **if** statement in MATLAB is:

if <expression 1>
% Executes when the expression 1 is *true*
<statement(s)>
elseif <expression 2>
% Executes when the boolean expression 2 is *true*
<statement(s)>
Elseif <expression 3>
% Executes when the boolean expression 3 is *true*
<statement(s)>
else
% Executes when the none of the above condition is *true*
<statement(s)>
end

Example 3.6 Write a script file to prompt the user to enter an integer, and then display whether the integer is *zero*, *positive* or *negative*.(named file "testNumber")

Sol:

```
n=input('Enter an integer : ');
if n>0
   disp('The number is Positive')
elseif n<0
   disp('The number is Negative')
else
   disp('The number is Zero')
end
```

>>testNumber
Enter an integer : **9**
The number is Positive

>>testNumber
Enter an integer : **0**
The number is Zero

Example 3.7 Grades are to be assigned as follows:

A 80% - 100%
B 65% - 79%
C 50% - 64%.

Write a script file to prompt the user to input a mark and display the appropriate grade. If the user enters a number *greater* than **100** or *less* than **zero**, display a message that the mark is *invalid*.(file name "testMark"

Sol:

```
mark=input('Enter the mark : ');
if mark > 100 | mark < 0
```

```
   disp('Invalid mark')
elseif mark >= 80
   disp('A')
elseif mark >= 65
   disp('B')
elseif mark >= 50
   disp('C')
else
   disp('Fail')
end
```

>> **testMark**
Enter the mark : 58
C
>> **testMark**
Enter the mark : 91
A
>> **testMark**
Enter the mark : 102
Invalid mark

Example 3.8: write a program to find the Y value when: (named file "Yvalue")

$$Y = \begin{cases} \dfrac{2}{x^3} & -10 \le x < 0 \\ 2 & x = 0 \\ \sqrt[3]{x^2+4} & 0 < x \le 7 \end{cases}$$

Sol:

```
x=input('Enter the x value : ');
if x<-10 | x>7
    disp('Undefined the Y value')
elseif x>=-10 & x<0
    Y=2/x^3;
    fprintf('The Y value = %0.3f\n ',Y);
elseif x>0 & x<=7
    Y=nthroot(sqrt(x^2+4),3);
    fprintf('The Y value = %0.3f\n ',Y);
else
    fprintf('The Y value = %d\n ',2);
end
```

>> **Yvalue**
Enter the x value : **9**
Undefined the Y value

>> **Yvalue**
Enter the x value : **0**
The Y value = 2

>> **Yvalue**
Enter the x value : **-5**
The Y value = -0.016

>> **Yvalue**
Enter the x value : **1**
The Y value = 1.308

3.4.2 The {switch} statement

A **switch** block conditionally executes one set of statements from several choices. Each choice is covered by a **case** statement. The switch block tests each case until one of the cases is *true*.

When a **case** is *true*, MATLAB executes the corresponding statements and then *exits* the switch block. The **otherwise** block is *optional* and executes only when *no case* is *true*. The *syntax* of **switch** statement in MATLAB is:

```
switch <switch_expression>
case <case_expression>
      <statement(s)>
case <case_expression>
      <statement(s)>
...
...
otherwise
     <statement(s)>
end
```

Example 3.9: Write a program to select a color by entering the 1st letter of its name: And handle the invalid letter (named with "colortest")

G	**Green**
Y	**Yellow**
W	**White**
R	**Red**
B	**Blue**
C	**Cyan**

Sol:

```
color=input('Enter color letter : ','s');
switch color
    case {'G','g'}
        disp('The color is Green');
    case {'Y','y'}
        disp('The color is Yellow');
    case {'R','r'}
```

```
        disp('The color is Red');
    case {'W','w'}
        disp('The color is White');
    case {'B','b'}
       disp('The color is Blue');
    case {'C','c'}
        disp('The color is Cyan');
    otherwise
        disp('Undefined Color');
end
```

>> **colortest**
Enter color letter : **y**
The color is **Yellow**

>> **colortest**
Enter color letter **: b**
The color is **Blue**

>> **colortest**
Enter color letter **: R**
The color is **Red**

Example 3.10: Write a program to display the name of day by giving the day number as the following:

1	Saturday
2	Sunday
3	Monday
4	Tuesday
5	Wednesday
6	Thursday
7	Friday

And handle the invalid number (named file "dayname")

Sol:

```
Nday=input('Enter The Day Number : ');
switch Nday
    case 1
        disp('The day is SATURDAY');
    case 2
         disp('The day is SUNDAY');
    case 3
         disp('The day is MONDAY');
    case 4
         disp('The day is TUESDAY');
    case 5
         disp('The day is WEDNESDAY');
```

```
    case 6
         disp('The day is THURSDAY');
    case 7
         disp('The day is FRIDAY');
    otherwise
         disp('Invalid');
end
```

>> **dayname**
Enter The Day Number : **3**
The day is MONDAY

>> **dayname**
Enter The Day Number : **7**
The day is FRIDAY

>> **dayname**
Enter The Day Number : **10**
Invalid

3.4.3 The {for loop} statement

A **for loop** is a repetition control structure that allows you to efficiently write a loop that needs to execute a specific number of times. The *syntax* of **for** statement in MATLAB is:

for index = ***initval : step : endval***
<statement(s)>
...
end

Increments **index** by the value **step** on each iteration, or decrements when **step** is *negative*, **step** is *omitted* when increment is **1**. For examples:

```
>> for N=10:20          % print the N values range between (10→20)
fprintf ('value of N: %d\n', N);
end
value of N: 10
value of N: 11
value of N: 12
value of N: 13
value of N: 14
value of N: 15
value of N: 16
value of N: 17
value of N: 18
value of N: 19
value of N: 20
```

```
>> for A = [24,18,17,23,28]                    % display the values of A
disp(A)
end
    24
    18
    17
    23
    28
```

Example 3.11: Create a script file to find $\sum_{x=1}^{x=n} \sqrt{x}$

Sol:

```
N=input('Enter N value : ');
xsum=0;
for x=1:N
    xsum=xsum+sqrt(x);
end
disp(xsum)
```

Enter N value : **7**
13.4776

Note: MATLAB allows to use more than one **for** loop, each one inside another loop. The *syntax* for a *nested* **for** loop statement in MATLAB is:

```
for m = 1:j
    for n = 1:k
      <statements>;
    end
end
```

Example 3.12: Create a script file to generate **(N X N)** matrix in form like:

$$\begin{bmatrix} \mathbf{1} & 0 & \mathbf{1} & 0 & \mathbf{1} \\ 0 & \mathbf{1} & 0 & \mathbf{1} & 0 \\ \mathbf{1} & 0 & \mathbf{1} & 0 & \mathbf{1} \\ 0 & \mathbf{1} & 0 & \mathbf{1} & 0 \\ \mathbf{1} & 0 & \mathbf{1} & 0 & \mathbf{1} \end{bmatrix}$$

Sol:

```
clear
N=input('Enter the square matrix size : ');
for i=1:N
    for j=1:N
        if mod(i+j,2)==0
            a(i,j)=1;
        else
            a(i,j)=0;
        end
    end
end
disp(a)
```

Enter the square matrix size : **5**

1	0	1	0	1
0	1	0	1	0
1	0	1	0	1
0	1	0	1	0
1	0	1	0	1

Example 3.13: Given two vectors **x** and **y** with random values, create a matrix **A** whose elements are defined as $A_{ij} = x_i \, . \, y_j$. Write a script file.

Sol:

```
clear;clc
x=randi([1,10],1,7);  % generates row vector x(7)
y=randi([1,4],5,1);   % generates column vector y(5)
for i=1:length(x)
    for j=1:length(y)
        A(i,j)=x(i)*y(j);
    end
end
disp(A)
```

3.4.4 The {while loop} statement

The **while** loop repeatedly executes statements while *condition* is **true**. The *syntax* of a **while** loop in MATLAB is:

while <expression>
<statement(s)>
…
End

The **while** loop repeatedly executes program statement(s) as long as the expression remains *true*.

Example 3.14: Write a program to compute the series:

$$y = 1 + \frac{1}{2} + \frac{1}{3} + \cdots + \frac{1}{n} \qquad n \neq 0$$

Sol:

```
clc;clear
N=input('Enter N value : ');
Y=0;i=1;
while i<=N
    Y=Y+1/i;
    i=i+1;
end
fprintf('Y= %.3f\n',Y)
```

Enter N value : **8**
Y= 2.718

Example 3.15: Write a program to generate the series (***1, 2, 4, 8, … , 1024***) and display it as a vector

Sol:

```
clear;clc;
n=0;i=1;
while 2^n<=1024
    A(i)=2^n;
    n=n+1;
    i=i+1;
end
disp(A')

           1
           2
           4
           8
          16
          32
          64
         128
         256
         512
        1024
```

Note: Also likes **for** loop, more than one **while** loop are used, one loop *inside* the another loop. The *syntax* for a *nested* **while** loop statement in MATLAB is as follows:

while <expression1>
    while <expression2>
        <statement(s)>
    end
end

Example 3.16: Write a program to display the **multiplication table**

Sol:

```
clc;clear;
x=1;
while x<=10
    y=1;
    while y<=10
        z(x,y)=x*y;
        y=y+1;
    end
    x=x+1;
end
```

```
disp(z);
```

1	2	3	4	5	6	7	8	9	10
2	4	6	8	10	12	14	16	18	20
3	6	9	12	15	18	21	24	27	30
4	8	12	16	20	24	28	32	36	40
5	10	15	20	25	30	35	40	45	50
6	12	18	24	30	36	42	48	54	60
7	14	21	28	35	42	49	56	63	70
8	16	24	32	40	48	56	64	72	80
9	18	27	36	45	54	63	72	81	90
10	20	30	40	50	60	70	80	90	100

3.4.5 The {break} statement

The **break** statement *terminates* execution of **for** or **while** loop. Statements in the loop that appear after the **break** statement are not executed. In nested loops, **break** exits only from the loop in which it occurs. Control passes to the statement following the end of that loop.

Example 3.17 Write a program to generate 100 random numbers range (1-50) use **rand** function, ***stop*** the operation when number =**33**. *Display* the numbers until it stopped

Sol:

```
clc;clear
counter=0;
for i=1:100
    x=((50-1)*rand+1);          % generate value range between(1-50)
    disp(x)
    counter=counter+1;
    if fix(x)==33               % the stop condition(convert to integer)
        fprintf('The no. of generated elements = %d\n
',counter)
        break;                  % exit from loop
    end
end
   20.6923
   31.9646
   49.2766
   28.4144
   46.7460
   36.2968
   24.7179
   32.3125
   44.4942
   10.7381
   20.3729
   49.6166
   20.7152
   33.2840
```

The no. of generated elements = **14**

3.4.6 The {continue} statement

The **continue** statement is used for *passing* control to *next* iteration of **for** or **while** loop. The **continue** statement in MATLAB works somewhat like the **break** statement. Instead of forcing termination, however, **'continue'** forces the next iteration of the loop to take place, skipping any code in between.

Example 3.18: Write a program to generate 10 integer x values range (0 – 3) and compute $y = \frac{1}{x}\ (x \neq 0)$, pass by when x=0. Find how many passes and display the y values.

Sol:

```
clear;clc
counter=0;
i=1;
while i<=10
    x=randi([0,3]);          % generate integer random numbers(0-3)
    y(i)=1/x;
    if (x==0)
        i=i+1;
        counter=counter+1;
        continue;
    end
i=i+1;
end
disp(y')
fprintf('the no. of passes : %d\n',counter)
```

0.50
0.33
0.50
0.33
Inf
Inf
0.33
1.00
Inf

the no. of passes : 3

3.5 User Defined Functions

A **function** is a group of statements that together perform a task. In MATLAB, functions are defined in *separate* files. *The **name** of the file and of the function should be the **same**.*

Functions operate on variables within their own workspace, which is also called the **local workspace**, separate from the workspace you access at the MATLAB command prompt which is called the **base workspace**. **Functions** can accept more than *one input* arguments and may return more than one *output* arguments.

Syntax of a **function** statement is:

function [out1, out2, ... , outN] = **myfun** (in1, in2, in3, ... , inN)

Example 3.19: Create a function file, named ***Nmax*** should be written in a file named ***Nmax.m***. It takes three numbers as argument and returns the maximum of the numbers.

Sol

```
function max=Nmax(a,b,c)
% This function calculates the maximum of the
% three given numbers as input
if (a>b) & (a>c)
    max=a;
elseif (b>c)
    max=b;
else
    max=c;
end
end
```

Comment describing the function

```
>> x= Nmax(12,35,1)
x =
   35
>> x= Nmax(12,-35,1)
x =
   12
>> x= Nmax(-12,-35,1)
x =
    1
```

Note: The comment lines that come right after the function statement provide the **help** text. These lines are *printed* when type:

```
>> help Nmax
 This function calculates the maximum of the
 three given numbers as input
```

Example 3.20: Create a function to *sort* a matrix column by column *ascending*

Sol:

```
function B= sortBycol(array)   % This function sorts a matrix column by column ascending
[m,n]=size(array);
V=reshape(array,1,m*n);        % convert matrix to vector
V=sort(V);
B=reshape(V,m,n);
End
```

```
>> A=[9 5 1 0;7 6 3 4;2 10 12 11]
A =
     9     5     1     0
     7     6     3     4
     2    10    12    11
```

```
>> sortBycol(A)
ans =
     0     3     6    10
     1     4     7    11
     2     5     9    12
```

3.6 Anonymous Functions

An **anonymous function** is a very simple, one-line function. The advantage of an anonymous function is that it does not have to be stored in an *M-file*, it can be created in the *Command Window* or in any *script*. The syntax for an anonymous function is:

fnhandle = @ (arguments) **functionbody**

Where ***fnhandle*** stores the ***function handle***; it is essentially a way of referring to the function. The handle is assigned to this name using the **@** operator. The arguments, in *parentheses*, correspond to the argument(s) that are passed to the function. For examples:

```
>> power = @(x,n) x.^n;   % defines function to compute x^n (where x is scalar or vector)
>> power (2,5)            % computes 2^5
ans =
   32

>> V=[2 3 6 1];           % creates vector V
>> power (V,5)            % computes the power for each elements of V
ans =
      32     243     7776      1
```

Example 3.21: Use an anonymous function to define:

1) ln
2) F° to C° temperature
3) Area of circle

Sol:

```
>> ln = @(x) log(x);      % defines ln
>> ln(500) , log(500)
ans =
   6.2146
ans =
   6.2146
```

```
>> FtoC = @(f) (f-32)/1.8;          % defines conversion function
>> FtoC(110)                        % converts 110 F°
ans =
  43.3333
>> FtoC(0)                          % converts 0 F°
ans =
 -17.7778

>> circlarea = @ (radius) pi * radius .^2;   % defines function area = πr^2
>> circlarea (8)
ans =
 201.0619
>> circlarea ([5 9 3 6])
ans =
   78.5398  254.4690   28.2743  113.0973
```

Notes: *Function handles* can also be created for functions other than anonymous functions, both built-in and user defined functions. For example, the following would create a function handle for the built-in **factorial** function:

```
>> Fact = @factorial;
>> Fact(8)
ans =
     40320
```

3.7 Primary and Sub-Functions

Any function other than an anonymous function must be defined within a file. Each function file contains a required primary function that appears first and any number of optional *sub-functions* that comes after the primary function and used by it. *Primary* functions can be called from outside of the file that defines them, either from command line or from other functions, but *sub-functions* cannot be called from command line or other functions, outside the function file. Sub-functions are visible only to the primary function and other sub-functions within the function file that defines them.

Example 3.22 Write a function named **quadratic** that would *calculate the roots* of a *quadratic equation*. The function file **quadratic.m** will contain the *primary* function ***quadratic*** and the *sub-function* ***disc***, which calculates the discriminant.

Sol:

```
Function [x1,x2]= quadratic(a,b,c)
%this function returns the roots of a quadratic equation.
%It takes 3 input arguments which are:
%the co-efficients of x2, x and the constant
```

```
d = disc(a,b,c);
x1 =(-b + d)/(2*a);
x2 =(-b - d)/(2*a);
end                      % end of quadratic(primary function)

function dis = disc(a,b,c)  % function calculates the discriminant
dis = sqrt(b^2-4*a*c);
end                         % end of sub-function
```

>> [r1,r2] = quadratic(-3,6,1)

r1 =
  -0.1547
r2 =
   2.1547

Exercises

Q1) Write an anonymous function to calculate and return the Volume of:
- Cube
- Cylinder
- Sphere
- Pyramid

Q2) Write an anonymous function to implement this. Compare yours to the built-in function **sinh**.

Hyperbolic sine(x)=($e^x - e^{-x}$)/2

Q3) Write a function *areaperim* that will calculate both the area and perimeter of a *polygon*. For a polygon with *n* sides inscribed in a circle with a radius of *r*, the area *A* and perimeter *P* of the polygon can be found by:

$$A = \frac{1}{2} n r^2 \sin\left(\frac{\pi}{n}\right) \qquad P = 2nr \sin\left(\frac{\pi}{n}\right)$$

Q4) The Fibonacci numbers is a sequence of numbers Fi: ***0 1 1 2 3 5 8*** ...
Where

a. $F_0 = 0$
b. $F_1 = 1$
c. $F_n = F_{n-2} + F_{n-1}$ ***if*** $n > 1$

Write a function to implement this definition. The function will receive one integer argument **n**, and it will return one integer value, which is the **nth** Fibonacci number.

Q5) Write a function *conevol* to calculate the cone volume which is given by:

$$V = \frac{1}{3} \pi r^2 h$$

Where r is the radius of the circular base and h is the height of the cone

Q6) A *closed cylinder* is being constructed of a material that costs a *dollar* amount per *square foot*. Write a function that will calculate and return the cost of the material, *rounded* up to the nearest square foot. The total surface area for the closed cylinder is:

$$SA = 2\pi r^2 + 2\pi r h$$

Where r is the radius and h is the height of the cylinder

Q7) Write a simple script that will calculate the volume of a hollow sphere that is

$$\frac{4\pi}{3}(r_0^3 - r_1^3)$$

Where r_1 is the *inner* radius and r_0 is the *outer* radius. Assign a value to a variable for the inner radius, and also assign a value to another variable for the outer radius. Then, using these variables, assign the volume to a third variable.

Q8) Write a function *nexthour* that will receive one integer argument, which is an hour of the day, and will return the next hour. This assumes a **12**-hour clock, so for example the next hour after **12** would be **1**. Here are two examples of calling this function.

>> ***fprintf('The next hour will be %d.\n',nexthour(3))***
The next hour will be 4.

>> ***fprintf('The next hour will be %d.\n',nexthour(12))***
The next hour will be 1.

Q9) Write a script to calculate the ***volume of a pyramid***, which is (***1/3 * base * height***), where the ***base*** is (***length * width***). Prompt the user to enter values for the **length**, **width**, and the **height** and then calculate the volume of the pyramid. When the user enters each value, he or she will then be prompted also for either **i** for *inches*, or **c** for *centimeters*. (Note: ***2.54cm = 1 inch***). The script should print the volume in *cubic inches* with <u>three decimal places</u>. As an example, <u>the format</u> will be:

```
This program will calculate the volume of a pyramid.
Enter the length of the base: 50
Is that i or c? i
Enter the width of the base: 6
Is that i or c? c
Enter the height: 4
Is that i or c? i
The volume of the pyramid is xxx.xxx cubic inches.
```

Q10) Write a function *createvec_m_to_n* that will create and return a vector of integers from **m** to **n** (where **m** is the *first* input argument and **n** is the *second*), regardless of whether **m** is <u>less</u> than **n** or <u>greater</u> than **n**. If **m** is <u>equal</u> to **n**, the vector will just be **1 × 1** or a *scalar*. Here are <u>some examples</u> of calling the function:

```
>> createvec_m_to_n(8,5)
ans =
     5    6    7    8
>> createvec_m_to_n(6,6)
ans =
     6
>> result = createvec_m_to_n(4,5)
result =
        4    5
>> help createvec_m_to_n
Creates a vector of integers from m to n
```

Q11) Write a script that will generate *one random integer*, and will print whether the random integer is an **even** or an **odd** number.

Q12) A *Pythagorean* triple is a set of positive integers ***(a,b,c)*** such that $a^2 + b^2 = c^2$. Write a function ***ispythag*** that will receive three positive integers (*a, b, c in that order*) and will return **1** for true if they form a Pythagorean triple, or **0** for false if not.

Q13) Write a script ***area_menu*** that will print a list consisting of ***cylinder***, ***circle***, and ***rectangle***. It prompts the user to choose one, and then prompts the user for the appropriate quantities (e.g., the radius of the circle) and then prints its area. If the user enters an *invalid choice*, the script simply prints **an error** message. The script use **switch** statement to accomplish this. Here are two examples of running it (units are assumed to be *inches*).

```
>> area_menu
Menu
1. Cylinder
2. Circle
3. Rectangle
Please choose one: 2
Enter the radius of the circle: 4.1
The area is 52.81

>> area_menu
Menu
1. Cylinder
2. Circle
3. Rectangle
Please choose one: 3
Enter the length: 4
Enter the width: 6
The area is 24.00
```

Q14) Let **x = [3 16 9 12 -1 0 -12 9 6 1].** Provide the command(s) that will:

- *set* the positive values of **x** to **zero**
- *set* values that are multiples of **3** to **3**
- *multiply* the even values of **x** by **5**
- *extract* the values of **x** that are *greater* than **10** into a vector called **y**
- *extract* the values of **x** that are *less* than **0** into a vector called **z**

Q15) Let **A = randi ([-10,10],6,6).** Perform the following (using ***find*** function):

- *find* the indices and list all elements of **A** which are *smaller* than **-3**
- *find* the indices and list all elements of **A** which are smaller than **5** and larger than **-1**
- *remove* those columns of **A** which contain at least one **0** element.

Q16) Assume that the months are represented by numbers from **1** to **12**. Write a script that asks you to provide a month and returns the number of days in that particular month. Alternatively, write a script that asks you to provide a *month name* (e.g. 'June') instead of a *number*. Use the **switch** function.

Q17) Write a ***for*** loop that will print the column of *real* numbers from **1.1** to **2.9** in steps of **0.1**.

Q18) Write a function *sumsteps2* that calculates and returns the sum of **1** to **n** in steps of **2**, where **n** is an argument passed to the function. Do this using a **for** loop

Q19) Write a function *prodby2* that will receive a value of a positive integer ***n*** and will calculate and return the *product* of the odd integers from **1** to ***n*** (or from **1** to ***n*–1** if ***n*** is even).

Q20) Write a function called *geomser* that will receive values of ***r*** and ***n***, and will calculate and return the sum of the geometric series:

$$1 + r + r^2 + r^3 + r^4 + \dots + r^n$$

Q21) Create a **1 × 6** vector of random integers, each in the range from **1** to **20**. Find the *minimum* and *maximum* values in the vector, also find the sum of vector.

Q22) Write a function that will receive a matrix as an input argument, and will calculate and return the overall *average* of all numbers in the matrix.

Q23) Create a vector of *five* random integers, each in the range from **–10** to **10**. Perform each of the following:
- *Subtract* **3** from each element.
- *Count* how many are positive.
- *Get* the *absolute* value of each element.
- *Find* the *maximum*.

Q24) Write a script that will print the following multiplication table:
```
1
2 4
3 6 9
4 8 12 16
5 10 15 20 25
```

Q25) The mathematician *Euler* proved the following:

$$\frac{\pi^2}{6} = 1 + \frac{1}{4} + \frac{1}{9} + \frac{1}{16} + \cdots$$

Loop until the sum is close to $\pi^2/6$

Q26) Write a script that will continue prompting the user for positive numbers, and storing them in a vector variable, until the user types a negative number.

Q27) An approximation for the *exponential* function can be found using what is called a *Maclaurin* series:

$$e^x \approx 1 + \frac{x^1}{1!} + \frac{x^2}{2!} + \frac{x^3}{3!} + \cdots$$

Write a program to investigate the value of e^x and the ***exp*** function.

Q28) The *area* of a triangle is:

$$area = \sqrt{s(s-a)(s-b)(s-c)}$$

Where ***a***, ***b***, and ***c*** are the lengths of the sides of the triangle, and ***s*** is equal to *half* the sum of the lengths of the three sides of the triangle. Write a script to calculate and print the *area* of the triangle.

Q29) Write a function *convert_sec* to convert seconds in term of (hours : minutes : seconds)

Q30) Determine the *sum* of the first **50** squared numbers with a control ***loop***.

Q31) Given **x = [4 1 6 -1 -2 2]** and **y = [6 2 -7 1 5 -1]**, *compute* matrices whose elements are created according to the following formulas:

- $a_{ij} = y_i / x_j$
- $b_i = x_i \; y_i$
- $c_{ij} = x_i /(2 + x_i + y_j)$
- $d_{ij} = 1/ \max(x_i; \; y_j)$

Q32) Write a script that *transposes* a matrix **A**. Check its correctness with the Matlab operation: **A'**.

Q33) Create an **m-by-n** array of *random* numbers (use ***rand*** function). Move through the array, element by element, and set any value that is *less* than **0.5** to **0** and any value that is *greater* than or *equal* to **0.5** to **1**.

4.1 Symbolic Algebra

Symbolic mathematics is used regularly in math, engineering, and science classes. It is often preferable to manipulate equations *symbolically* before you substitute values for variables. Its means doing mathematics on symbols (not numbers!).For example, ***a* + *a*** is ***2a***. The symbolic math functions are in the *Symbolic Math Toolbox* in MATLAB. Toolboxes contain related functions and are add-ons to MATLAB. The Symbolic Math Toolbox includes an alternative method for solving equations.

4.2 Creating Symbolic Variables and Expressions

Before we can solve any equations, we need to create some symbolic variables. Simple symbolic variables can be created in two ways. For example, to create the symbolic variable ***x*** , type either

```
>> syms x
```

OR

```
>> x = sym ('x');
```

Both techniques set the character **'x'** equal to the symbolic variable **x**. More complicated variables can be created by using existing symbolic variables, as in the expression:

```
>> y = 2*(x - 3)^2/(x^2 + 6*x -9)
```

Notice that both **x** and **y** are *symbolic* variables, **whos** command showing that:

```
>> whos
  Name      Size            Bytes  Class    Attributes

  x         1x1                60  sym
  y         1x1                60  sym
```

The **syms** command is particularly convenient, because it can be used to create multiple symbolic variables at the same time, as with the command

```
>>syms pi r h
```

These variables could be combined mathematically to create another symbolic variable, **Vcylinder**:

```
>> Vcylinder=pi*r^2*h
```

The **sym** function can be used to create either an entire expression or an entire equation. For example

>> E = sym ('m*c^2')

Creates a symbolic variable named **E**. Notice that **m** and **c** are not listed in the workspace window, they have not been specifically defined as symbolic variables. Instead, the input to **sym** was a character string, identified by the *single quotes* inside the function.

```
>> whos
  Name          Size            Bytes  Class    Attributes

  Vcylinder     1x1                60  sym
  h             1x1                60  sym
  r             1x1                60  sym
```

All basic mathematical operations can be performed on symbolic variables and expressions (e.g., add, subtract, multiply, divide, raise to a power, etc.). For examples:

```
>> A=sym('x^2');
>> B=sym('x^4');
>> A/B
ans =
1/x^2

>> sqrt(B)
ans =
(x^4)^(1/2)

>> A^3
ans =
x^6

>> B*A
ans =
x^6

>> A + sym('5*x^2')          % adding the x^2 and 5x^2 to result in 6x^2
ans =
6*x^2

>> sym ('z^3 + 2*z^3')
ans =
3*z^3
```

Example 4.1: Generate symbolic series:

$$\boldsymbol{y = x \quad x^2 \quad x^3 \quad x^4 \ldots x^n}$$

$$\boldsymbol{z = \frac{1}{2x} \quad \frac{1}{4x} \quad \frac{1}{6x} \cdots \frac{1}{2nx}}$$

Sol:

```
>> syms x
>> n=7;
>> y=x.^(1:n)                    % uses element by element .^ with variable x
y =
[ x, x^2, x^3, x^4, x^5, x^6, x^7]

>> n=16;
>> z=1./(x*(2:2:n))              % uses element by element ./ with variable x
z =
[ 1/(2*x), 1/(4*x), 1/(6*x), 1/(8*x), 1/(10*x), 1/(12*x), 1/(14*x), 1/(16*x)]
```

Notice that the series results appeared as vectors. Also the **sym** function uses to create the symbolic matrix. For examples:

```
>> A= sym('a', 3)                % creates a matrix (3x3) of symbolic variable a
A =
[ a1_1, a1_2, a1_3]
[ a2_1, a2_2, a2_3]
[ a3_1, a3_2, a3_3]

>> A= sym('a' , [3 5])           % creates a matrix (3x5) of symbolic variable a
A =
[ a1_1, a1_2, a1_3, a1_4, a1_5]
[ a2_1, a2_2, a2_3, a2_4, a2_5]
[ a3_1, a3_2, a3_3, a3_4, a3_5]

>> A= sym ('a%d%d' , [3 5])      % approve the appearance by removing underscore
A =
[ a11, a12, a13, a14, a15]
[ a21, a22, a23, a24, a25]
[ a31, a32, a33, a34, a35]
```

Example 4.2: Use an anonymous function to create a symbolic matrix as shown:

$$\begin{bmatrix} \frac{1}{1*1} & \cdots & \frac{1}{1*n} \\ \vdots & \ddots & \vdots \\ \frac{1}{m*1} & \cdots & \frac{1}{n*m} \end{bmatrix}$$

Sol:

```
>> SymbolicMatrix=@(m,n)  sym(1./((1:m)'*(1:n)));
>> SymbolicMatrix(3,5)
ans =
[   1, 1/2, 1/3,  1/4,  1/5]
[ 1/2, 1/4, 1/6,  1/8, 1/10]
[ 1/3, 1/6, 1/9, 1/12, 1/15]
```

Note: In symbolic expressions the **real** numbers are converted to **rational values**, for examples:

```
>> sym (2.5 + 3.75)
ans =
25/4
```

```
>> sym(sqrt(5.5))
ans =
(2^(1/2)*11^(1/2))/2
```

```
>> sym(9.7^2/2)
ans =
9409/200
```

4.3 Simplification Functions

There are several functions that work with expressions, and simplify the terms such as:

4.3.1 simplify Function

The ***simplify*** function does whatever it can to *simplify* expressions, including gathering *like terms*. For example:

```
>> y=sym ('x^2+3*x-5=1');
>> simplify (y)
ans =
x*(x + 3) = 6
```

```
>> z = sym ('3*x-(x+3)*(x-3)^2');
>> simplify (z)
ans =
3*x - (x - 3)^2*(x + 3)
```

```
>> w = sym ('x^3-1 = (x-3)*(x+3)');
>> simplify (w)
ans =
```

```
x^3 + 8 = x^2
 >> syms x
 >> simplify (cos(x)^2 + sin(x)^2)
ans =
1

>> simplify (tan(x)^2 - sec(x)^2)
ans =
-1
```

4.3.2 expand Function

The ***expand*** function *multiplies* out all the portions of the expression or equation. For examples:

```
 >> syms x
 >> expand ((x-2)*(x-4))
ans =
x^2 - 6*x + 8

 >> syms y
 >> expand (sin(x+y))
ans =
cos(x)*sin(y) + cos(y)*sin(x)

>> expand ((x+8)^3)
ans =
x^3 + 24*x^2 + 192*x + 512

 >> y = (1-x)^3
y =
-(x - 1)^3
 >> expand (y)
ans =
- x^3 + 3*x^2 - 3*x + 1
```

4.3.3 factor Function

The ***factor*** function uses to *analysis* the equations to their factors. For examples:

```
 >> syms x
 >> factor (x^3-1)
ans =
(x - 1)*(x^2 + x + 1)

 >> syms y
```

```
>> factor (x^4-y^2)
ans =
(x^2 - y)*(x^2 + y)

>> factor (sym('15236987456'))      % factors symbolic number
ans =
   2^6*173*1376173
```

4.3.4 collect Function

The *collect* function uses to *collect* coefficients. For examples:

```
>> syms x,y
>> collect ((x-1)^2*(x+1))
ans =
x^3 - x^2 - x + 1

>> collect ((x^2-x^3)^2-4)
ans =
x^6 - 2*x^5 + x^4 - 4

>> collect ((x^2-x^3)^2*(y-1))
ans =
(y - 1)*x^6 + (2 - 2*y)*x^5 + (y - 1)*x^4

>> collect ( (x^3-x^2)^2 - (y-1)^3 , y)      % collects y coefficient only
ans =
- y^3 + 3*y^2 - 3*y + (x^2 - x^3)^2 + 1
```

4.3.5 subs Function

The *subs* function will *substitute* a value for a symbolic variable in an expression or in an equation. For examples:

```
>> myexp = x^3 + 3*x^2 - 2
myexp =
x^3 + 3*x^2 - 2
>> x = 3;
>> subs (myexp,x)
ans =
     52

>> syms x y
>> subs (x^2-y^2+x*y-3 , x , 2)      % substitutes variable x only with 2
ans =
```

```
- y^2 + 2*y + 1
>> subs (x^2-y^2+x*y-3,{x , y},{3 , -2})     % substitutes variables x and y with (3 , -2)
ans =
     -4
```

4.4 Solving Expressions and Equations

A highly useful function in the symbolic toolbox is ***solve***. It can be used to determine the *roots* of expressions, to find numerical answers when there is a single variable, and to solve for an unknown symbolically. The ***solve*** function can also solve systems of equations, the ***solve*** function allows the user to find analytical solutions to a variety of problems.

4.4.1 solve Function

The function ***solve*** solves an equation and returns the *root(s)* as symbolic expressions. The solution can be converted to numbers using any *numeric* function, such as ***double***, for example:

```
>> syms x
>> R = solve ('2*x^2 + x = 6')
R =
  -2
 3/2

>> double (R)          % double function converts symbolic results to real numbers
ans =
   -2.0000
    1.5000
```

The ***solve*** function sets the expression equal to *zero* and solves for the roots. For example:

```
>> solve ('3*x^2 + x')
ans =
 -1/3
    0
```

If there is more than one variable, MATLAB *preferentially* solves for ***x***. If there is no ***x*** in the expression, MATLAB finds the variable closest to ***x***. For example:

```
>> solve ('a*x^2+b*x +c')
ans =
 -(b + (b^2 - 4*a*c)^(1/2))/(2*a)
 -(b - (b^2 - 4*a*c)^(1/2))/(2*a)
```

However, it is possible to specify which variable to solve for:

```
>> solve ('a*x^2+b*x +c', 'a')        % solves for variable a
ans =
-(c + b*x)/x^2
```

MATLAB can also solve <u>sets of equations</u>. In this example, the solutions for ***x***, ***y***, and ***z*** are returned as a ***structure*** consisting of <u>fields</u> for ***x***, ***y***, and ***z***. The individual solutions are symbolic expressions stored in fields of the structure.

```
>> R=solve ('4*x-2*y+z=7' , 'x+y+5*z=10' , '-2*x+3*y-z=2')
R =
    x: [1x1 sym]
    y: [1x1 sym]
    z: [1x1 sym]
```

To *refer* to the individual solutions, which are in the structure fields, the *dot operator* (**.**) is used.

```
>> x = R.x          % returns the value of variable x using ( . ) operation
x =
   124/41

>> y = R.y          % returns the value of variable y using ( . ) operation
y =
    121/41

>> z = R.z          % returns the value of variable z using ( . ) operation
z =
    33/41
```

The ***double*** function can then be used to *covert* the *symbolic expressions* to *numbers*, and <u>store</u> the results from the three unknowns in <u>a vector</u>.

```
>> double ([x y z])
ans =
    3.0244    2.9512    0.8049
```

4.5 Calculus

MATLAB provides various ways for solving problems of differential and integral calculus, solving differential equations of any degree and calculation of limits. Best of all, you can easily plot the graphs of complex functions and check maxima, minima and other stationery points on a graph by solving the original function, as well as its derivative. We will deal with the problems of calculus, and discuss pre-calculus concepts i.e., calculating limits of functions and verifying the properties of limits. We will also discuss solving differential equations. Finally, we will discuss integral calculus.

4.5.1 Limit Calculation

The ***limit*** function takes *expression* as an argument and finds the limit of the expression as the independent variable goes to zero. For examples:

```
>> syms  x
>> limit ((x^3+5)/(x^4+7))              % x tends to zero as default
ans =
     5/7

>> limit ((x -3)/(x-1) , -1)            % x tends to -1
ans =
     2
```

Algebraic Limit Theorem provides some basic properties of limits. These are as follows:

$$\begin{aligned}
\lim_{x\to p}(f(x)+g(x)) &= \lim_{x\to p} f(x)+\lim_{x\to p} g(x)\\
\lim_{x\to p}(f(x)-g(x)) &= \lim_{x\to p} f(x)-\lim_{x\to p} g(x)\\
\lim_{x\to p}(f(x)\cdot g(x)) &= \lim_{x\to p} f(x)\cdot\lim_{x\to p} g(x)\\
\lim_{x\to p}(f(x)/g(x)) &= \lim_{x\to p} f(x)/\lim_{x\to p} g(x)
\end{aligned}$$

Example 4.3: Two functions: $f(x) = (3x + 5)/(x - 3)$ and $g(x) = x^2 + 1$. *Calculate* the ***limits*** of the functions as x tends to 4, of both functions and verify the basic properties of limits using these two functions and MATLAB.

```
>> syms x
>> f = (3*x +5)/(x-3);
>> g = x^2+1;
>> lim_f = limit (f,4)
lim_f =
      17

>> lim_g = limit (g,4)
lim_g =
      17

>> limAdd = limit (f + g,4)
limAdd =
      34
```

```
>> limSub = limit (f - g,4)
limSub =
       0

>> limMulti = limit (f * g,4)
limMulti =
       289

>> limDiv = limit (f / g,4)
limDiv =
       1
```

When limits of a function ***f(x)*** has *discontinuity* at ***x = a***. This leads to the concept of *left-handed* and *right-handed* limits. A left-handed limit is defined as the limit as ***x → a***, from the left, i.e., ***x*** approaches **a**, for values of ***x < a***. A right-handed limit is defined as the limit as ***x → a***, from the right, i.e., ***x*** approaches ***a***, for values of ***x > a***. When the left-handed limit and right-handed limits are *not equal*, the limit does not exist. For example:

```
>> f =(x -3)/abs(x-3);
>> left_lim = limit (f, x, 3, 'left')
left_lim =
       -1

>> right_lim = limit (f, x, 3, 'right')
right_lim =
       1
```

4.5.2 Differential

MATLAB provides the ***diff*** function for computing *symbolic derivatives*. In its simplest form, for examples:

```
>> syms t
>> f = 3*t^2+2*t^(-2);
>> diff (f)
ans =
       6*t - 4/t^3

>> syms x
>> diff ((x^2 + 3)*(x + 2))
ans =
       2*x*(x + 2) + x^2 + 3

>> der = diff ((2*t^2 + 3*t)/(t^3 + 1))
der =
```

```
(4*t + 3)/(t^3 + 1) - (3*t^2*(2*t^2 + 3*t))/(t^3 + 1)^2
```

>> **diff (cos(x)^2)**
ans =
```
    -2*cos(x)*sin(x)
```

>> **diff(exp(3*x^3))**
ans =
```
    9*x^2*exp(3*x^3)
```

>> **diff (log(t))**
ans =
```
    1/t
```
>> **diff (log10(t))**
ans =
```
    1/(t*log(10))
```

To compute higher derivatives of a function ***f***, we use the *syntax*: ***diff(f,n)***. For examples:

>> **f=2*x^3-3*x^2+4*x-1;**
>> **der1= diff (f)**
der1 =
```
    6*x^2 - 6*x + 4
```

>> **der2= diff(f,2)**
der2 =
```
    12*x - 6
```

>> **der3= diff(f,3)**
der3 =
```
    12
```

The basic rules of derivatives for function ***f*** and ***g*** are:

$$[f+g]' = f' + g'$$
$$[f-g]' = f' - g'$$
$$[fg]' = f'g + fg' \qquad \text{product rule}$$
$$\left[\frac{f}{g}\right]' = \frac{f'g - fg'}{g^2} \qquad \text{quotient rule}$$
$$[g(f)]' = g'(f)\cdot f' \qquad \text{chain rule}$$

Example 4.4: Two functions ***f(x)=2x²-x+2*** and ***g(x)=3x³-8***, prove the product rule ***(f . g)'=f'.g + f . g'***. Write a program to verify the result.

Sol:

```
syms x
f=2*x^2-x+2;                    % defining f(x)=2x^2-x+2
g=3*x^3-3*x;                    % defining g(x)=3x^3-3x
lhs=diff(f*g);
rhs= diff(f)*g+diff(g)*f;
if lhs==rhs                     % verify the product rule of derivative
    disp('the LHS is equal RHS and the result is :')
    disp(lhs)
else
    disp('there is an Error')
end
```

```
the LHS is equal RHS and the result is :
(9*x^2 - 3)*(2*x^2 - x + 2) - (4*x - 1)*(3*x - 3*x^3)
```

Example 4.5: Write a script to solve a problem. Given that a function ***y = f(x) = 3 sin(x) + 7 cos (5x)***. We will have to find out whether the equation ***f" + f = -5cos (2x)*** holds true.

Sol:

```
syms x
y =3*sin(x)+7*cos(5*x);         % defining the function
lhs = diff(y,2)+y;              % evaluating the lhs of the equation
rhs =-5*cos(2*x);               % rhs of the equation
if lhs==rhs
    disp('Yes, the equation holds true');
else
    disp('No, the equation does not hold true');
end
disp('Value of LHS is: ')
disp(lhs);
```

```
No, the equation does not hold true
Value of LHS is:
-168*cos(5*x)
```

Note: MATLAB provides the **dsolve** function for solving differential equations symbolically. The most basic form of the **dsolve** function for finding the solution to a single equation is: ***dsolve ('eqn')*** where ***eqn*** is a text string used to enter the equation. It returns a *symbolic* solution with *default* independent variable is ***t*** and a

set of arbitrary constants that MATLAB labels **C1**, **C2**, and so on. The equation: $f''(x) + 2f'(x) = 5\sin 3x$ should be *entered* as: **'D2y + 2Dy = 5*sin(3*x)'** where derivatives are indicated with a **"D"**. For example, the 1st differential equation:
y' =5y

```
>> s = dsolve ('Dy = 5*y')
s =
   C2*exp(5*t)
```

For 2nd differential equation: **y" - y = 0 , y(0) = -1 , y'(0) = 2.**

```
>> dsolve ('D2y - y = 0' , 'y(0) = -1' , 'Dy(0) = 2')
ans =
    exp(t)/2 - 3/(2*exp(t))
```

To substitute the variable ***t*** with any other variables, the expression should be:

```
>> dsolve ('D2y - y = 0' , 'y(0) = -1' , 'Dy(0) = 2' , 'x')
ans =
    exp(x)/2 - 3/(2*exp(x))
```

4.5.3 Integration

MATLAB provides an ***int*** function for calculating *integral* of an expression. For examples:

```
>> syms x
>> f=2*x;
>> int (f)
ans =
    x^2

>> syms x n
>> int(n^x)
ans =
    n^x/log(n)

>> int (x^n)
ans =
   piecewise([n = -1, log(x)], [n <> -1, x^(n + 1)/(n + 1)])

>> f= sin(n*x);
>> int(f)
ans =
    -cos(n*x)/n
```

```
>> syms a t
>> int (a*cos(pi*t))
ans =
     (a*sin(pi*t))/pi
```

```
>> syms x
>> f= int (x^5*cos(5*x))
f =
(24*cos(5*x))/3125 + (24*x*sin(5*x))/625 - (12*x^2*cos(5*x))/125
+ (x^4*cos(5*x))/5 - (4*x^3*sin(5*x))/25 + (x^5*sin(5*x))/5
```

As shown before, the result of integration function seems difficult to understand, so MATLAB provides the ***pretty*** function which returns an expression in a more readable format, for example:

```
>> pretty(f)
                                           2              4              3              5
 24 cos(5 x)    24 x sin(5 x)    12 x  cos(5 x)    x  cos(5 x)    4 x  sin(5 x)    x  sin(5 x)
 ----------- + ------------- - -------------- + ----------- - ------------- + -----------
    3125            625              125              5              25              5
```

The ***int*** function can be used for *definite* integration by passing the *limits* over which you want to calculate the integral. To calculate:

$$\int_a^b f(x)dx = f(b) - f(a)$$

The *syntax* of ***int*** function is: `int(x,a,b).` For example, to calculate the value of $\int_2^9 xdx$

```
>> syms x
>> int (x,2,9)
ans =
     77/2
```

<u>Example 4.6</u>: Calculate the *area* enclosed between the x-axis, and the curve $y = x^3-2x+5$ and the ordinates $x = 1$ and $x = 2$.

<u>Sol:</u>

The required area is given by : $A = \int_1^2 (x^3 - 2x + 5)dx$ and the commands are:

```
>> syms x
>> f =x^3-2*x+5;
>> area=int(f,1,2)
area =
     23/4
>> disp('Area = '), disp (double(area)) % converts and displays the result to a real number
Area =
```

```
    5.7500
```

Example 4.7: Find the area under the curve: $f(x) = x^2 \cos(x)$ for $-4 \le x \le 9$.

Sol:

```
>> f=x^2*cos(x);
>> area=int (f,-4,9)
area =
    8*cos(4) + 18*cos(9) + 14*sin(4) + 79*sin(9)

>> fprintf ('the area = %0.3f \n', double(area))
the area = 0.333
```

Exercises

Q1) Create the following symbolic ***expressions*** using either the ***sym*** or ***syms*** functions:

I. x^2-1
II. $(x+1)^2$
III. ax^2-2
IV. ax^2+bx+c
V. ax^3+bx^2+cx+d
VI. $\frac{y^2-x^2}{a\,xy^{(2b-c)}}$
VII. $sin^2x+cosy$
VIII. $tan^2y+\frac{sinx}{secy}$

Q2) Use the symbolic expressions from **Q1** to find:

1) Multiply **I** and **II** and named result ***y1***
2) Divide **I** by **II** and named result ***y2***
3) Add **III** and **IV** and named result ***y3***
4) Multiply **VII** and **VIII**, named result ***y4***
5) Divide **VII** by **VIII**, named result ***y5***
6) Use the ***factor***, ***expand***, ***collect*** and ***simplify*** functions on ***y1*** ,***y2*** , ***y3*** , ***y4*** and ***y5***.
7) Find the final result of **VII** ,**VIII** and ***y5*** when ***x=30°*** and ***y=70°***

Q3) Define series *symbolically* :

- $1\ \frac{1}{2}\ \frac{1}{3}\ \frac{1}{4}\dots\frac{1}{n}$
- $\frac{3}{1\times2}\ \frac{4}{2\times3}\ \frac{5}{3\times4}\dots\frac{(n+2)}{n\times(n+1)}$
- $-1\ -\frac{1}{3}\ -\frac{1}{9}\dots-\frac{1}{3^n}$
- $\frac{\pi}{2}\ \frac{2\pi}{2}\ \frac{3\pi}{2}\dots\frac{n\pi}{2}$
- $\frac{y}{x}\ \frac{y^2}{x^3}\ \frac{y^3}{x^5}\dots\frac{y^n}{x^{2n-1}}$

Q4) Use the variables and expressions in **Q1**:

- Use the ***solve*** function to solve **I** and **II**
- Use the ***solve*** function to solve **III** , for both ***x*** and ***a***,
- Find the value of ***x*** and ***a*** by solving both **II** and **III**. Then find the same values when (exp. **II** equals *3*) and (exp. **III** equals *5*)

Q5) Consider the following system of *linear* equations:

$$5x + 6y - 3z = 10$$
$$3x - 3y + 2z = 14$$
$$2x - 4y - 12z = 24$$

Use the ***solve*** function to solve for ***x***, ***y***, and ***z***, ***resolve*** equations using *linear algebra* techniques.

Q6) Consider the following *nonlinear* system of equations:

$$x^2 + 5y - 3z^3 = 15$$
$$4x + y^2 - z = 10$$
$$x + y + z = 15$$

Solve the *nonlinear* system with the ***solve*** function. Make your results more readable.

- Define a vector ***v*** of the even numbers from ***0*** to ***10***. *Substitute* this vector into **I** and **II**

Q7) Find the *1st* derivative of the following expressions:

$$x^2 + x - 1$$
$$\sin(x)$$
$$\tan(x)$$
$$\ln(x)$$

Q8) Find the *1st* and *2nd* partial derivatives with respect to ***x*** of the following expressions:

$$ax^2 + bx + c$$
$$x^{0.5} - 3y$$
$$\tan(x + y)$$
$$3x + 4y - 3xy$$
$$2y - 3x^2$$

Refined 2nd partial derivative with respect to ***y***

Q9) Integrate the expressions in **Q8** and **Q9** with respect to ***x***, then integrate the expressions in **Q9** with respect to ***y***

Q10) Perform a double integration with respect to y for each of the expressions in **Q9**

Q11) A college student goes to the cafeteria and buys lunch. The next day he spends twice as much. The third day he spends **$1** less than he did the second day. At the end of **3** days he has spent **$35**. How much did he spend each day? Solve this problem.

Q12) Consider the following set of ***seven*** equations:

$$
\begin{aligned}
3x_1 + 4x_2 + 2x_3 - x_4 + x_5 + 7x_6 + x_7 &= 42\\
2x_1 - 2x_2 + 3x_3 - 4x_4 + 5x_5 + 2x_6 + 8x_7 &= 32\\
x_1 + 2x_2 + 3x_3 + x_4 + 2x_5 + 4x_6 + 6x_7 &= 12\\
5x_1 + 10x_2 + 4x_3 + 3x_4 + 9x_5 - 2x_6 + x_7 &= -5\\
3x_1 + 2x_2 - 2x_3 - 4x_4 - 5x_5 - 6x_6 + 7x_7 &= 10\\
-2x_1 + 9x_2 + x_3 + 3x_4 - 3x_5 + 5x_6 + x_7 &= 18\\
x_1 - 2x_2 - 8x_3 + 4x_4 + 2x_5 + 4x_6 + 5x_7 &= 17
\end{aligned}
$$

Define a *symbolic* variable for each of the equations, and use MATLAB to *solve* for each unknown. **Compare** the amount of time it takes to solve the preceding problem by using symbolic math with the ***tic*** and ***toc*** functions, whose *syntax* is:

tic
⋮
code to be timed
⋮
toc

Q13) Determine the ***1st*** and ***2nd*** *derivatives* of the following functions:

- $f_1(x) = y = x^3 - 4x^2 + 3x + 8$
- $f_2(x) = y = (x^2 - 2x + 1)(x - 1)$
- $f_3(x) = y = \cos(2x)\sin(x)$
- $f_4(x) = y = 3xe^{4x^2}$

Q14) Use MATLAB symbolic functions to perform the following integrations:

$$\int (x^2 + 1)dx$$

$$\int_{0.2}^{1.3} (x^2 + x)dx$$

$$\int (x^2 + y^2)dx$$

$$\int_{3.5}^{21} (ax^2 + bx + c)dx$$

Q15) The following polynomial represent the ***altitude*** in meters during the first ***48*** hours following the launch of a ***weather balloon***:

$$h(t) = -0.12t^4 + 12t^3 - 380t^2 + 4100t + 220$$

Assume that the unit of ***t*** is hours.

1) Find the *velocity* which it's the ***1st*** *derivative* of the altitude to determine the equation for the velocity of the balloon.
2) Find the *acceleration* is the derivative of *velocity*, or the ***2nd*** *derivative* of the altitude, to determine the equation for the acceleration of the balloon.
3) Determine when the balloon hits the ground. Because ***h*(*t*)** is a *fourth-order* polynomial, there will be four answers. However, only one answer will be physically meaningful.
4) Determine the *maximum* height reached by the balloon. Use the fact that the *velocity* of the balloon is zero at the maximum height.