MATLAB
numerical computing

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About the Tutorial

MATLAB is a programming language developed by MathWorks. It started out as a matrix programming language where linear algebra programming was simple. It can be run both under interactive sessions and as a batch job.

This tutorial gives you aggressively a gentle introduction of MATLAB programming language. It is designed to give students fluency in MATLAB programming language. Problem-based MATLAB examples have been given in simple and easy way to make your learning fast and effective.

Audience

This tutorial has been prepared for the beginners to help them understand basic to advanced functionality of MATLAB. After completing this tutorial you will find yourself at a moderate level of expertise in using MATLAB from where you can take yourself to next levels.

Prerequisites

We assume you have a little knowledge of any computer programming and understand concepts like variables, constants, expressions, statements, etc. If you have done programming in any other high-level language like C, C++ or Java, then it will be very much beneficial and learning MATLAB will be like a fun for you.

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Table of Contents

1. OVERVIEW

MATLAB (matrix laboratory) is a fourth-generation high-level programming language and interactive environment for numerical computation, visualization and programming.

MATLAB is developed by MathWorks.

It allows matrix manipulations; plotting of functions and data; implementation of algorithms; creation of user interfaces; interfacing with programs written in other languages, including C, C++, Java, and FORTRAN; analyze data; develop algorithms; and create models and applications.

It has numerous built-in commands and math functions that help you in mathematical calculations, generating plots, and performing numerical methods.

MATLAB's Power of Computational Mathematics

MATLAB is used in every facet of computational mathematics. Following are some commonly used mathematical calculations where it is used most commonly:

- Dealing with Matrices and Arrays
- 2-D and 3-D Plotting and graphics
- Linear Algebra
- Algebraic Equations
- Non-linear Functions
- Statistics
- Data Analysis
- Calculus and Differential Equations
- Numerical Calculations
- Integration
- Transforms
- Curve Fitting
- Various other special functions

Features of MATLAB

Following are the basic features of MATLAB:

- It is a high-level language for numerical computation, visualization and application development.

- It also provides an interactive environment for <u>iterative</u> exploration, design and problem solving.

- It provides vast library of mathematical functions for linear algebra, statistics, Fourier analysis, filtering, optimization, numerical integration and solving ordinary differential equations.

- It provides built-in graphics for visualizing data and tools for creating custom plots.

- MATLAB's programming interface gives development tools for improving code quality, maintainability, and maximizing performance.

- It provides tools for building applications with custom graphical interfaces.

- It provides functions for integrating MATLAB based algorithms with external applications and languages such as C, Java, .NET and Microsoft Excel.

Uses of MATLAB

MATLAB is widely used as a computational tool in science and engineering encompassing the fields of physics, chemistry, math and all engineering streams. It is used in a range of applications including:

- signal processing and Communications

- image and video Processing

- control systems

- test and measurement

- computational finance

- computational biology

2. ENVIRONMENT

Local Environment Setup

Setting up MATLAB environment is a matter of few clicks. The installer can be downloaded from http://in.mathworks.com/downloads/web_downloads:

MathWorks provides the licensed product, a trial version and a student version as well. You need to log into the site and wait a little for their approval.

After downloading the installer the software can be installed through few clicks.
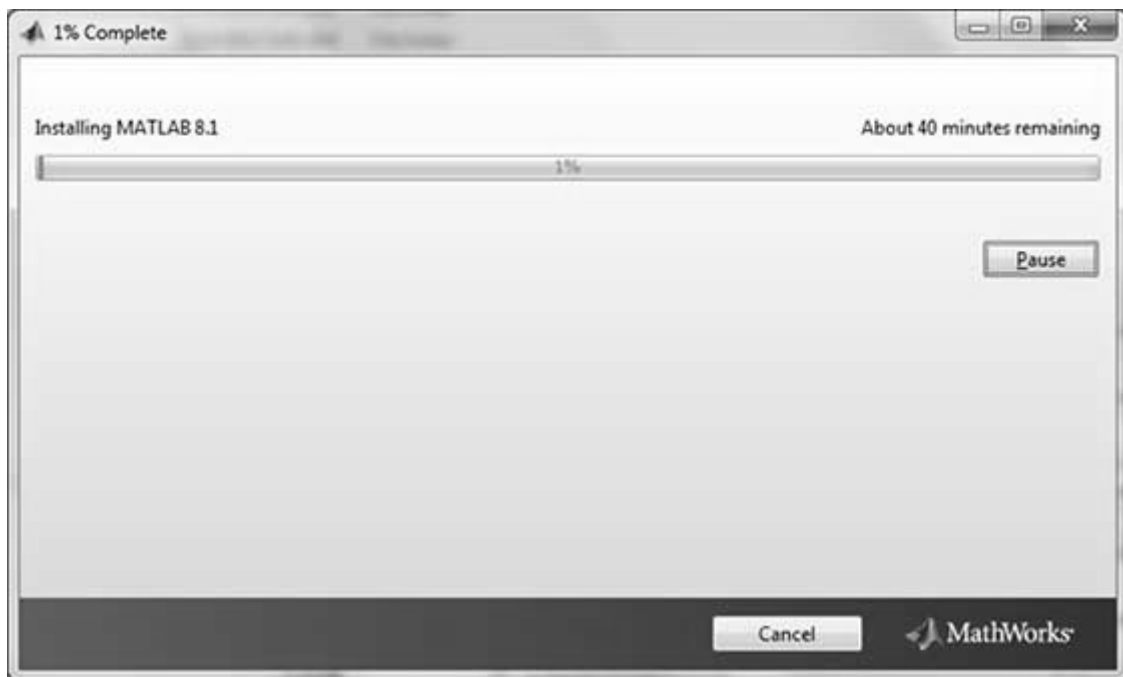
Understanding the MATLAB Environment

MATLAB development IDE can be launched from the icon created on the desktop. The main working window in MATLAB is called the desktop. When MATLAB is started, the desktop appears in its default layout:
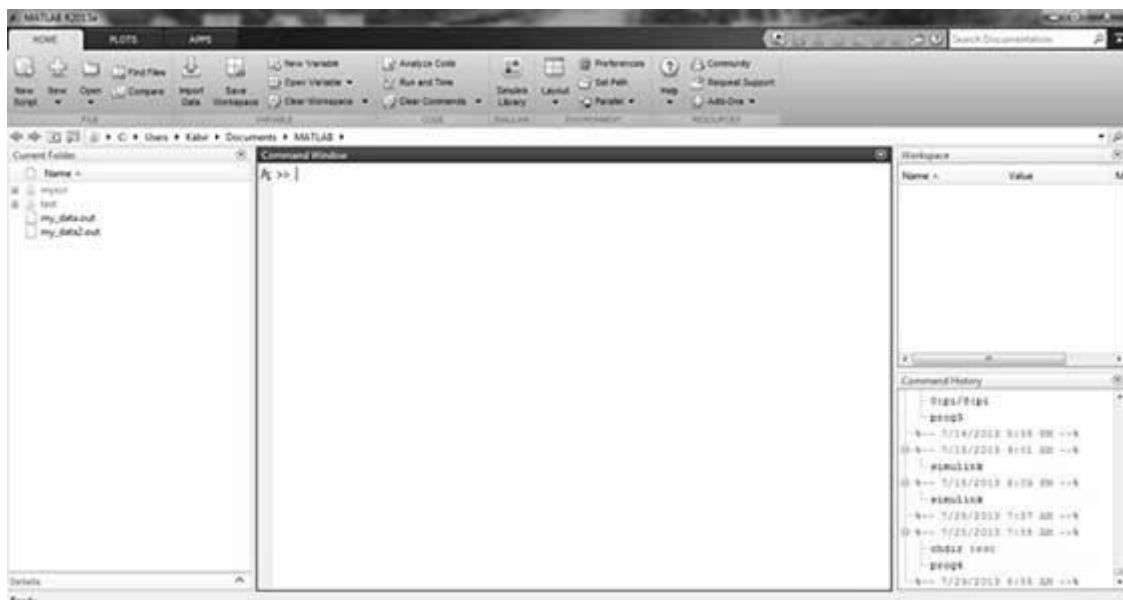
The desktop has the following panels:

Current Folder - This panel allows you to access the project folders and files.
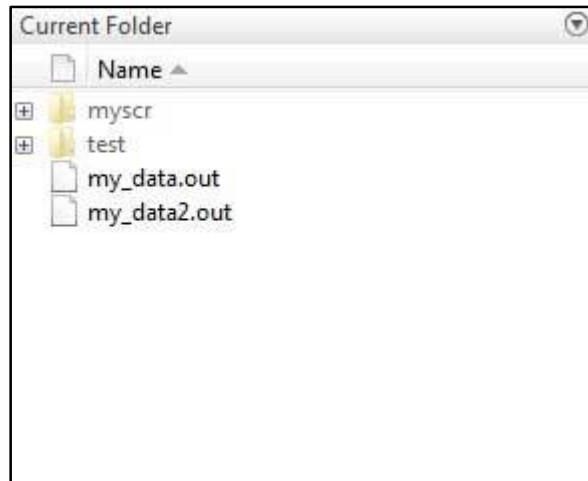
Command Window - This is the main area where commands can be entered at the command line. It is indicated by the command prompt (>>).
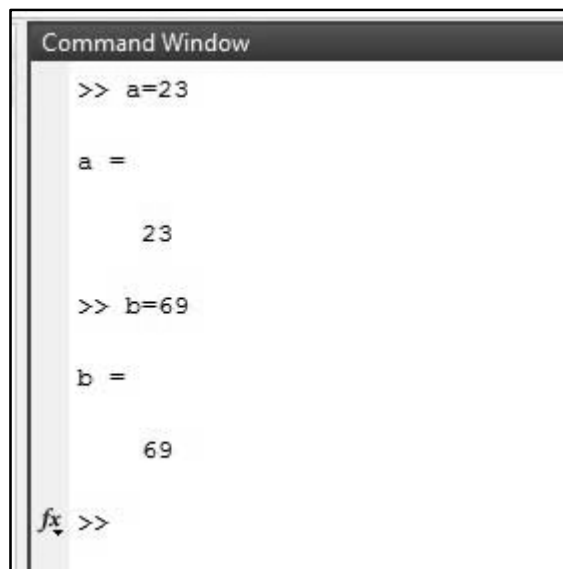
Workspace - The workspace shows all the variables created and/or imported from files.
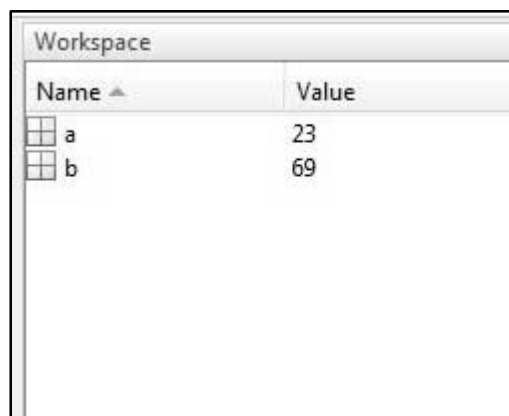
Command History - This panel shows or rerun commands that are entered at the command line.

Set up GNU Octave

If you are willing to use Octave on your machine (Linux, BSD, OS X or Windows), then kindly download latest version from http://www.gnu.org/software/octave/download.html. You can check the given installation instructions for your machine

3. BASIC SYNTAX

MATLAB environment behaves like a super-complex calculator. You can enter commands at the >> command prompt.

MATLAB is an interpreted environment. In other words, you give a command and MATLAB executes it right away.

Hands on Practice

Type a valid expression, for example,

```
5 + 5
```

And press ENTER

When you click the Execute button, or type Ctrl+E, MATLAB executes it immediately and the result returned is:

```
ans = 10
```

Let us take up few more examples:

```
3 ^ 2        % 3 raised to the power of 2
```

When you click the Execute button, or type Ctrl+E, MATLAB executes it immediately and the result returned is:

```
ans = 9
```

Another example,

```
sin(pi /2)     % sine of angle 90o
```

When you click the Execute button, or type Ctrl+E, MATLAB executes it immediately and the result returned is:

```
ans = 1
```

Another example,

```
7/0              % Divide by zero
```

When you click the Execute button, or type Ctrl+E, MATLAB executes it immediately and the result returned is:

```
ans = Inf

warning: division by zero
```

Another example,

```
732 * 20.3
```

When you click the Execute button, or type Ctrl+E, MATLAB executes it immediately and the result returned is:

```
ans =  1.4860e+04
```

MATLAB provides some special expressions for some mathematical symbols, like pi for π, Inf for ∞, i (and j) for √-1 etc. **Nan** stands for 'not a number'.

Use of Semicolon (;) in MATLAB

Semicolon (;) indicates end of statement. However, if you want to suppress and hide the MATLAB output for an expression, add a semicolon after the expression.

For example,

```
x = 3;

y = x + 5
```

When you click the Execute button, or type Ctrl+E, MATLAB executes it immediately and the result returned is:

```
y =  8
```

Adding Comments

The percent symbol (%) is used for indicating a comment line. For example,

```
x = 9      % assign the value 9 to x
```

You can also write a block of comments using the block comment operators % { and % }.

The MATLAB editor includes tools and context menu items to help you add, remove, or change the format of comments.

Commonly used Operators and Special Characters

MATLAB supports the following commonly used operators and special characters:

Operator	Purpose
+	Plus; addition operator.
-	Minus; subtraction operator.
*	Scalar and matrix multiplication operator.
.*	Array multiplication operator.
^	Scalar and matrix exponentiation operator.
.^	Array exponentiation operator.
****	Left-division operator.
/	Right-division operator.
.	Array left-division operator.
./	Array right-division operator.
:	Colon; generates regularly spaced elements and represents an entire row or column.

( )	Parentheses; encloses function arguments and array indices; overrides precedence.
[ ]	Brackets; enclosures array elements.
.	Decimal point.
...	Ellipsis; line-continuation operator
,	Comma; separates statements and elements in a row
;	Semicolon; separates columns and suppresses display.
%	Percent sign; designates a comment and specifies formatting.
_	Quote sign and transpose operator.
._	Non-conjugated transpose operator.
=	Assignment operator.

Special Variables and Constants

MATLAB supports the following special variables and constants:

Name	Meaning
ans	Most recent answer.
eps	Accuracy of floating-point precision.
i,j	The imaginary unit $\sqrt{-1}$.
Inf	Infinity.

NaN	Undefined numerical result (not a number).
pi	The number π

Naming Variables

Variable names consist of a letter followed by any number of letters, digits or underscore.

MATLAB is **case-sensitive**.

Variable names can be of any length, however, MATLAB uses only first N characters, where N is given by the function **namelengthmax**.

Saving Your Work

The **save** command is used for saving all the variables in the workspace, as a file with .mat extension, in the current directory.

For example,

```
save myfile
```

You can reload the file anytime later using the **load** command.

```
load myfile
```

4. VARIABLES

In MATLAB environment, every variable is an array or matrix.

You can assign variables in a simple way. For example,

```
x = 3        % defining x and initializing it with a value
```

MATLAB will execute the above statement and return the following result:

```
x =

     3
```

It creates a 1-by-1 matrix named *x* and stores the value 3 in its element. Let us check another example,

```
x = sqrt(16)      % defining x and initializing it with an expression
```

MATLAB will execute the above statement and return the following result:

```
x =

     4
```

Please note that:

Once a variable is entered into the system, you can refer to it later.

Variables must have values before they are used.

When an expression returns a result that is not assigned to any variable, the system assigns it to a variable named ans, which can be used later.

For example,

```
sqrt(78)
```

MATLAB will execute the above statement and return the following result:

```
ans =

    8.8318
```

You can use this variable *ans*:

```
9876/ans
```

MATLAB will execute the above statement and return the following result:

```
ans =

   1.1182e+03
```

Let's look at another example:

```
x = 7 * 8;

y = x * 7.89
```

MATLAB will execute the above statement and return the following result:

```
y =

  441.8400
```

Multiple Assignments

You can have multiple assignments on the same line. For example,

```
a = 2; b = 7; c = a * b;
```

MATLAB will execute the above statement and return the following result:

```
c =

    14
```

I have forgotten the Variables!

The **who** command displays all the variable names you have used.

```
who
```

MATLAB will execute the above statement and return the following result:

```
Your variables are:

a    ans  b    c    x    y
```

The **whos** command displays little more about the variables:

Variables currently in memory

Type of each variables

Memory allocated to each variable

Whether they are complex variables or not

```
whos
```

MATLAB will execute the above statement and return the following result:

```
  Name      Size            Bytes  Class     Attributes


  a         1x1                 8  double

  ans       1x1                 8  double

  b         1x1                 8  double

  c         1x1                 8  double

  x         1x1                 8  double

  y         1x1                 8  double
```

The **clear** command deletes all (or the specified) variable(s) from the memory.

```
clear x     % it will delete x, won't display anything

clear       % it will delete all variables in the workspace

            %  peacefully and unobtrusively
```

Long Assignments

Long assignments can be extended to another line by using an ellipses (...). For example,

```
initial_velocity = 0;

acceleration = 9.8;
```

```
time = 20;

final_velocity = initial_velocity ...

    + acceleration * time
```

MATLAB will execute the above statement and return the following result:

```
final_velocity =

   196
```

The format Command

By default, MATLAB displays numbers with four decimal place values. This is known as *short format*.

However, if you want more precision, you need to use the **format** command.

The **format long** command displays 16 digits after decimal.

For example:

```
format long
x = 7 + 10/3 + 5 ^ 1.2
```

MATLAB will execute the above statement and return the following result:

```
x =

   17.231981640639408
```

Another example,

```
format short
x = 7 + 10/3 + 5 ^ 1.2
```

MATLAB will execute the above statement and return the following result:

```
x =

   17.2320
```

The **format bank** command rounds numbers to two decimal places. For example,

```
format bank

daily_wage = 177.45;

weekly_wage = daily_wage * 6
```

MATLAB will execute the above statement and return the following result:

```
weekly_wage =

      1064.70
```

MATLAB displays large numbers using exponential notation.

The **format short e** command allows displaying in exponential form with four decimal places plus the exponent.

For example,

```
format short e

4.678 * 4.9
```

MATLAB will execute the above statement and return the following result:

```
ans =

   2.2922e+01
```

The **format long e** command allows displaying in exponential form with four decimal places plus the exponent. For example,

```
format long e

x = pi
```

MATLAB will execute the above statement and return the following result:

```
x =

    3.141592653589793e+00
```

The **format rat** command gives the closest rational expression resulting from a calculation. For example,

```
format rat
```

```
4.678 * 4.9
```

MATLAB will execute the above statement and return the following result:

```
ans =

   2063/90
```

Creating Vectors

A vector is a one-dimensional array of numbers. MATLAB allows creating two types of vectors:

Row vectors

Column vectors

Row vectors are created by enclosing the set of elements in square brackets, using space or comma to delimit the elements.

For example,

```
r = [7 8 9 10 11]
```

MATLAB will execute the above statement and return the following result:

```
r =

  Columns 1 through 4

     7              8              9             10

  Column 5

     11
```

Another example,

```
r = [7 8 9 10 11];

t = [2, 3, 4, 5, 6];

res = r + t
```

MATLAB will execute the above statement and return the following result:

```
res =

  Columns 1 through 4

      9           11           13           15

  Column 5

     17
```

Column vectors are created by enclosing the set of elements in square brackets, using semicolon (;) to delimit the elements.

```
c = [7;  8;  9;  10; 11]
```

MATLAB will execute the above statement and return the following result:

```
c =

     7

     8

     9

    10

    11
```

Creating Matrices

A matrix is a two-dimensional array of numbers.

In MATLAB, a matrix is created by entering each row as a sequence of space or comma separated elements, and end of a row is demarcated by a semicolon. For example, let us create a 3-by-3 matrix as:

```
m = [1 2 3; 4 5 6; 7 8 9]
```

MATLAB will execute the above statement and return the following result:

```
m =

     1           2           3

     4           5           6
```

7	8	9

5. COMMANDS

MATLAB is an interactive program for numerical computation and data visualization. You can enter a command by typing it at the MATLAB prompt '>>' on the **Command Window**.

In this section, we will provide lists of commonly used general MATLAB commands.

Commands for Managing a Session

MATLAB provides various commands for managing a session. The following table provides all such commands:

Command	Purpose
clc	Clears command window.
clear	Removes variables from memory.
exist	Checks for existence of file or variable.
global	Declares variables to be global.
help	Searches for a help topic.
lookfor	Searches help entries for a keyword.
quit	Stops MATLAB.
who	Lists current variables.
whos	Lists current variables (long display).

Commands for Working with the System

MATLAB provides various useful commands for working with the system, like saving the current work in the workspace as a file and loading the file later.

It also provides various commands for other system-related activities like, displaying date, listing files in the directory, displaying current directory, etc.

The following table displays some commonly used system-related commands:

Command	Purpose
cd	Changes current directory.
date	Displays current date.
delete	Deletes a file.
diary	Switches on/off diary file recording.
dir	Lists all files in current directory.
load	Loads workspace variables from a file.
path	Displays search path.
pwd	Displays current directory.
save	Saves workspace variables in a file.
type	Displays contents of a file.
what	Lists all MATLAB files in the current directory.
wklread	Reads .wk1 spreadsheet file.

Input and Output Commands

MATLAB provides the following input and output related commands:

Command	Purpose
disp	Displays contents of an array or string.
fscanf	Read formatted data from a file.
format	Controls screen-display format.
fprintf	Performs formatted writes to screen or file.
input	Displays prompts and waits for input.
;	Suppresses screen printing.

The **fscanf** and **fprintf** commands behave like C scanf and printf functions. They support the following format codes:

Format Code	Purpose
%s	Format as a string.
%d	Format as an integer.
%f	Format as a floating point value.
%e	Format as a floating point value in scientific notation.
%g	Format in the most compact form: %f or %e.
\n	Insert a new line in the output string.
\t	Insert a tab in the output string.

The format function has the following forms used for numeric display:

Format Function	Display up to
format short	Four decimal digits (default).
format long	16 decimal digits.
format short e	Five digits plus exponent.
format long e	16 digits plus exponents.
format bank	Two decimal digits.
format +	Positive, negative, or zero.
format rat	Rational approximation.
format compact	Suppresses some line feeds.
format loose	Resets to less compact display mode.

Vector, Matrix, and Array Commands

The following table shows various commands used for working with arrays, matrices and vectors:

Command	Purpose
cat	Concatenates arrays.
find	Finds indices of nonzero elements.
length	Computes number of elements.
linspace	Creates regularly spaced vector.

logspace	Creates logarithmically spaced vector.
max	Returns largest element.
min	Returns smallest element.
prod	Product of each column.
reshape	Changes size.
size	Computes array size.
sort	Sorts each column.
sum	Sums each column.
eye	Creates an identity matrix.
ones	Creates an array of ones.
zeros	Creates an array of zeros.
cross	Computes matrix cross products.
dot	Computes matrix dot products.
det	Computes determinant of an array.
inv	Computes inverse of a matrix.
pinv	Computes pseudoinverse of a matrix.
rank	Computes rank of a matrix.
rref	Computes reduced row echelon form.

cell	Creates cell array.
celldisp	Displays cell array.
cellplot	Displays graphical representation of cell array.
num2cell	Converts numeric array to cell array.
deal	Matches input and output lists.
iscell	Identifies cell array.

Plotting Commands

MATLAB provides numerous commands for plotting graphs. The following table shows some of the commonly used commands for plotting:

Command	Purpose
axis	Sets axis limits.
fplot	Intelligent plotting of functions.
grid	Displays gridlines.
plot	Generates xy plot.
print	Prints plot or saves plot to a file.
title	Puts text at top of plot.
xlabel	Adds text label to x-axis.
ylabel	Adds text label to y-axis.
axes	Creates axes objects.

close	Closes the current plot.
close all	Closes all plots.
figure	Opens a new figure window.
gtext	Enables label placement by mouse.
hold	Freezes current plot.
legend	Legend placement by mouse.
refresh	Redraws current figure window.
set	Specifies properties of objects such as axes.
subplot	Creates plots in sub windows.
text	Places string in figure.
bar	Creates bar chart.
loglog	Creates log-log plot.
polar	Creates polar plot.
semilogx	Creates semi log plot. (logarithmic abscissa).
semilogy	Creates semi log plot. (logarithmic ordinate).
stairs	Creates stairs plot.
stem	Creates stem plot.

6. M-FILES

So far, we have used MATLAB environment as a calculator. However, MATLAB is also a powerful programming language, as well as an interactive computational environment.

In previous chapters, you have learned how to enter commands from the MATLAB command prompt. MATLAB also allows you to write series of commands into a file and execute the file as complete unit, like writing a function and calling it.

The M Files

MATLAB allows writing two kinds of program files:

Scripts - script files are program files with **.m extension**. In these files, you write series of commands, which you want to execute together. Scripts do not accept inputs and do not return any outputs. They operate on data in the workspace.

Functions - functions files are also program files with **.m extension**. Functions can accept inputs and return outputs. Internal variables are local to the function.

You can use the MATLAB editor or any other text editor to create your **.m** files. In this section, we will discuss the script files. A script file contains multiple sequential lines of MATLAB commands and function calls. You can run a script by typing its name at the command line.

Creating and Running Script File

To create scripts files, you need to use a text editor. You can open the MATLAB editor in two ways:

Using the command prompt

Using the IDE

If you are using the command prompt, type **edit** in the command prompt. This will open the editor. You can directly type **edit** and then the filename (with .m extension)

```
edit

Or

edit <filename>
```

The above command will create the file in default MATLAB directory. If you want to store all program files in a specific folder, then you will have to provide the entire path.

Let us create a folder named progs. Type the following commands at the command prompt(>>):

```
mkdir progs    % create directory progs under default directory

chdir progs    % changing the current directory to progs

edit  prog1.m  % creating an m file named prog1.m
```

If you are creating the file for first time, MATLAB prompts you to confirm it. Click Yes.
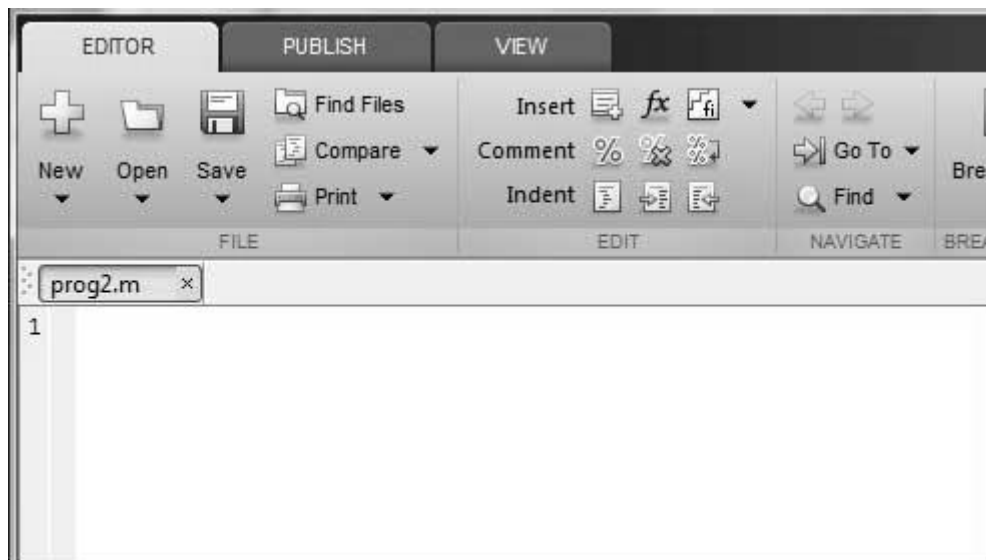
Alternatively, if you are using the IDE, choose NEW -> Script. This also opens the editor and creates a file named Untitled. You can name and save the file after typing the code.

Type the following code in the editor:

```
NoOfStudents = 6000;

TeachingStaff = 150;

NonTeachingStaff = 20;

Total = NoOfStudents + TeachingStaff ...

    + NonTeachingStaff;
```

```
disp(Total);
```

After creating and saving the file, you can run it in two ways:

Clicking the **Run** button on the editor window or

Just typing the filename (without extension) in the command prompt: >> prog1

The command window prompt displays the result:

```
6170
```

Example

Create a script file, and type the following code:

```
a = 5; b = 7;

c = a + b

d = c + sin(b)

e = 5 * d

f = exp(-d)
```

When the above code is compiled and executed, it produces the following result:

```
c =

    12

d =

   12.6570

e =

   63.2849

f =

   3.1852e-06
```

7. DATA TYPES

MATLAB does not require any type declaration or dimension statements. Whenever MATLAB encounters a new variable name, it creates the variable and allocates appropriate memory space.

If the variable already exists, then MATLAB replaces the original content with new content and allocates new storage space, where necessary.

For example,

```
Total = 42
```

The above statement creates a 1-by-1 matrix named 'Total' and stores the value 42 in it.

Data Types Available in MATLAB

MATLAB provides 15 fundamental data types. Every data type stores data that is in the form of a matrix or array. The size of this matrix or array is a minimum of 0-by-0 and this can grow up to a matrix or array of any size.

The following table shows the most commonly used data types in MATLAB:

Data Type	Description
int8	8-bit signed integer
uint8	8-bit unsigned integer
int16	16-bit signed integer
uint16	16-bit unsigned integer
int32	32-bit signed integer
uint32	32-bit unsigned integer
int64	64-bit signed integer

uint64	64-bit unsigned integer
single	single precision numerical data
double	double precision numerical data
logical	logical values of 1 or 0, represent true and false respectively
char	character data (strings are stored as vector of characters)
cell array	array of indexed cells, each capable of storing an array of a different dimension and data type
structure	C-like structures, each structure having named fields capable of storing an array of a different dimension and data type
function handle	pointer to a function
user classes	objects constructed from a user-defined class
java classes	objects constructed from a Java class

Example

Create a script file with the following code:

```
str = 'Hello World!'

n = 2345

d = double(n)

un = uint32(789.50)

rn = 5678.92347

c = int32(rn)
```

When the above code is compiled and executed, it produces the following result:

```
str =

Hello World!

n =

   2345

d =

   2345

un =

   790

rn =

   5.6789e+03

c =

   5679
```

Data Type Conversion

MATLAB provides various functions for converting a value from one data type to another. The following table shows the data type conversion functions:

Function	Purpose
Char	Convert to character array (string)
int2str	Convert integer data to string
mat2str	Convert matrix to string
num2str	Convert number to string
str2double	Convert string to double-precision value

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str2num	Convert string to number
native2unicode	Convert numeric bytes to Unicode characters
unicode2native	Convert Unicode characters to numeric bytes
base2dec	Convert base N number string to decimal number
bin2dec	Convert binary number string to decimal number
dec2base	Convert decimal to base N number in string
dec2bin	Convert decimal to binary number in string
dec2hex	Convert decimal to hexadecimal number in string
hex2dec	Convert hexadecimal number string to decimal number
hex2num	Convert hexadecimal number string to double-precision number
num2hex	Convert singles and doubles to IEEE hexadecimal strings
cell2mat	Convert cell array to numeric array
cell2struct	Convert cell array to structure array
cellstr	Create cell array of strings from character array
mat2cell	Convert array to cell array with potentially different sized cells
num2cell	Convert array to cell array with consistently sized cells
struct2cell	Convert structure to cell array

Determination of Data Types

MATLAB provides various functions for identifying data type of a variable.

Following table provides the functions for determining the data type of a variable:

Function	Purpose
is	Detect state
isa	Determine if input is object of specified class
iscell	Determine whether input is cell array
iscellstr	Determine whether input is cell array of strings
ischar	Determine whether item is character array
isfield	Determine whether input is structure array field
isfloat	Determine if input is floating-point array
ishghandle	True for Handle Graphics object handles
isinteger	Determine if input is integer array
isjava	Determine if input is Java object
islogical	Determine if input is logical array
isnumeric	Determine if input is numeric array
isobject	Determine if input is MATLAB object
isreal	Check if input is real array
isscalar	Determine whether input is scalar

isstr	Determine whether input is character array
isstruct	Determine whether input is structure array
isvector	Determine whether input is vector
class	Determine class of object
validateattributes	Check validity of array
whos	List variables in workspace, with sizes and types

Example

Create a script file with the following code:

```
x = 3

isinteger(x)

isfloat(x)

isvector(x)

isscalar(x)

isnumeric(x)


x = 23.54

isinteger(x)

isfloat(x)

isvector(x)

isscalar(x)

isnumeric(x)


x = [1 2 3]
```

```
isinteger(x)

isfloat(x)

isvector(x)

isscalar(x)


x = 'Hello'

isinteger(x)

isfloat(x)

isvector(x)

isscalar(x)

isnumeric(x)
```

When you run the file, it produces the following result:

```
x =

      3

ans =

      0

ans =

      1

ans =

      1

ans =

      1

ans =

      1

x =

   23.5400
```

```
ans =

     0

ans =

     1

ans =

     1

ans =

     1

ans =

     1

x =

     1     2     3

ans =

     0

ans =

     1

ans =

     1

ans =

     0

x =

Hello

ans =

     0

ans =

     0
```

```
ans =

        1

ans =

        0

ans =

        0
```

8. OPERATORS

An operator is a symbol that tells the compiler to perform specific mathematical or logical manipulations. MATLAB is designed to operate primarily on whole matrices and arrays. Therefore, operators in MATLAB work both on scalar and non-scalar data. MATLAB allows the following types of elementary operations:

Arithmetic Operators

Relational Operators

Logical Operators

Bitwise Operations

Set Operations

Arithmetic Operators

MATLAB allows two different types of arithmetic operations:

Matrix arithmetic operations

Array arithmetic operations

Matrix arithmetic operations are same as defined in linear algebra. Array operations are executed element by element, both on one-dimensional and multidimensional array.

The matrix operators and array operators are differentiated by the period (.) symbol. However, as the addition and subtraction operation is same for matrices and arrays, the operator is same for both cases. The following table gives brief description of the operators:

Operator	Description
+	Addition or unary plus. A+B adds the values stored in variables A and B. A and B must have the same size, unless one is a scalar. A scalar can be added to a matrix of any size.
-	Subtraction or unary minus. A-B subtracts the value of B from A. A and B must have the same size, unless one is a scalar. A scalar can be subtracted from a matrix of any size.

*	Matrix multiplication. C = A*B is the linear algebraic product of the matrices A and B. More precisely, $$C(i, j) = \sum_{k=1}^{n} A(i,k)B(k, j)$$ For non-scalar A and B, the number of columns of A must be equal to the number of rows of B. A scalar can multiply a matrix of any size.
.*	Array multiplication. A.*B is the element-by-element product of the arrays A and B. A and B must have the same size, unless one of them is a scalar.
/	Slash or matrix right division. B/A is roughly the same as B*inv(A). More precisely, B/A = (A'\B')'.
./	Array right division. A./B is the matrix with elements A(i,j)/B(i,j). A and B must have the same size, unless one of them is a scalar.
\	Backslash or matrix left division. If A is a square matrix, A\B is roughly the same as inv(A)*B, except it is computed in a different way. If A is an n-by-n matrix and B is a column vector with n components, or a matrix with several such columns, then X = A\B is the solution to the equation AX = B. A warning message is displayed if A is badly scaled or nearly singular.
.\	Array left division. A.\B is the matrix with elements B(i,j)/A(i,j). A and B must have the same size, unless one of them is a scalar.
^	Matrix power. X^p is X to the power p, if p is a scalar. If p is an integer, the power is computed by repeated squaring. If the integer is negative, X is inverted first. For other values of p, the calculation involves eigenvalues and eigenvectors, such that if [V,D] = eig(X), then X^p = V*D.^p/V.
.^	Array power. A.^B is the matrix with elements A(i,j) to the B(i,j) power. A and B must have the same size, unless one of them is a scalar.

'	Matrix transpose. A' is the linear algebraic transpose of A. For complex matrices, this is the complex conjugate transpose.
.'	Array transpose. A.' is the array transpose of A. For complex matrices, this does not involve conjugation.

Example

The following examples show the use of arithmetic operators on scalar data. Create a script file with the following code:

```
a = 10;

b = 20;

c = a + b

d = a - b

e = a * b

f = a / b

g = a \ b

x = 7;

y = 3;

z = x ^ y
```

When you run the file, it produces the following result:

```
c =

    30

d =

   -10

e =

   200

f =

    0.5000
```

```
g =

    2

z =

  343
```

Functions for Arithmetic Operations

Apart from the above-mentioned arithmetic operators, MATLAB provides the following commands/functions used for similar purpose:

Function	Description
uplus(a)	Unary plus; increments by the amount a
plus (a,b)	Plus; returns a + b
uminus(a)	Unary minus; decrements by the amount a
minus(a, b)	Minus; returns a - b
times(a, b)	Array multiply; returns a.*b
mtimes(a, b)	Matrix multiplication; returns a* b
rdivide(a, b)	Right array division; returns a ./ b
ldivide(a, b)	Left array division; returns a.\ b
mrdivide(A, B)	Solve systems of linear equations $xA = B$ for x
mldivide(A, B)	Solve systems of linear equations $Ax = B$ for x
power(a, b)	Array power; returns a.^b
mpower(a, b)	Matrix power; returns a ^ b

cumprod(A)	Cumulative product; returns an array of the same size as the array A containing the cumulative product. If A is a vector, then cumprod(A) returns a vector containing the cumulative product of the elements of A. If A is a matrix, then cumprod(A) returns a matrix containing the cumulative products for each column of A. If A is a multidimensional array, then cumprod(A) acts along the first non-singleton dimension.
cumprod(A, dim)	Returns the cumulative product along dimension *dim*.
cumsum(A)	Cumulative sum; returns an array A containing the cumulative sum. If A is a vector, then cumsum(A) returns a vector containing the cumulative sum of the elements of A. If A is a matrix, then cumsum(A) returns a matrix containing the cumulative sums for each column of A. If A is a multidimensional array, then cumsum(A) acts along the first non-singleton dimension.
cumsum(A, dim)	Returns the cumulative sum of the elements along dimension *dim*.
diff(X)	Differences and approximate derivatives; calculates differences between adjacent elements of X. If X is a vector, then diff(X) returns a vector, one element shorter than X, of differences between adjacent elements: [X(2)-X(1) X(3)-X(2) ... X(n)-X(n-1)] If X is a matrix, then diff(X) returns a matrix of row differences: [X(2:m,:)-X(1:m-1,:)]
diff(X,n)	Applies *diff* recursively n times, resulting in the nth difference.

diff(X,n,dim)	It is the nth difference function calculated along the dimension specified by scalar dim. If order n equals or exceeds the length of dimension dim, diff returns an empty array.
prod(A)	Product of array elements; returns the product of the array elements of A. If A is a vector, then prod(A) returns the product of the elements. If A is a nonempty matrix, then prod(A) treats the columns of A as vectors and returns a row vector of the products of each column. If A is an empty 0-by-0 matrix, prod(A) returns 1. If A is a multidimensional array, then prod(A) acts along the first non-singleton dimension and returns an array of products. The size of this dimension reduces to 1 while the sizes of all other dimensions remain the same. The prod function computes and returns B as single if the input, A, is single. For all other numeric and logical data types, prod computes and returns B as double
prod(A,dim)	Returns the products along dimension dim. For example, if A is a matrix, prod(A,2) is a column vector containing the products of each row.
prod(____,datatype)	Multiplies in and returns an array in the class specified by datatype.
sum(A)	Sum of array elements; returns sums along different dimensions of an array. If A is floating point, that is double or single, B is accumulated natively, that is in the same class as A, and B has the same class as A. If A is not floating point, B is accumulated in double and B has class double. If A is a vector, sum(A) returns the sum of the elements.

tutorialspoint
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	If A is a matrix, sum(A) treats the columns of A as vectors, returning a row vector of the sums of each column.
	If A is a multidimensional array, sum(A) treats the values along the first non-singleton dimension as vectors, returning an array of row vectors.
sum(A,dim)	Sums along the dimension of *A* specified by scalar *dim*.
sum(..., 'double') **sum(..., dim,'double')**	Perform additions in double-precision and return an answer of type double, even if A has data type single or an integer data type. This is the default for integer data types.
sum(..., 'native') **sum(..., dim,'native')**	Perform additions in the native data type of A and return an answer of the same data type. This is the default for single and double.
ceil(A)	Round toward positive infinity; rounds the elements of A to the nearest integers greater than or equal to A.
fix(A)	Round toward zero
floor(A)	Round toward negative infinity; rounds the elements of A to the nearest integers less than or equal to A.
idivide(a, b) **idivide(a, b,'fix')**	Integer division with rounding option; is the same as a./b except that fractional quotients are rounded toward zero to the nearest integers.
idivide(a, b, 'round')	Fractional quotients are rounded to the nearest integers.
idivide(A, B, 'floor')	Fractional quotients are rounded toward negative infinity to the nearest integers.

idivide(A, B, 'ceil')	Fractional quotients are rounded toward infinity to the nearest integers.
mod (X,Y)	Modulus after division; returns X - n.*Y where n = floor(X./Y). If Y is not an integer and the quotient X./Y is within round off error of an integer, then n is that integer. The inputs X and Y must be real arrays of the same size, or real scalars (provided Y ~=0). Please note: mod(X,0) is X mod(X,X) is 0 mod(X,Y) for X~=Y and Y~=0 has the same sign as Y
rem (X,Y)	Remainder after division; returns X - n.*Y where n = fix(X./Y). If Y is not an integer and the quotient X./Y is within round off error of an integer, then n is that integer. The inputs X and Y must be real arrays of the same size, or real scalars (provided Y ~=0). Please note that: rem(X,0) is NaN rem(X,X) for X~=0 is 0 rem(X,Y) for X~=Y and Y~=0 has the same sign as X.
round(X)	Round to nearest integer; rounds the elements of X to the nearest integers. Positive elements with a fractional part of 0.5 round up to the nearest positive integer. Negative elements with a fractional part of -0.5 round down to the nearest negative integer.

Relational Operators

Relational operators can also work on both scalar and non-scalar data. Relational operators for arrays perform element-by-element comparisons between two arrays and return a logical array of the same size, with elements set to logical 1 (true) where the relation is true and elements set to logical 0 (false) where it is not.

The following table shows the relational operators available in MATLAB:

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

Example

Create a script file and type the following code:

```
a = 100;

b = 200;

if (a >= b)

max = a

else

max = b

end
```

When you run the file, it produces following result:

```
max =

   200
```

Apart from the above-mentioned relational operators, MATLAB provides the following commands/functions used for the same purpose:

Function	Description
eq(a, b)	Tests whether a is equal to b
ge(a, b)	Tests whether a is greater than or equal to b
gt(a, b)	Tests whether a is greater than b
le(a, b)	Tests whether a is less than or equal to b
lt(a, b)	Tests whether a is less than b
ne(a, b)	Tests whether a is not equal to b
isequal	Tests arrays for equality
isequaln	Tests arrays for equality, treating NaN values as equal

Example

Create a script file and type the following code:

```
% comparing two values

a = 100;

b = 200;

if (ge(a,b))

max = a

else

max = b

end

% comparing two different values

a = 340;

b = 520;
```

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```
if (le(a, b))

disp(' a is either less than or equal to b')

else

disp(' a is greater than b')

end
```

When you run the file, it produces the following result:

```
max =

   200

 a is either less than or equal to b
```

Logical Operators

MATLAB offers two types of logical operators and functions:

Element-wise - These operators operate on corresponding elements of logical arrays.

Short-circuit - These operators operate on scalar and logical expressions.

Element-wise logical operators operate element-by-element on logical arrays. The symbols &, |, and ~ are the logical array operators AND, OR, and NOT.

Short-circuit logical operators allow short-circuiting on logical operations. The symbols && and || are the logical short-circuit operators AND and OR.

Example

Create a script file and type the following code:

```
a = 5;

b = 20;

   if ( a && b )

        disp('Line 1 - Condition is true');

   end

   if ( a || b )

        disp('Line 2 - Condition is true');
```

```
    end

    % lets change the value of a and b

    a = 0;

    b = 10;

    if ( a && b )

        disp('Line 3 - Condition is true');

    else

        disp('Line 3 - Condition is not true');

    end

    if (~(a && b))


        disp('Line 4 - Condition is true');

    end
```

When you run the file, it produces following result:

```
Line 1 - Condition is true

Line 2 - Condition is true

Line 3 - Condition is not true

Line 4 - Condition is true
```

Functions for Logical Operations

Apart from the above-mentioned logical operators, MATLAB provides the following commands or functions used for the same purpose:

Function	Description
and(A, B)	Finds logical AND of array or scalar inputs; performs a logical AND of all input arrays A, B, etc. and returns an array containing elements set to either logical 1 (true) or logical 0 (false). An

	element of the output array is set to 1 if all input arrays contain a nonzero element at that same array location. Otherwise, that element is set to 0.
not(A)	Finds logical NOT of array or scalar input; performs a logical NOT of input array A and returns an array containing elements set to either logical 1 (true) or logical 0 (false). An element of the output array is set to 1 if the input array contains a zero value element at that same array location. Otherwise, that element is set to 0.
or(A, B)	Finds logical OR of array or scalar inputs; performs a logical OR of all input arrays A, B, etc. and returns an array containing elements set to either logical 1 (true) or logical 0 (false). An element of the output array is set to 1 if any input arrays contain a nonzero element at that same array location. Otherwise, that element is set to 0.
xor(A, B)	Logical exclusive-OR; performs an exclusive OR operation on the corresponding elements of arrays A and B. The resulting element C(i,j,...) is logical true (1) if A(i,j,...) or B(i,j,...), but not both, is nonzero.
all(A)	Determine if all array elements of array A are nonzero or true. If A is a vector, all(A) returns logical 1 (true) if all the elements are nonzero and returns logical 0 (false) if one or more elements are zero. If A is a nonempty matrix, all(A) treats the columns of A as vectors, returning a row vector of logical 1's and 0's. If A is an empty 0-by-0 matrix, all(A) returns logical 1 (true). If A is a multidimensional array, all(A) acts along the first non-singleton dimension and returns an array of logical values. The size of this dimension

	reduces to 1 while the sizes of all other dimensions remain the same.
all(A, dim)	Tests along the dimension of A specified by scalar *dim*.
any(A)	Determine if any array elements are nonzero; tests whether any of the elements along various dimensions of an array is a nonzero number or is logical 1 (true). The *any* function ignores entries that are NaN (Not a Number).
	If A is a vector, any(A) returns logical 1 (true) if any of the elements of A is a nonzero number or is logical 1 (true), and returns logical 0 (false) if all the elements are zero.
	If A is a nonempty matrix, any(A) treats the columns of A as vectors, returning a row vector of logical 1's and 0's.
	If A is an empty 0-by-0 matrix, any(A) returns logical 0 (false).
	If A is a multidimensional array, any(A) acts along the first non-singleton dimension and returns an array of logical values. The size of this dimension reduces to 1 while the sizes of all other dimensions remain the same.
any(A,dim)	Tests along the dimension of A specified by scalar *dim*.
False	Logical 0 (false)
false(n)	is an n-by-n matrix of logical zeros
false(m, n)	is an m-by-n matrix of logical zeros.
false(m, n, p, ...)	is an m-by-n-by-p-by-... array of logical zeros.

false(size(A))	is an array of logical zeros that is the same size as array A.
false(...,'like',p)	is an array of logical zeros of the same data type and sparsity as the logical array p.
ind = find(X)	Find indices and values of nonzero elements; locates all nonzero elements of array X, and returns the linear indices of those elements in a vector. If X is a row vector, then the returned vector is a row vector; otherwise, it returns a column vector. If X contains no nonzero elements or is an empty array, then an empty array is returned.
ind = find(X, k) **ind = find(X, k, 'first')**	Returns at most the first k indices corresponding to the nonzero entries of X. k must be a positive integer, but it can be of any numeric data type.
ind = find(X, k, 'last')	returns at most the last k indices corresponding to the nonzero entries of X.
[row,col] = find(X, ...)	Returns the row and column indices of the nonzero entries in the matrix X. This syntax is especially useful when working with sparse matrices. If X is an N-dimensional array with N > 2, col contains linear indices for the columns.
[row,col,v] = find(X, ...)	Returns a column or row vector v of the nonzero entries in X, as well as row and column indices. If X is a logical expression, then v is a logical array. Output v contains the non-zero elements of the logical array obtained by evaluating the expression X.
islogical(A)	Determine if input is logical array; returns true if A is a logical array and false otherwise. It also returns true if A is an instance of a class that is derived from the logical class.

logical(A)	Convert numeric values to logical; returns an array that can be used for logical indexing or logical tests.
True	Logical 1 (true)
true(n)	is an n-by-n matrix of logical ones.
true(m, n)	is an m-by-n matrix of logical ones.
true(m, n, p, ...)	is an m-by-n-by-p-by-... array of logical ones.
true(size(A))	is an array of logical ones that is the same size as array A.
true(...,'like', p)	is an array of logical ones of the same data type and sparsity as the logical array p.

Example

Create a script file and type the following code:

```
a = 60; % 60 = 0011 1100

b = 13; % 13 = 0000 1101

c = bitand(a, b)      % 12 = 0000 1100

c = bitor(a, b)       % 61 = 0011 1101

c = bitxor(a, b)      % 49 = 0011 0001

c = bitshift(a, 2)    % 240 = 1111 0000 */

c = bitshift(a,-2)     % 15 = 0000 1111 */
```

When you run the file, it displays the following result:

```
c =

    12

c =
```

```
     61

c =

     49

c =

    240

c =

     15
```

Bitwise Operations

Bitwise operators work on bits and perform bit-by-bit operation. The truth tables for &, |, and ^ are as follows:

p	q	p & q	p | q	p ^ q
0	0	0	0	0
0	1	0	1	1
1	1	1	1	0
1	0	0	1	1

Assume if A = 60; and B = 13; Now in binary format they will be as follows:

A = 0011 1100

B = 0000 1101

A&B = 0000 1100

A|B = 0011 1101

A^B = 0011 0001

~A = 1100 0011

MATLAB provides various functions for bit-wise operations like 'bitwise and', 'bitwise or' and 'bitwise not' operations, shift operation, etc.

The following table shows the commonly used bitwise operations:

Function	Purpose
bitand(a, b)	Bit-wise AND of integers *a* and *b*
bitcmp(a)	Bit-wise complement of *a*
bitget(a,pos)	Get bit at specified position *pos*, in the integer array *a*
bitor(a, b)	Bit-wise OR of integers *a* and *b*
bitset(a, pos)	Set bit at specific location *pos* of *a*
bitshift(a, k)	Returns *a* shifted to the left by *k* bits, equivalent to multiplying by 2^k. Negative values of k correspond to shifting bits right or dividing by $2^{|k|}$ and rounding to the nearest integer towards negative infinite. Any overflow bits are truncated.
bitxor(a, b)	Bit-wise XOR of integers *a* and *b*
swapbytes	Swap byte ordering

Example

Create a script file and type the following code:

```
a = 60; % 60 = 0011 1100

b = 13; % 13 = 0000 1101

c = bitand(a, b)      % 12 = 0000 1100

c = bitor(a, b)       % 61 = 0011 1101

c = bitxor(a, b)      % 49 = 0011 0001

c = bitshift(a, 2)    % 240 = 1111 0000 */

c = bitshift(a,-2)     % 15 = 0000 1111 */
```

When you run the file, it displays the following result:

```
c =

    12

c =

    61

c =

    49

    240

c =

    15
```

Set Operations

MATLAB provides various functions for set operations, like union, intersection and testing for set membership, etc.

The following table shows some commonly used set operations:

Function	Description
intersect(A,B)	Set intersection of two arrays; returns the values common to both A and B. The values returned are in sorted order.
intersect(A,B,'rows')	Treats each row of A and each row of B as single entities and returns the rows common to both A and B. The rows of the returned matrix are in sorted order.
ismember(A,B)	Returns an array the same size as A, containing 1 (true) where the elements of A are found in B. Elsewhere, it returns 0 (false).

57

ismember(A,B,'rows')	Treats each row of A and each row of B as single entities and returns a vector containing 1 (true) where the rows of matrix A are also rows of B. Elsewhere, it returns 0 (false).
issorted(A)	Returns logical 1 (true) if the elements of A are in sorted order and logical 0 (false) otherwise. Input A can be a vector or an N-by-1 or 1-by-N cell array of strings. A is considered to be sorted if A and the output of sort(A) are equal.
issorted(A, 'rows')	Returns logical 1 (true) if the rows of two-dimensional matrix A are in sorted order, and logical 0 (false) otherwise. Matrix A is considered to be sorted if A and the output of sortrows(A) are equal.
setdiff(A,B)	Sets difference of two arrays; returns the values in A that are not in B. The values in the returned array are in sorted order.
setdiff(A,B,'rows')	Treats each row of A and each row of B as single entities and returns the rows from A that are not in B. The rows of the returned matrix are in sorted order. The 'rows' option does not support cell arrays.
setxor	Sets exclusive OR of two arrays
union	Sets union of two arrays
unique	Unique values in array

Example

Create a script file and type the following code:

```
a = [7 23 14 15 9 12 8 24 35]

b = [ 2 5 7 8 14 16 25 35 27]

u = union(a, b)
```

```
i = intersect(a, b)

s = setdiff(a, b)
```

When you run the file, it produces the following result:

```
a =

    7    23    14    15     9    12     8    24    35

b =

    2     5     7     8    14    16    25    35    27

u =

  Columns 1 through 11

    2     5     7     8     9    12    14    15    16    23    24

  Columns 12 through 14

   25    27    35

i =

    7     8    14    35

s =

    9    12    15    23    24
```

59

9. DECISION MAKING

Decision making structures require that the programmer should specify one or more conditions to be evaluated or tested by the program, along with a statement or statements to be executed if the condition is determined to be true, and optionally, other statements to be executed if the condition is determined to be false.

Following is the general form of a typical decision making structure found in most of the programming languages:
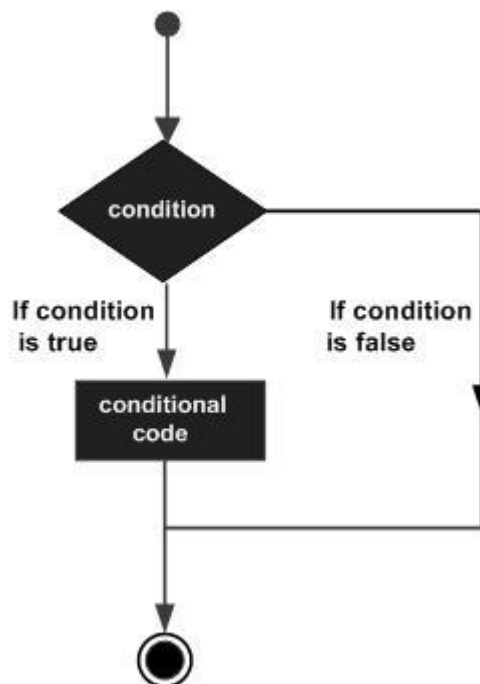
MATLAB provides following types of decision making statements. Click the following links to check their detail:

Statement	Description
if ... end statement	An if ... end statement consists of a boolean expression followed by one or more statements.
if...else...end statement	An if statement can be followed by an optional else statement, which executes when the boolean expression is false.

60

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If... elseif...elseif...else...end statements	An if statement can be followed by one (or more) optional elseif... and an else statement, which is very useful to test various conditions.
nested if statements	You can use one if or elseif statement inside another if or elseif statement(s).
switch statement	A switch statement allows a variable to be tested for equality against a list of values.
nested switch statements	You can use one switch statement inside another switch statement(s).

if... end Statement

An **if ... end** statement consists of an **if** statement and a boolean expression followed by one or more statements. It is delimited by the **end** statement.

Syntax

The syntax of an if statement in MATLAB is:

```
if <expression>

% statement(s) will execute if the boolean expression is true

<statements>

end
```

If the expression evaluates to true, then the block of code inside the if statement will be executed. If the expression evaluates to false, then the first set of code after the end statement will be executed.

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Flow Diagram

Example

Create a script file and type the following code:

```
a = 10;
% check the condition using if statement
   if a < 20
   % if condition is true then print the following
      fprintf('a is less than 20\n' );
   end
fprintf('value of a is : %d\n', a);
```

When you run the file, it displays the following result:

```
a is less than 20
value of a is : 10
```

if...else...end Statement

An if statement can be followed by an optional else statement, which executes when the expression is false.

Syntax

The syntax of an if...else statement in MATLAB is:

```
if <expression>

% statement(s) will execute if the boolean expression is true

<statement(s)>

else

<statement(s)>

% statement(s) will execute if the boolean expression is false

end
```

If the boolean expression evaluates to true, then the if block of code will be executed, otherwise else block of code will be executed.

Flow Diagram
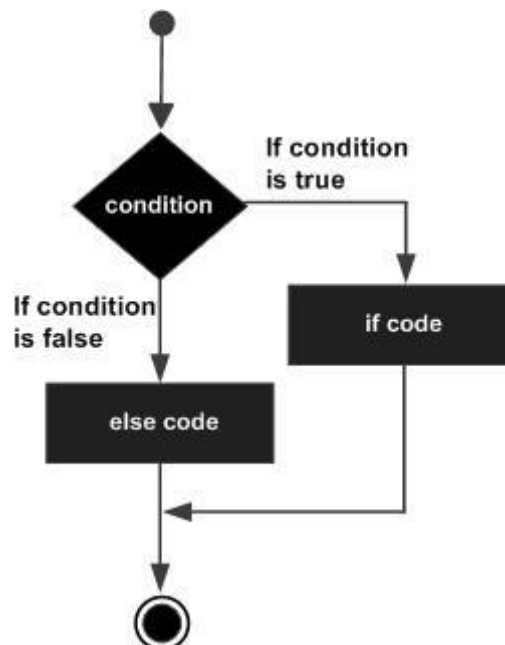
Example

Create a script file and type the following code:

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```
a = 100;

% check the boolean condition

  if a < 20

      % if condition is true then print the following

      fprintf('a is less than 20\n' );

  else

      % if condition is false then print the following

      fprintf('a is not less than 20\n' );

  end

  fprintf('value of a is : %d\n', a);
```

When the above code is compiled and executed, it produces the following result:

```
a is not less than 20

value of a is : 100
```

if...elseif...elseif...else...end Statements

An **if** statement can be followed by one (or more) optional **elseif...** and an **else** statement, which is very useful to test various conditions.

When using if... elseif...else statements, there are few points to keep in mind:

An if can have zero or one else's and it must come after any elseif's.

An if can have zero to many elseif's and they must come before the else.

Once an else if succeeds, none of the remaining elseif's or else's will be tested.

Syntax

```
if <expression 1>

% Executes when the expression 1 is true

<statement(s)>

elseif <expression 2>

% Executes when the boolean expression 2 is true
```

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```
<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

Create a script file and type the following code in it:

```
a = 100;

%check the boolean condition

   if a == 10

        % if condition is true then print the following

      fprintf('Value of a is 10\n' );

   elseif( a == 20 )

      % if else if condition is true

      fprintf('Value of a is 20\n' );

    elseif a == 30

       % if else if condition is true

      fprintf('Value of a is 30\n' );

   else

       % if none of the conditions is true '

        fprintf('None of the values are matching\n');

    fprintf('Exact value of a is: %d\n', a );
```

```
    end
```

When the above code is compiled and executed, it produces the following result:

```
None of the values are matching

Exact value of a is: 100
```

The Nested if Statements

It is always legal in MATLAB to nest if-else statements which means you can use one if or elseif statement inside another if or elseif statement(s).

Syntax

The syntax for a nested if statement is as follows:

```
if <expression 1>

% Executes when the boolean expression 1 is true

   if <expression 2>

      % Executes when the boolean expression 2 is true

   end

end
```

You can nest elseif...else in the similar way as you have nested if statement.

Example

Create a script file and type the following code in it:

```
a = 100;

b = 200;

   % check the boolean condition

  if( a == 100 )


      % if condition is true then check the following

      if( b == 200 )
```

```
        % if condition is true then print the following

        fprintf('Value of a is 100 and b is 200\n' );

    end


  end

  fprintf('Exact value of a is : %d\n', a );

  fprintf('Exact value of b is : %d\n', b );
```

When you run the file, it displays:

```
Value of a is 100 and b is 200

Exact value of a is : 100

Exact value of b is : 200
```

The switch Statement

A switch block conditionally executes one set of statements from several choices. Each choice is covered by a case statement.

An evaluated switch_expression is a scalar or string.

An evaluated case_expression is a scalar, a string or a cell array of scalars or strings.

The switch block tests each case until one of the cases is true. A case is true when:

For numbers, eq(case_expression,switch_expression).

For strings, strcmp(case_expression,switch_expression).

For objects that support the eq function,eq(case_expression,switch_expression).

For a cell array case_expression, at least one of the elements of the cell array matches switch_expression, as defined above for numbers, strings and objects.

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.

Syntax

The syntax of switch statement in MATLAB is:

```
switch <switch_expression>

   case <case_expression>

     <statements>

   case <case_expression>

     <statements>

     ...

     ...

   otherwise

       <statements>

end
```

Example

Create a script file and type the following code in it:

```
grade = 'B';

   switch(grade)

   case 'A'

     fprintf('Excellent!\n' );

   case 'B'

      fprintf('Well done\n' );

   case 'C'

     fprintf('Well done\n' );

   case 'D'

     fprintf('You passed\n' );


   case 'F'

     fprintf('Better try again\n' );
```

68

```
   otherwise

     fprintf('Invalid grade\n' );

   end
```

When you run the file, it displays:

```
Well done

Your grade is  B
```

The Nested Switch Statements

It is possible to have a switch as part of the statement sequence of an outer switch. Even if the case constants of the inner and outer switch contain common values, no conflicts will arise.

Syntax

The syntax for a nested switch statement is as follows:

```
switch(ch1)

   case 'A'

   fprintf('This A is part of outer switch');

      switch(ch2)

        case 'A'

          fprintf('This A is part of inner switch' );

         case 'B'

         fprintf('This B is part of inner switch' );

      end

case 'B'

fprintf('This B is part of outer switch' );

end
```

Example

Create a script file and type the following code in it:

```
a = 100;

b = 200;

switch(a)

    case 100

       fprintf('This is part of outer switch %d\n', a );

       switch(b)

         case 200

            fprintf('This is part of inner switch %d\n', a );

       end

end

fprintf('Exact value of a is : %d\n', a );

fprintf('Exact value of b is : %d\n', b );
```

When you run the file, it displays:

```
This is part of outer switch 100

This is part of inner switch 100

Exact value of a is : 100

Exact value of b is : 200
```

10. LOOP TYPES

There may be a situation when you need to execute a block of code several number of times. In general, statements are executed sequentially. The first statement in a function is executed first, followed by the second, and so on.

Programming languages provide various control structures that allow for more complicated execution paths.

A loop statement allows us to execute a statement or group of statements multiple times and following is the general form of a loop statement in most of the programming languages:
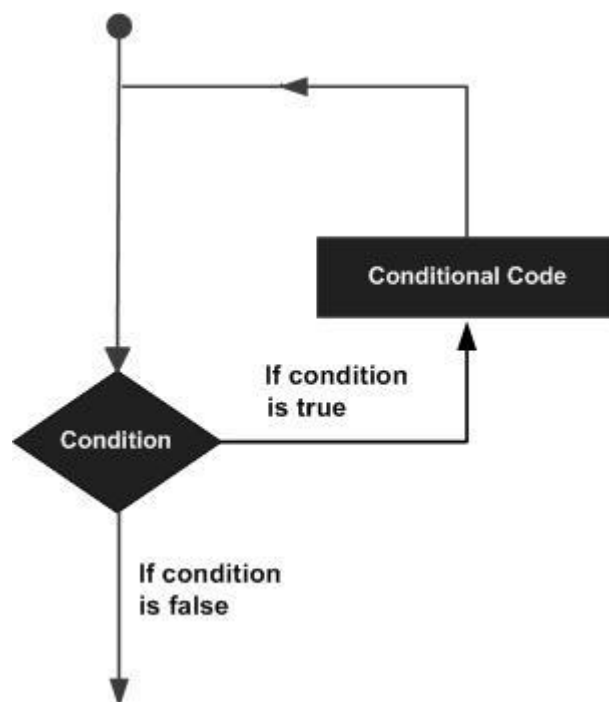
MATLAB provides following types of loops to handle looping requirements. Click the following links to check their detail:

Loop Type	Description
while loop	Repeats a statement or group of statements while a given condition is true. It tests the condition before executing the loop body.

for loop	Executes a sequence of statements multiple times and abbreviates the code that manages the loop variable.
nested loops	You can use one or more loops inside any another loop.

The while Loop

The while loop repeatedly executes statements while condition is true.

Syntax

The syntax of a while loop in MATLAB is:

```
while <expression>

   <statements>

end
```

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

An expression is true when the result is nonempty and contains all nonzero elements (logical or real numeric). Otherwise, the expression is false.

Example

Create a script file and type the following code:

```
a = 10;

% while loop execution

while( a < 20 )

  fprintf('value of a: %d\n', a);

  a = a + 1;

end
```

When you run the file, it displays the following result:

```
value of a: 10

value of a: 11
```

```
value of a: 12

value of a: 13

value of a: 14

value of a: 15

value of a: 16

value of a: 17

value of a: 18

value of a: 19
```

The for Loop

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.

Syntax

The syntax of a **for loop** in MATLAB is:

```
for index = values

   <program statements>

        ...

end
```

values has one of the following forms:

Format	Description
initval:endval	increments the index variable from *initval* to *endval* by 1, and repeats execution of *program statements* until *index* is greater than *endval*.
initval:step:endval	increments *index* by the value step on each iteration, or decrements when step is negative.

valArray	creates a column vector *index* from subsequent columns of array*valArray* on each iteration. For example, on the first iteration, index = valArray(:,1). The loop executes for a maximum of n times, where n is the number of columns of *valArray*, given by numel(valArray, 1, :). The input *valArray* can be of any MATLAB data type, including a string, cell array, or struct.

Example 1

Create a script file and type the following code:

```
for a = 10:20

  fprintf('value of a: %d\n', a);

end
```

When you run the file, it displays the following result:

```
value of a: 10

value of a: 11

value of a: 12

value of a: 13

value of a: 14

value of a: 15

value of a: 16

value of a: 17

value of a: 18

value of a: 19

value of a: 20
```

Example 2

Create a script file and type the following code:

```
for a = 1.0: -0.1: 0.0

   disp(a)

end
```

When you run the file, it displays the following result:

```
1

   0.9000

   0.8000

   0.7000

   0.6000

   0.5000

   0.4000

   0.3000

   0.2000

   0.1000
```

```
   0
```

Example 3

Create a script file and type the following code:

```
for a = [24,18,17,23,28]
    disp(a)
end
```

When you run the file, it displays the following result:

```
   24


   18


   17


   23


   28
```

The Nested Loops

MATLAB allows to use one loop inside another loop. Following section shows few examples to illustrate the concept.

Syntax

The syntax for a nested for loop statement in MATLAB is as follows:

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

```
end
```

The syntax for a nested while loop statement in MATLAB is as follows:

```
while <expression1>

   while <expression2>

      <statements>

   end

end
```

Example

Let us use a nested for loop to display all the prime numbers from 1 to 100. Create a script file and type the following code:

```
for i=2:100

      for j=2:100

       if(~mod(i,j))

            break; % if factor found, not prime

        end

      end

      if(j > (i/j))

         fprintf('%d is prime\n', i);

      end

end
```

When you run the file, it displays the following result:

```
2 is prime

3 is prime

5 is prime

7 is prime
```

```
11 is prime

13 is prime

17 is prime

19 is prime

23 is prime

29 is prime

31 is prime

37 is prime

41 is prime

43 is prime

47 is prime

53 is prime

59 is prime

61 is prime

67 is prime

71 is prime

73 is prime

79 is prime

83 is prime

89 is prime

97 is prime
```

Loop Control Statements

Loop control statements change execution from its normal sequence. When execution leaves a scope, all automatic objects that were created in that scope are destroyed.

MATLAB supports the following control statements. Click the following links to check their detail.

Control Statement	Description
break statement	Terminates the loop statement and transfers execution to the statement immediately following the loop.
continue statement	Causes the loop to skip the remainder of its body and immediately retest its condition prior to reiterating.

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.

Flow Diagram
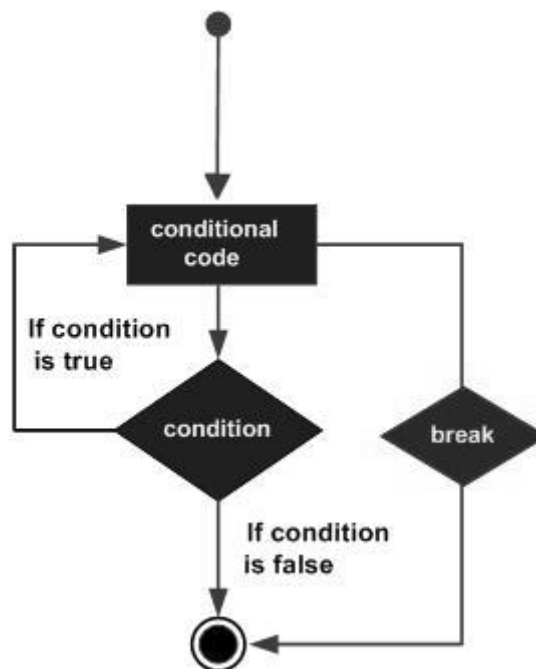
Example

Create a script file and type the following code:

```
a = 10;

% while loop execution

 while (a < 20 )

     fprintf('value of a: %d\n', a);

     a = a+1;

     if( a > 15)

        % terminate the loop using break statement

         break;

     end

  end
```

When you run the file, it displays the following result:

```
value of a: 10

value of a: 11

value of a: 12

value of a: 13

value of a: 14

value of a: 15
```

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.

Flow Diagram

Example

Create a script file and type the following code:

```
a = 10;

%while loop execution

while a < 20

  if a == 15

      % skip the iteration

      a = a + 1;

      continue;

  end

  fprintf('value of a: %d\n', a);

  a = a + 1;

end
```

When you run the file, it displays the following result:

```
value of a: 10

value of a: 11

value of a: 12

value of a: 13

value of a: 14

value of a: 16

value of a: 17

value of a: 18

value of a: 19
```
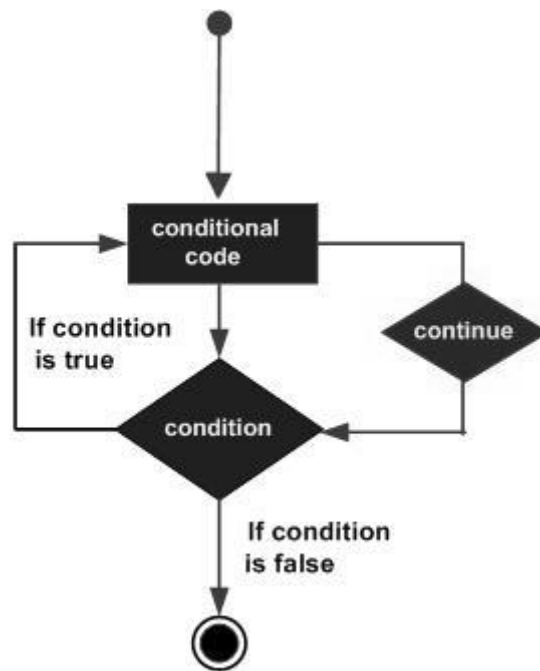
11. VECTORS

A vector is a one-dimensional array of numbers. MATLAB allows creating two types of vectors:

Row vectors

Column vectors

Row Vectors

Row vectors are created by enclosing the set of elements in square brackets, using space or comma to delimit the elements.

```
r = [7 8 9 10 11]
```

MATLAB will execute the above statement and return the following result:

```
r =

  Columns 1 through 4

      7            8            9           10

  Column 5

     11
```

Column Vectors

Column vectors are created by enclosing the set of elements in square brackets, using semicolon to delimit the elements.

```
c = [7;  8;  9;  10; 11]
```

MATLAB will execute the above statement and return the following result:

```
c =

      7

      8
```

```
    9

   10

   11
```

Referencing the Elements of a Vector

You can reference one or more of the elements of a vector in several ways. The i[th]component of a vector v is referred as v(i). For example:

```
v = [ 1; 2; 3; 4; 5; 6]; % creating a column vector of 6 elements

v(3)
```

MATLAB will execute the above statement and return the following result:

```
ans =

    3
```

When you reference a vector with a colon, such as v(:), all the components of the vector are listed.

```
v = [ 1; 2; 3; 4; 5; 6]; % creating a column vector of 6 elements

v(:)
```

MATLAB will execute the above statement and return the following result:

```
ans =

    1

    2

    3

    4

    5

    6
```

MATLAB allows you to select a range of elements from a vector.

For example, let us create a row vector *rv* of 9 elements, then we will reference the elements 3 to 7 by writing **rv(3:7)** and create a new vector named *sub_rv*.

```
rv = [1 2 3 4 5 6 7 8 9];

sub_rv = rv(3:7)
```

MATLAB will execute the above statement and return the following result:

```
sub_rv =

     3     4     5     6     7
```

Vector Operations

In this section, let us discuss the following vector operations:

Addition and Subtraction of Vectors

Scalar Multiplication of Vectors

Transpose of a Vector

Appending Vectors

Magnitude of a Vector

Vector Dot Product

Vectors with Uniformly Spaced Elements

Addition and Subtraction of Vectors

You can add or subtract two vectors. Both the operand vectors must be of same type and have same number of elements.

Example

Create a script file with the following code:

```
A = [7, 11, 15, 23, 9];

B = [2, 5, 13, 16, 20];

C = A + B;

D = A - B;
```

```
disp(C);

disp(D);
```

When you run the file, it displays the following result:

```
9    16    28    39    29

5     6     2     7    -11
```

Scalar Multiplication of Vectors

When you multiply a vector by a number, this is called the **scalar multiplication**. Scalar multiplication produces a new vector of same type with each element of the original vector multiplied by the number.

Example

Create a script file with the following code:

```
v = [ 12 34 10 8];

m = 5 * v
```

When you run the file, it displays the following result:

```
m =

    60   170    50    40
```

Please note that you can perform all scalar operations on vectors. For example, you can add, subtract and divide a vector with a scalar quantity.

Transpose of a Vector

The transpose operation changes a column vector into a row vector and vice versa. The transpose operation is represented by a single quote (').

Example

Create a script file with the following code:

```
r = [ 1 2 3 4 ];

tr = r';
```

86

```
v = [1;2;3;4];

tv = v';

disp(tr); disp(tv);
```

When you run the file, it displays the following result:

```
    1

    2

    3

    4


    1    2    3    4
```

Appending Vectors

MATLAB allows you to append vectors together to create new vectors.

If you have two row vectors r1 and r2 with n and m number of elements, to create a row vector r of n plus m elements, by appending these vectors, you write:

```
r = [r1,r2]
```

You can also create a matrix r by appending these two vectors, the vector r2, will be the second row of the matrix:

```
r = [r1;r2]
```

However, to do this, both the vectors should have same number of elements.

Similarly, you can append two column vectors c1 and c2 with n and m number of elements. To create a column vector c of n plus m elements, by appending these vectors, you write:

```
c = [c1; c2]
```

You can also create a matrix c by appending these two vectors; the vector c2 will be the second column of the matrix:

```
c = [c1, c2]
```

However, to do this, both the vectors should have same number of elements.

Example

Create a script file with the following code:

```
r1 = [ 1 2 3 4 ];

r2 = [5 6 7 8 ];

r = [r1,r2]

rMat = [r1;r2]


c1 = [ 1; 2; 3; 4 ];

c2 = [5; 6; 7; 8 ];

c = [c1; c2]

cMat = [c1,c2]
```

When you run the file, it displays the following result:

```
r =

    1    2    3    4    5    6    7    8

rMat =

    1    2    3    4

    5    6    7    8

c =

    1

    2

    3

    4

    5
```

```
      6

      7

      8

cMat =

      1     5

      2     6

      3     7

      4     8
```

Magnitude of a Vector

Magnitude of a vector v with elements v1, v2, v3, …, vn, is given by the equation:

$|v| = \sqrt{(v1^2 + v2^2 + v3^2 + \ldots + vn^2)}$

You need to take the following steps to calculate the magnitude of a vector:

Take the product of the vector with itself, using **array multiplication** (.*). This produces a vector sv, whose elements are squares of the elements of vector v.

sv = v.*v;

Use the sum function to get the **sum** of squares of elements of vector v. This is also called the dot product of vector v.

dp= sum(sv);

Use the **sqrt** function to get the square root of the sum which is also the magnitude of the vector v.

mag = sqrt(s);

Example

Create a script file with the following code:

```
v = [1: 2: 20];

sv = v.* v;      %the vector with elements

             % as square of v's elements

dp = sum(sv);     % sum of squares -- the dot product

mag = sqrt(dp);  % magnitude
```

```
disp('Magnitude:'); disp(mag);
```

When you run the file, it displays the following result:

```
Magnitude:

   36.4692
```

Vector Dot Product

Dot product of two vectors a = (a1, a2, …, an) and b = (b1, b2, …, bn) is given by:

a.b = ∑(ai.bi)

Dot product of two vectors a and b is calculated using the **dot** function.

```
dot(a, b);
```

Example

Create a script file with the following code:

```
v1 = [2 3 4];

v2 = [1 2 3];

dp = dot(v1, v2);

disp('Dot Product:'); disp(dp);
```

When you run the file, it displays the following result:

```
Dot Product:

    20
```

Vectors with Uniformly Spaced Elements

MATLAB allows you to create a vector with uniformly spaced elements.

To create a vector v with the first element f, last element l, and the difference between elements is any real number n, we write:

```
v = [f : n : l]
```

Example

Create a script file with the following code:

```
v = [1: 2: 20];

sqv = v.^2;

disp(v);disp(sqv);
```

When you run the file, it displays the following result:

```
1    3    5    7    9    11   13   15   17   19

1    9    25   49   81   121  169  225  289  361
```

12. MATRIX

A matrix is a two-dimensional array of numbers.

In MATLAB, you create a matrix by entering elements in each row as comma or space delimited numbers and using semicolons to mark the end of each row.

For example, let us create a 4-by-5 matrix *a*:

```
a = [ 1 2 3 4 5; 2 3 4 5 6; 3 4 5 6 7; 4 5 6 7 8]
```

MATLAB will execute the above statement and return the following result:

```
a =

     1     2     3     4     5

     2     3     4     5     6

     3     4     5     6     7

     4     5     6     7     8
```

Referencing the Elements of a Matrix

To reference an element in the mth row and nth column, of a matrix *mx*, we write:

```
mx(m, n);
```

For example, to refer to the element in the 2nd row and 5th column, of the matrix *a*, as created in the last section, we type:

```
a = [ 1 2 3 4 5; 2 3 4 5 6; 3 4 5 6 7; 4 5 6 7 8];

a(2,5)
```

MATLAB will execute the above statement and return the following result:

```
ans =

     6
```

To reference all the elements in the mth column we type A(:,m).

Let us create a column vector v, from the elements of the 4th row of the matrix a:

```
a = [ 1 2 3 4 5; 2 3 4 5 6; 3 4 5 6 7; 4 5 6 7 8];

v = a(:,4)
```

MATLAB will execute the above statement and return the following result:

```
v =

    4

    5

    6

    7
```

You can also select the elements in the mth through nth columns, for this we write:

```
a(:,m:n)
```

Let us create a smaller matrix taking the elements from the second and third columns:

```
a = [ 1 2 3 4 5; 2 3 4 5 6; 3 4 5 6 7; 4 5 6 7 8];

a(:, 2:3)
```

MATLAB will execute the above statement and return the following result:

```
ans =

    2    3

    3    4

    4    5

    5    6
```

In the same way, you can create a sub-matrix taking a sub-part of a matrix.

```
a = [ 1 2 3 4 5; 2 3 4 5 6; 3 4 5 6 7; 4 5 6 7 8];
```

```
a(:, 2:3)
```

MATLAB will execute the above statement and return the following result:

```
ans =

     2     3

     3     4

     4     5

     5     6
```

In the same way, you can create a sub-matrix taking a sub-part of a matrix.

For example, let us create a sub-matrix *sa* taking the inner subpart of a:

```
3     4     5

4     5     6
```

To do this, write:

```
a = [ 1 2 3 4 5; 2 3 4 5 6; 3 4 5 6 7; 4 5 6 7 8];

sa = a(2:3,2:4)
```

MATLAB will execute the above statement and return the following result:

```
sa =

     3     4     5

     4     5     6
```

Deleting a Row or a Column in a Matrix

You can delete an entire row or column of a matrix by assigning an empty set of square braces [] to that row or column. Basically, [] denotes an empty array.

For example, let us delete the fourth row of a:

```
a = [ 1 2 3 4 5; 2 3 4 5 6; 3 4 5 6 7; 4 5 6 7 8];
```

```
a( 4 , : ) = []
```

MATLAB will execute the above statement and return the following result:

```
a =

    1    2    3    4    5

    2    3    4    5    6

    3    4    5    6    7
```

Next, let us delete the fifth column of a:

```
a = [ 1 2 3 4 5; 2 3 4 5 6; 3 4 5 6 7; 4 5 6 7 8];

a(: , 5)=[]
```

MATLAB will execute the above statement and return the following result:

```
a =

    1    2    3    4

    2    3    4    5

    3    4    5    6

    4    5    6    7
```

Example

In this example, let us create a 3-by-3 matrix m, then we will copy the second and third rows of this matrix twice to create a 4-by-3 matrix.

Create a script file with the following code:

```
a = [ 1 2 3 ; 4 5 6; 7 8 9];

new_mat = a([2,3,2,3],:)
```

When you run the file, it displays the following result:

```
new_mat =

    4    5    6
```

```
7     8     9

4     5     6

7     8     9
```

Matrix Operations

In this section, let us discuss the following basic and commonly used matrix operations:

Addition and Subtraction of Matrices

Division of Matrices

Scalar Operations of Matrices

Transpose of a Matrix

Concatenating Matrices

Matrix Multiplication

Determinant of a Matrix

Inverse of a Matrix

Addition and Subtraction of Matrices

You can add or subtract matrices. Both the operand matrices must have the same number of rows and columns.

Example

Create a script file with the following code:

```
a = [ 1 2 3 ; 4 5 6; 7 8 9];

b = [ 7 5 6 ; 2 0 8; 5 7 1];

c = a + b

d = a - b
```

When you run the file, it displays the following result:

```
c =

    8     7     9

    6     5    14
```

```
    12    15    10

d =

    -6    -3    -3

     2     5    -2

     2     1     8
```

Division (Left, Right) of Matrix

You can divide two matrices using left (\) or right (/) division operators. Both the operand matrices must have the same number of rows and columns.

Example

Create a script file with the following code:

```
a = [ 1 2 3 ; 4 5 6; 7 8 9];

b = [ 7 5 6 ; 2 0 8; 5 7 1];

c = a / b

d = a \ b
```

When you run the file, it displays the following result:

```
c =

  -0.52542   0.68644   0.66102

  -0.42373   0.94068   1.01695

  -0.32203   1.19492   1.37288


d =

  -3.27778  -1.05556  -4.86111

  -0.11111   0.11111  -0.27778
```

```
   3.05556   1.27778   4.30556
```

Scalar Operations of Matrices

When you add, subtract, multiply or divide a matrix by a number, this is called the **scalar operation**.

Scalar operations produce a new matrix with same number of rows and columns with each element of the original matrix added to, subtracted from, multiplied by or divided by the number.

Example

Create a script file with the following code:

```
a = [ 10 12 23 ; 14 8 6; 27 8 9];

b = 2;

c = a + b

d = a - b

e = a * b

f = a / b
```

When you run the file, it displays the following result:

```
c =

   12   14   25

   16   10    8

   29   10   11

d =

    8   10   21

   12    6    4

   25    6    7

e =

   20   24   46
```

```
    28    16    12

    54    16    18

f =

    5.0000    6.0000    11.5000

    7.0000    4.0000     3.0000

   13.5000    4.0000     4.5000
```

Transpose of a Matrix

The transpose operation switches the rows and columns in a matrix. It is represented by a single quote(').

Example

Create a script file with the following code:

```
a = [ 10 12 23 ; 14 8 6; 27 8 9]

b = a'
```

When you run the file, it displays the following result:

```
a =

    10    12    23

    14     8     6

    27     8     9

b =

    10    14    27

    12     8     8

    23     6     9
```

Concatenating Matrices

You can concatenate two matrices to create a larger matrix. The pair of square brackets '[]' is the concatenation operator.

MATLAB allows two types of concatenations:

Horizontal concatenation

Vertical concatenation

When you concatenate two matrices by separating those using commas, they are just appended horizontally. It is called horizontal concatenation.

Alternatively, if you concatenate two matrices by separating those using semicolons, they are appended vertically. It is called vertical concatenation.

Example

Create a script file with the following code:

```
a = [ 10 12 23 ; 14 8 6; 27 8 9]

b = [ 12 31 45 ; 8 0 -9; 45 2 11]

c = [a, b]

d = [a; b]
```

When you run the file, it displays the following result:

```
a =

    10    12    23

    14     8     6

    27     8     9

b =

    12    31    45

     8     0    -9

    45     2    11

c =

    10    12    23    12    31    45

    14     8     6     8     0    -9

    27     8     9    45     2    11

d =
```

```
    10    12    23

    14     8     6

    27     8     9

    12    31    45

     8     0    -9

    45     2    11
```

Matrix Multiplication

Consider two matrices A and B. If A is an m x n matrix and B is an n x p matrix, they could be multiplied together to produce an m x n matrix C. Matrix multiplication is possible only if the number of columns n in A is equal to the number of rows n in B.

In matrix multiplication, the elements of the rows in the first matrix are multiplied with corresponding columns in the second matrix.

Each element in the $(i, j)^{th}$ position, in the resulting matrix C, is the summation of the products of elements in i^{th} row of first matrix with the corresponding element in the jth column of the second matrix.

Matrix multiplication in MATLAB is performed by using the * operator.

Example

Create a script file with the following code:

```
a = [ 1 2 3; 2 3 4; 1 2 5]

b = [ 2 1 3 ; 5 0 -2; 2 3 -1]

prod = a * b
```

When you run the file, it displays the following result:

```
a =

     1     2     3

     2     3     4

     1     2     5
```

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```
b =

     2     1     3

     5     0    -2

     2     3    -1

prod =

    18    10    -4

    27    14    -4

    22    16    -6
```

Determinant of a Matrix

Determinant of a matrix is calculated using the **det** function of MATLAB. Determinant of a matrix A is given by det(A).

Example

Create a script file with the following code:

```
a = [ 1 2 3; 2 3 4; 1 2 5]
det(a)
```

When you run the file, it displays the following result:

```
a =

     1     2     3

     2     3     4

     1     2     5

ans =

    -2
```

Inverse of a Matrix

The inverse of a matrix A is denoted by A^{-1} such that the following relationship holds:

```
AA−1 = A−1A = 1
```

The inverse of a matrix does not always exist. If the determinant of the matrix is zero, then the inverse does not exist and the matrix is singular.

Inverse of a matrix in MATLAB is calculated using the **inv** function. Inverse of a matrix A is given by inv(A).

Example

Create a script file and type the following code:

```
a = [ 1 2 3; 2 3 4; 1 2 5]

inv(a)
```

When you run the file, it displays the following result:

```
a =

    1    2    3

    2    3    4

    1    2    5

ans =

  -3.5000    2.0000    0.5000

   3.0000   -1.0000   -1.0000

  -0.5000         0    0.5000
```

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13. ARRAYS

All variables of all data types in MATLAB are multidimensional arrays. A vector is a one-dimensional array and a matrix is a two-dimensional array.

We have already discussed vectors and matrices. In this chapter, we will discuss multidimensional arrays. However, before that, let us discuss some special types of arrays.

Special Arrays in MATLAB

In this section, we will discuss some functions that create some special arrays. For all these functions, a single argument creates a square array, double arguments create rectangular array.

The **zeros()** function creates an array of all zeros:

For example:

```
zeros(5)
```

MATLAB will execute the above statement and return the following result:

```
ans =

     0     0     0     0     0

     0     0     0     0     0

     0     0     0     0     0

     0     0     0     0     0

     0     0     0     0     0
```

The **ones()** function creates an array of all ones:

For example:

```
ones(4,3)
```

MATLAB will execute the above statement and return the following result:

```
ans =

    1    1    1

    1    1    1

    1    1    1

    1    1    1
```

The **eye()** function creates an identity matrix.

For example:

```
eye(4)
```

MATLAB will execute the above statement and return the following result:

```
ans =

    1    0    0    0

    0    1    0    0

    0    0    1    0

    0    0    0    1
```

The **rand()** function creates an array of uniformly distributed random numbers on (0,1):

For example:

```
rand(3, 5)
```

MATLAB will execute the above statement and return the following result:

```
ans =

    0.8147    0.9134    0.2785    0.9649    0.9572

    0.9058    0.6324    0.5469    0.1576    0.4854

    0.1270    0.0975    0.9575    0.9706    0.8003
```

A Magic Square

A **magic square** is a square that produces the same sum, when its elements are added row-wise, column-wise or diagonally.

The **magic()** function creates a magic square array. It takes a singular argument that gives the size of the square. The argument must be a scalar greater than or equal to 3.

```
magic(4)
```

MATLAB will execute the above statement and return the following result:

```
ans =

   16    2    3   13

    5   11   10    8

    9    7    6   12

    4   14   15    1
```

Multidimensional Arrays

An array having more than two dimensions is called a multidimensional array in MATLAB. Multidimensional arrays in MATLAB are an extension of the normal two-dimensional matrix.

Generally to generate a multidimensional array, we first create a two-dimensional array and extend it.

For example, let's create a two-dimensional array a.

```
a = [7 9 5; 6 1 9; 4 3 2]
```

MATLAB will execute the above statement and return the following result:

```
a =

    7    9    5

    6    1    9

    4    3    2
```

The array *a* is a 3-by-3 array; we can add a third dimension to *a*, by providing the values like:

```
a(:, :, 2)= [ 1 2 3; 4 5 6; 7 8 9]
```

MATLAB will execute the above statement and return the following result:

```
a(:,:,1) =

     7     9     5

     6     1     9

     4     3     2


a(:,:,2) =

     1     2     3

     4     5     6

     7     8     9
```

We can also create multidimensional arrays using the ones(), zeros() or the rand() functions.

For example,

```
b = rand(4,3,2)
```

MATLAB will execute the above statement and return the following result:

```
b(:,:,1) =

    0.0344    0.7952    0.6463

    0.4387    0.1869    0.7094

    0.3816    0.4898    0.7547

    0.7655    0.4456    0.2760


b(:,:,2) =

    0.6797    0.4984    0.2238
```

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```
    0.6551    0.9597    0.7513

    0.1626    0.3404    0.2551

    0.1190    0.5853    0.5060
```

We can also use the **cat()** function to build multidimensional arrays. It concatenates a list of arrays along a specified dimension:

Syntax for the cat() function is:

```
B = cat(dim, A1, A2...)
```

Where,

B is the new array created

A1, *A2*, ... are the arrays to be concatenated

dim is the dimension along which to concatenate the arrays

Example

Create a script file and type the following code into it:

```
a = [9 8 7; 6 5 4; 3 2 1];

b = [1 2 3; 4 5 6; 7 8 9];

c = cat(3, a, b, [ 2 3 1; 4 7 8; 3 9 0])
```

When you run the file, it displays:

```
c(:,:,1) =

     9     8     7

     6     5     4

     3     2     1

c(:,:,2) =

     1     2     3

     4     5     6

     7     8     9

c(:,:,3) =
```

```
    2    3    1

    4    7    8

    3    9    0
```

Array Functions

MATLAB provides the following functions to sort, rotate, permute, reshape, or shift array contents.

Function	Purpose
length	Length of vector or largest array dimension
ndims	Number of array dimensions
numel	Number of array elements
size	Array dimensions
iscolumn	Determines whether input is column vector
isempty	Determines whether array is empty
ismatrix	Determines whether input is matrix
isrow	Determines whether input is row vector
isscalar	Determines whether input is scalar
isvector	Determines whether input is vector
blkdiag	Constructs block diagonal matrix from input arguments
circshift	Shifts array circularly
ctranspose	Complex conjugate transpose

diag	Diagonal matrices and diagonals of matrix
flipdim	Flips array along specified dimension
fliplr	Flips matrix from left to right
flipud	Flips matrix up to down
ipermute	Inverses permute dimensions of N-D array
permute	Rearranges dimensions of N-D array
repmat	Replicates and tile array
reshape	Reshapes array
rot90	Rotates matrix 90 degrees
shiftdim	Shifts dimensions
issorted	Determines whether set elements are in sorted order
sort	Sorts array elements in ascending or descending order
sortrows	Sorts rows in ascending order
squeeze	Removes singleton dimensions
transpose	Transpose
vectorize	Vectorizes expression

Examples

The following examples illustrate some of the functions mentioned above.

Length, Dimension and Number of elements:

Create a script file and type the following code into it:

```
x = [7.1, 3.4, 7.2, 28/4, 3.6, 17, 9.4, 8.9];

length(x)  % length of x vector

y = rand(3, 4, 5, 2);

ndims(y)    % no of dimensions in array y

s = ['Zara', 'Nuha', 'Shamim', 'Riz', 'Shadab'];

numel(s)    % no of elements in s
```

When you run the file, it displays the following result:

```
ans =

    8

ans =

    4

ans =

    23
```

Circular Shifting of the Array Elements:

Create a script file and type the following code into it:

```
a = [1 2 3; 4 5 6; 7 8 9]  % the original array a

b = circshift(a,1)  %  circular shift first dimension values down by 1.

c = circshift(a,[1 -1]) % circular shift first dimension values % down by 1

                    % and second dimension values to the left % by 1.
```

When you run the file, it displays the following result:

```
a =

    1    2    3

    4    5    6

    7    8    9

```

```
b =

    7    8    9

    1    2    3

    4    5    6


c =

    8    9    7

    2    3    1

    5    6    4
```

Sorting Arrays

Create a script file and type the following code into it:

```
v = [ 23 45 12 9 5 0 19 17]  % horizonal vector

sort(v)   %sorting v

m = [2 6 4; 5 3 9; 2 0 1]  %  two dimensional array

sort(m, 1)   % sorting m along the row

sort(m, 2)   % sorting m along the column
```

When you run the file, it displays the following result:

```
v =

    23    45    12     9     5     0    19    17

ans =

     0     5     9    12    17    19    23    45

m =

     2     6     4

     5     3     9

     2     0     1
```

```
ans =

     2     0     1

     2     3     4

     5     6     9

ans =

     2     4     6

     3     5     9

     0     1     2
```

Cell Array

Cell arrays are arrays of indexed cells where each cell can store an array of a different dimensions and data types.

The **cell** function is used for creating a cell array. Syntax for the cell function is:

```
C = cell(dim)

C = cell(dim1,...,dimN)

D = cell(obj)
```

Where,

C is the cell array;

dim is a scalar integer or vector of integers that specifies the dimensions of cell array C;

dim1, ... , dimN are scalar integers that specify the dimensions of C;

obj is One of the following:

Java array or object

.NET array of type System.String or System.Object

Example

Create a script file and type the following code into it:

```
c = cell(2, 5);

c = {'Red', 'Blue', 'Green', 'Yellow', 'White'; 1 2 3 4 5}
```

113

When you run the file, it displays the following result:

```
c =

    'Red'    'Blue'    'Green'    'Yellow'    'White'

    [  1]    [  2]    [    3]    [    4]    [    5]
```

Accessing Data in Cell Arrays

There are two ways to refer to the elements of a cell array:

Enclosing the indices in first bracket (), to refer to sets of cells

Enclosing the indices in braces {}, to refer to the data within individual cells

When you enclose the indices in first bracket, it refers to the set of cells.

Cell array indices in smooth parentheses refer to sets of cells.

For example:

```
c = {'Red', 'Blue', 'Green', 'Yellow', 'White'; 1 2 3 4 5};

c(1:2,1:2)
```

MATLAB will execute the above statement and return the following result:

```
ans =

    'Red'    'Blue'

    [  1]    [  2]
```

You can also access the contents of cells by indexing with curly braces.

For example:

```
c = {'Red', 'Blue', 'Green', 'Yellow', 'White'; 1 2 3 4 5};

c{1, 2:4}
```

MATLAB will execute the above statement and return the following result:

```
ans =

    Blue
```

```
ans =

   Green

ans =

   Yellow
```

14. COLON NOTATION

The **colon(:)** is one of the most useful operator in MATLAB. It is used to create vectors, subscript arrays, and specify for iterations.

If you want to create a row vector, containing integers from 1 to 10, you write:

```
1:10
```

MATLAB executes the statement and returns a row vector containing the integers from 1 to 10:

```
ans =

    1    2    3    4    5    6    7    8    9    10
```

If you want to specify an increment value other than one, for example:

```
100: -5: 50
```

MATLAB executes the statement and returns the following result:

```
ans =

   100    95    90    85    80    75    70    65    60    55    50
```

Let us take another example:

```
0:pi/8:pi
```

MATLAB executes the statement and returns the following result:

```
ans =

  Columns 1 through 7

        0    0.3927    0.7854    1.1781    1.5708    1.9635    2.3562

  Columns 8 through 9

    2.7489    3.1416
```

You can use the colon operator to create a vector of indices to select rows, columns or elements of arrays.

The following table describes its use for this purpose (let us have a matrix A):

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

Example

Create a script file and type the following code in it:

```
A = [1 2 3 4; 4 5 6 7; 7 8 9 10]

A(:,2)      % second column of A

A(:,2:3)    % second and third column of A

A(2:3,2:3)  % second and third rows and second and third columns
```

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When you run the file, it displays the following result:

```
A =

     1     2     3     4

     4     5     6     7

     7     8     9    10


ans =

     2

     5

     8


ans =

     2     3

     5     6

     8     9


ans =

     5     6

     8     9
```

15. NUMBERS

MATLAB supports various numeric classes that include signed and unsigned integers and single-precision and double-precision floating-point numbers. By default, MATLAB stores all numeric values as double-precision floating point numbers.

You can choose to store any number or array of numbers as integers or as single-precision numbers.

All numeric types support basic array operations and mathematical operations.

Conversion to Various Numeric Data Types

MATLAB provides the following functions to convert to various numeric data types:

Function	Purpose
Double	Converts to double precision number
Single	Converts to single precision number
int8	Converts to 8-bit signed integer
int16	Converts to 16-bit signed integer
int32	Converts to 32-bit signed integer
int64	Converts to 64-bit signed integer
uint8	Converts to 8-bit unsigned integer
uint16	Converts to 16-bit unsigned integer
uint32	Converts to 32-bit unsigned integer
uint64	Converts to 64-bit unsigned integer

Example

Create a script file and type the following code:

```
x = single([5.32 3.47 6.28]) .* 7.5

x = double([5.32 3.47 6.28]) .* 7.5

x = int8([5.32 3.47 6.28]) .* 7.5

x = int16([5.32 3.47 6.28]) .* 7.5

x = int32([5.32 3.47 6.28]) .* 7.5

x = int64([5.32 3.47 6.28]) .* 7.5
```

When you run the file, it shows the following result:

```
x =

   39.9000   26.0250   47.1000

x =


   39.9000   26.0250   47.1000

x =

   38   23   45

x =

    38     23     45

x =

         38         23         45

x =

               38               23               45
```

Example

Let us extend the previous example a little more. Create a script file and type the following code:

```
x = int32([5.32 3.47 6.28]) .* 7.5
```

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```
x = int64([5.32 3.47 6.28]) .* 7.5

x = num2cell(x)
```

When you run the file, it shows the following result:

```
x =

       38          23          45

x =

             38                  23                  45

x =

   [38]    [23]    [45]
```

Smallest and Largest Integers

The functions **intmax()** and **intmin()** return the maximum and minimum values that can be represented with all types of integer numbers.

Both the functions take the integer data type as the argument, for example, intmax(int8) or intmin(int64) and return the maximum and minimum values that you can represent with the integer data type.

Example

The following example illustrates how to obtain the smallest and largest values of integers. Create a script file and write the following code in it:

```
% displaying the smallest and largest signed integer data

str = 'The range for int8 is:\n\t%d to %d ';

sprintf(str, intmin('int8'), intmax('int8'))

str = 'The range for int16 is:\n\t%d to %d ';

sprintf(str, intmin('int16'), intmax('int16'))

str = 'The range for int32 is:\n\t%d to %d ';

sprintf(str, intmin('int32'), intmax('int32'))

str = 'The range for int64 is:\n\t%d to %d ';
```

```
sprintf(str, intmin('int64'), intmax('int64'))



% displaying the smallest and largest unsigned integer data

str = 'The range for uint8 is:\n\t%d to %d ';

sprintf(str, intmin('uint8'), intmax('uint8'))

str = 'The range for uint16 is:\n\t%d to %d ';

sprintf(str, intmin('uint16'), intmax('uint16'))

str = 'The range for uint32 is:\n\t%d to %d ';

sprintf(str, intmin('uint32'), intmax('uint32'))

str = 'The range for uint64 is:\n\t%d to %d ';

sprintf(str, intmin('uint64'), intmax('uint64'))
```

When you run the file, it shows the following result:

```
ans =

The range for int8 is:

      -128 to 127

ans =

The range for int16 is:

      -32768 to 32767

ans =

The range for int32 is:

      -2147483648 to 2147483647

ans =

The range for int64 is:

      -9223372036854775808 to 9223372036854775807

ans =

The range for uint8 is:
```

```
      0 to 255

ans =

The range for uint16 is:

      0 to 65535

ans =

The range for uint32 is:

      0 to 4294967295

ans =

The range for uint64 is:

      0 to 1.844674e+19
```

Smallest and Largest Floating Point Numbers

The functions **realmax()** and **realmin()** return the maximum and minimum values that can be represented with floating point numbers.

Both the functions when called with the argument 'single', return the maximum and minimum values that you can represent with the single-precision data type and when called with the argument 'double', return the maximum and minimum values that you can represent with the double-precision data type.

Example

The following example illustrates how to obtain the smallest and largest floating point numbers. Create a script file and write the following code in it:

```
% displaying the smallest and largest single-precision

% floating point number

str = 'The range for single is:\n\t%g to %g and\n\t %g to  %g';

sprintf(str, -realmax('single'), -realmin('single'), ...

    realmin('single'), realmax('single'))

% displaying the smallest and largest double-precision

% floating point number
```

```
str = 'The range for double is:\n\t%g to %g and\n\t %g to  %g';

sprintf(str, -realmax('double'), -realmin('double'), ...

    realmin('double'), realmax('double'))
```

When you run the file, it displays the following result:

```
ans =

The range for single is:

      -3.40282e+38 to -1.17549e-38 and

       1.17549e-38 to  3.40282e+38

ans =

The range for double is:

      -1.79769e+308 to -2.22507e-308 and

       2.22507e-308 to  1.79769e+308
```

16. STRINGS

Creating a character string is quite simple in MATLAB. In fact, we have used it many times. For example, you type the following in the command prompt:

```
my_string = 'Tutorial''s Point'
```

MATLAB will execute the above statement and return the following result:

```
my_string =

Tutorial's Point
```

MATLAB considers all variables as arrays, and strings are considered as character arrays. Let us use the **whos** command to check the variable created above:

```
whos
```

MATLAB will execute the above statement and return the following result:

```
Name          Size          Bytes  Class    Attributes

my_string     1x16             32  char
```

Interestingly, you can use numeric conversion functions like **uint8** or **uint16** to convert the characters in the string to their numeric codes. The **char** function converts the integer vector back to characters:

Example

Create a script file and type the following code into it:

```
my_string = 'Tutorial''s Point';

str_ascii = uint8(my_string)        % 8-bit ascii values

str_back_to_char= char(str_ascii)

str_16bit = uint16(my_string)       % 16-bit ascii values

str_back_to_char = char(str_16bit)
```

When you run the file, it displays the following result:

```
str_ascii =

  Columns 1 through 14

    84  117  116  111  114  105   97  108   39  115   32   80  111  105

  Columns 15 through 16

  110  116

str_back_to_char =

Tutorial's Point

str_16bit =

  Columns 1 through 10

      84     117     116     111     114     105      97     108      39     115

  Columns 11 through 16

      32      80     111     105     110     116

str_back_to_char =

Tutorial's Point
```

Rectangular Character Array

The strings we have discussed so far are one-dimensional character arrays; however, we need to store more than that. We need to store more dimensional textual data in our program. This is achieved by creating rectangular character arrays.

Simplest way of creating a rectangular character array is by concatenating two or more one-dimensional character arrays, either vertically or horizontally as required.

You can combine strings vertically in either of the following ways:

Using the MATLAB concatenation operator **[]** and separating each row with a semicolon (;).Please note that in this method each row must contain the same number of characters. For strings with different lengths, you should pad with space characters as needed.

Using the **char** function. If the strings are of different lengths, char pads the shorter strings with trailing blanks so that each row has the same number of characters.

Example

Create a script file and type the following code into it:

```
doc_profile = ['Zara Ali                        '; ...
              'Sr. Surgeon                     '; ...
              'R N Tagore Cardiology Research Center']
doc_profile = char('Zara Ali', 'Sr. Surgeon', ...
                'RN Tagore Cardiology Research Center')
```

When you run the file, it displays the following result:

```
doc_profile =

Zara Ali

Sr. Surgeon

R N Tagore Cardiology Research Center

doc_profile =

Zara Ali

Sr. Surgeon

RN Tagore Cardiology Research Center
```

You can combine strings horizontally in either of the following ways:

Using the MATLAB concatenation operator, **[]** and separating the input strings with a comma or a space. This method preserves any trailing spaces in the input arrays.

Using the string concatenation function, **strcat**. This method removes trailing spaces in the inputs

Example

Create a script file and type the following code into it:

```
name =    'Zara Ali                        ';
position = 'Sr. Surgeon                     ';
```

```
worksAt =  'R N Tagore Cardiology Research Center';

profile = [name ', ' position ', ' worksAt]

profile = strcat(name, ', ', position, ', ', worksAt)
```

When you run the file, it displays the following result:

```
profile =

Zara Ali                          , Sr. Surgeon                          , R N
Tagore Cardiology Research Center

profile =

Zara Ali,Sr. Surgeon,R N Tagore Cardiology Research Center
```

Combining Strings into a Cell Array

From our previous discussion, it is clear that combining strings with different lengths could be a pain as all strings in the array has to be of the same length. We have used blank spaces at the end of strings to equalize their length.

However, a more efficient way to combine the strings is to convert the resulting array into a cell array.

MATLAB cell array can hold different sizes and types of data in an array. Cell arrays provide a more flexible way to store strings of varying length.

The **cellstr** function converts a character array into a cell array of strings.

Example

Create a script file and type the following code into it:

```
name =     'Zara Ali                          ';

position = 'Sr. Surgeon                       ';

worksAt =  'R N Tagore Cardiology Research Center';

profile = char(name, position, worksAt);

profile = cellstr(profile);

disp(profile)
```

When you run the file, it displays the following result:

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```
'Zara Ali'

'Sr. Surgeon'

'R N Tagore Cardiology Research Center'
```

String Functions in MATLAB

MATLAB provides numerous string functions creating, combining, parsing, comparing and manipulating strings.

Following table provides brief description of the string functions in MATLAB:

Function	Purpose
Functions for storing text in character arrays, combine character arrays, etc.	
blanks	Create string of blank characters
cellstr	Create cell array of strings from character array
char	Convert to character array (string)
iscellstr	Determine whether input is cell array of strings
ischar	Determine whether item is character array
sprintf	Format data into string
strcat	Concatenate strings horizontally
strjoin	Join strings in cell array into single string
Functions for identifying parts of strings, find and replace substrings	
ischar	Determine whether item is character array
isletter	Array elements that are alphabetic letters

isspace	Array elements that are space characters
isstrprop	Determine whether string is of specified category
sscanf	Read formatted data from string
strfind	Find one string within another
strrep	Find and replace substring
strsplit	Split string at specified delimiter
strtok	Selected parts of string
validatestring	Check validity of text string
symvar	Determine symbolic variables in expression
regexp	Match regular expression (case sensitive)
regexpi	Match regular expression (case insensitive)
regexprep	Replace string using regular expression
regexptranslate	Translate string into regular expression
Functions for string comparison	
strcmp	Compare strings (case sensitive)
strcmpi	Compare strings (case insensitive)
strncmp	Compare first n characters of strings (case sensitive)
strncmpi	Compare first n characters of strings (case insensitive)

Functions for changing string to upper- or lowercase, creating or removing white space	
deblank	Strip trailing blanks from end of string
strtrim	Remove leading and trailing white space from string
lower	Convert string to lowercase
upper	Convert string to uppercase
strjust	Justify character array

Examples

The following examples illustrate some of the above-mentioned string functions:

Formatting Strings

Create a script file and type the following code into it:

```
A = pi*1000*ones(1,5);

sprintf(' %f \n %.2f \n %+.2f \n %12.2f \n %012.2f \n', A)
```

When you run the file, it displays the following result:

```
ans =

 3141.592654

 3141.59

 +3141.59

      3141.59

 000003141.59
```

Joining Strings

Create a script file and type the following code into it:

```
%cell array of strings
```

```matlab
str_array = {'red','blue','green', 'yellow', 'orange'};


% Join strings in cell array into single string
str1 = strjoin("-", str_array)
str2 = strjoin(",", str_array)
```

When you run the file, it displays the following result:

```
str1 =

red blue green yellow orange

str2 =

red , blue , green , yellow , orange
```

Finding and Replacing Strings

Create a script file and type the following code into it:

```matlab
students = {'Zara Ali', 'Neha Bhatnagar', ...

        'Monica Malik', 'Madhu Gautam', ...

        'Madhu Sharma', 'Bhawna Sharma',...

        'Nuha Ali', 'Reva Dutta', ...

        'Sunaina Ali', 'Sofia Kabir'};


% The strrep function searches and replaces sub-string.

new_student = strrep(students(8), 'Reva', 'Poulomi')
% Display first names

first_names = strtok(students)
```

When you run the file, it displays the following result:

```
new_student =
```

132

```
    'Poulomi Dutta'

first_names =

  Columns 1 through 6

    'Zara'    'Neha'    'Monica'    'Madhu'    'Madhu'    'Bhawna'

  Columns 7 through 10

    'Nuha'    'Reva'    'Sunaina'    'Sofia'
```

Comparing Strings

Create a script file and type the following code into it:

```
str1 = 'This is test'

str2 = 'This is text'

if (strcmp(str1, str2))

 sprintf('%s and %s are equal', str1, str2)

else

 sprintf('%s and %s are not equal', str1, str2)

end
```

When you run the file, it displays the following result:

```
str1 =

This is test

str2 =

This is text

ans =

This is test and This is text are not equal
```

17. 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

The following function named *mymax* should be written in a file named *mymax.m*. It takes five numbers as argument and returns the maximum of the numbers.

Create a function file, named mymax.m and type the following code in it:

```
function max = mymax(n1, n2, n3, n4, n5)

%This function calculates the maximum of the

% five numbers given as input

max =  n1;

if(n2 > max)

    max = n2;

end

if(n3 > max)

   max = n3;

end

if(n4 > max)

    max = n4;
```

134

```
  end

if(n5 > max)

    max = n5;

end
```

The first line of a function starts with the keyword **function**. It gives the name of the function and order of arguments. In our example, the *mymax* function has five input arguments and one output argument.

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

```
help mymax
```

MATLAB will execute the above statement and return the following result:

```
This function calculates the maximum of the

 five numbers given as input
```

You can call the function as:

```
mymax(34, 78, 89, 23, 11)
```

MATLAB will execute the above statement and return the following result:

```
ans =

    89
```

Anonymous Functions

An anonymous function is like an inline function in traditional programming languages, defined within a single MATLAB statement. It consists of a single MATLAB expression and any number of input and output arguments.

You can define an anonymous function right at the MATLAB command line or within a function or script.

This way you can create simple functions without having to create a file for them.

The syntax for creating an anonymous function from an expression is

```
f = @(arglist)expression
```

Example

In this example, we will write an anonymous function named power, which will take two numbers as input and return first number raised to the power of the second number.

Create a script file and type the following code in it:

```
power = @(x, n) x.^n;

result1 = power(7, 3)

result2 = power(49, 0.5)

result3 = power(10, -10)

result4 = power (4.5, 1.5)
```

When you run the file, it displays:

```
result1 =

    343

result2 =

     7

result3 =

   1.0000e-10

result4 =

    9.5459
```

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

Let us write a function named quadratic that would calculate the roots of a quadratic equation. The function would take three inputs, the quadratic co-efficient, the linear co-efficient and the constant term. It would return the roots.

The function file quadratic.m will contain the primary function *quadratic* and the sub-function *disc*, which calculates the discriminant.

Create a function file *quadratic.m* and type the following code in it:

```
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 term

% It returns the roots

d = disc(a,b,c);

x1 = (-b + d) / (2*a);

x2 = (-b - d) / (2*a);

end % end of quadratic


function dis = disc(a,b,c)

%function calculates the discriminant

dis = sqrt(b^2 - 4*a*c);

end % end of sub-function
```

You can call the above function from command prompt as:

```
quadratic(2,4,-4)
```

MATLAB will execute the above statement and will give the following result:

```
ans =

    0.7321
```

Nested Functions

You can define functions within the body of another function. These are called nested functions. A nested function contains any or all of the components of any other function.

Nested functions are defined within the scope of another function and they share access to the containing function's workspace.

A nested function follows the below syntax:

```
function x = A(p1, p2)
...
B(p2)

   function y = B(p3)

   ...

   end
...
end
```

Example

Let us rewrite the function *quadratic*, from previous example, however, this time the disc function will be a nested function.

Create a function file *quadratic2.m* and type the following code in it:

```
function [x1,x2] = quadratic2(a,b,c)

function disc  % nested function

d = sqrt(b^2 - 4*a*c);

end % end of function disc
```

```
disc;

x1 = (-b + d) / (2*a);

x2 = (-b - d) / (2*a);

end % end of function quadratic2
```

You can call the above function from command prompt as:

```
quadratic2(2,4,-4)
```

MATLAB will execute the above statement and return the following result:

```
ans =

    0.7321
```

Private Functions

A private function is a primary function that is visible only to a limited group of other functions. If you do not want to expose the implementation of a function(s), you can create them as private functions.

Private functions reside in **subfolders** with the special name **private**.

They are visible only to functions in the parent folder.

Example

Let us rewrite the *quadratic* function. This time, however, the *disc* function calculating the discriminant, will be a private function.

Create a subfolder named private in working directory. Store the following function file *disc.m* in it:

```
function dis = disc(a,b,c)

%function calculates the discriminant

dis = sqrt(b^2 - 4*a*c);

end % end of sub-function
```

Create a function quadratic3.m in your working directory and type the following code in it:

```
function [x1,x2] = quadratic3(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 term

% It returns the roots

d = disc(a,b,c);

x1 = (-b + d) / (2*a);

x2 = (-b - d) / (2*a);

end % end of quadratic3
```

You can call the above function from command prompt as:

```
quadratic3(2,4,-4)
```

MATLAB will execute the above statement and return the following result:

```
ans =

    0.7321
```

Global Variables

Global variables can be shared by more than one function. For this, you need to declare the variable as global in all the functions.

If you want to access that variable from the base workspace, then declare the variable at the command line.

The global declaration must occur before the variable is actually used in a function. It is a good practice to use capital letters for the names of global variables to distinguish them from other variables.

Example

Let us create a function file named average.m and type the following code in it:

```
function avg = average(nums)

global TOTAL

avg = sum(nums)/TOTAL;

end
```

Create a script file and type the following code in it:

```
global TOTAL;

TOTAL = 10;

n = [34, 45, 25, 45, 33, 19, 40, 34, 38, 42];

av = average(n)
```

When you run the file, it will display the following result:

```
av =

   35.5000
```

18. DATA IMPORT

Importing data in MATLAB means loading data from an external file. The **importdata** function allows loading various data files of different formats. It has the following five forms:

S.N.	Function and Description
1	**A = importdata(filename)** Loads data into array A from the file denoted by *filename*.
2	**A = importdata('-pastespecial')** Loads data from the system clipboard rather than from a file.
3	**A = importdata(____, delimiterIn)** Interprets *delimiterIn* as the column separator in ASCII file, filename, or the clipboard data. You can use *delimiterIn* with any of the input arguments in the above syntaxes.
4	**A = importdata(____, delimiterIn, headerlinesIn)** Loads data from ASCII file, filename, or the clipboard, reading numeric data starting from line *headerlinesIn+1*.
5	**[A, delimiterOut, headerlinesOut] = importdata(____)** dditionally returns the detected delimiter character for the input ASCII file in*delimiterOut* and the detected number of header lines in *headerlinesOut*, using any of the input arguments in the previous syntaxes.

By default, Octave does not have support for *importdata()* function, so you will have to search and install this package to make following examples work with your Octave installation.

Example 1

Let us load and display an image file. Create a script file and type the following code in it:

```
filename = 'smile.jpg';

A = importdata(filename);

image(A);
```

When you run the file, MATLAB displays the image file. However, you must store it in the current directory.
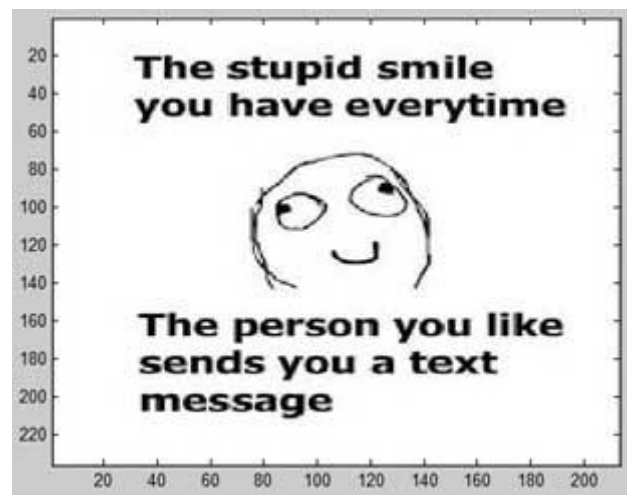
Example 2

In this example, we import a text file and specify Delimiter and Column Header. Let us create a space-delimited ASCII file with column headers, named *weeklydata.txt*.

Our text file weeklydata.txt looks like this:

```
SunDay  MonDay  TuesDay  WednesDay  ThursDay  FriDay  SaturdDay

95.01   76.21   61.54    40.57      55.79     70.28   81.53

73.11   45.65   79.19    93.55      75.29     69.87   74.68

60.68   41.85   92.18    91.69      81.32     90.38   74.51

48.60   82.14   73.82    41.03      0.99      67.22   93.18

89.13   44.47   57.63    89.36      13.89     19.88   46.60
```

Create a script file and type the following code in it:

```
filename = 'weeklydata.txt';

delimiterIn = ' ';
```

```
headerlinesIn = 1;

A = importdata(filename,delimiterIn,headerlinesIn);

% View data

for k = [1:7]

    disp(A.colheaders{1, k})

    disp(A.data(:, k))

    disp(' ')

end
```

When you run the file, it displays the following result:

```
SunDay

    95.0100

    73.1100

    60.6800

    48.6000

    89.1300


MonDay

    76.2100

    45.6500

    41.8500

    82.1400

    44.4700


TuesDay

    61.5400

    79.1900
```

```
   92.1800

   73.8200

   57.6300


WednesDay

   40.5700

   93.5500

   91.6900

   41.0300

   89.3600


ThursDay

   55.7900

   75.2900

   81.3200

    0.9900

   13.8900


FriDay

   70.2800

   69.8700

   90.3800

   67.2200

   19.8800


SatureDay

   81.5300
```

```
    74.6800

    74.5100

    93.1800

    46.6000
```

Example 3

In this example, let us import data from clipboard.

Copy the following lines to the clipboard:

Mathematics is simple

Create a script file and type the following code:

```
A = importdata('-pastespecial')
```

When you run the file, it displays the following result:

```
A =

    'Mathematics is simple'
```

Low-Level File I/O

The *importdata* function is a high-level function. The low-level file I/O functions in MATLAB allow the most control over reading or writing data to a file. However, these functions need more detailed information about your file to work efficiently.

MATLAB provides the following functions for read and write operations at the byte or character level:

Function	Description
fclose	Close one or all open files
feof	Test for end-of-file
ferror	Information about file I/O errors

fgetl	Read line from file, removing newline characters
fgets	Read line from file, keeping newline characters
fopen	Open file, or obtain information about open files
fprintf	Write data to text file
fread	Read data from binary file
frewind	Move file position indicator to beginning of open file
fscanf	Read data from text file
fseek	Move to specified position in file
ftell	Position in open file
fwrite	Write data to binary file

Import Text Data Files with Low-Level I/O

MATLAB provides the following functions for low-level import of text data files:

The **fscanf** function reads formatted data in a text or ASCII file.

The **fgetl** and **fgets** functions read one line of a file at a time, where a newline character separates each line.

The **fread** function reads a stream of data at the byte or bit level.

Example

We have a text data file 'myfile.txt' saved in our working directory. The file stores rainfall data for three months; June, July and August for the year 2012.

The data in myfile.txt contains repeated sets of time, month and rainfall measurements at five places. The header data stores the number of months M; so we have M sets of measurements.

The file looks like this:

```
Rainfall Data
```

```
Months: June, July, August


M=3

12:00:00

June-2012

17.21  28.52  39.78  16.55 23.67

19.15  0.35   17.57  NaN   12.01

17.92  28.49  17.40  17.06 11.09

9.59   9.33   NaN    0.31  0.23

10.46  13.17  NaN    14.89 19.33

20.97  19.50  17.65  14.45 14.00

18.23  10.34  17.95  16.46 19.34

09:10:02

July-2012

12.76  16.94  14.38  11.86 16.89

20.46  23.17  NaN    24.89 19.33

30.97  49.50  47.65  24.45 34.00

18.23  30.34  27.95  16.46 19.34

30.46  33.17  NaN    34.89  29.33

30.97  49.50  47.65  24.45 34.00

28.67  30.34  27.95  36.46 29.34

15:03:40

August-2012

17.09  16.55  19.59  17.25 19.22

17.54  11.45  13.48  22.55 24.01

NaN    21.19  25.85  25.05 27.21
```

```
26.79  24.98  12.23  16.99 18.67

17.54  11.45  13.48  22.55 24.01

NaN    21.19  25.85  25.05 27.21

26.79  24.98  12.23  16.99 18.67
```

We will import data from this file and display this data. Take the following steps:

Open the file with **fopen** function and get the file identifier.

Describe the data in the file with **format specifiers**, such as '**%s**' for a string, '**%d**' for an integer, or '**%f**' for a floating-point number.

To skip literal characters in the file, include them in the format description. To skip a data field, use an asterisk ('*') in the specifier.

For example, to read the headers and return the single value for M, we write:

```
M = fscanf(fid, '%*s %*s\n%*s %*s %*s %*s\nM=%d\n\n', 1);
```

By default, **fscanf** reads data according to our format description until it does not find any match for the data, or it reaches the end of the file. Here we will use for loop for reading 3 sets of data and each time, it will read 7 rows and 5 columns.

We will create a structure named *mydata* in the workspace to store data read from the file. This structure has three fields - *time*, *month*, and *raindata* array.

Create a script file and type the following code in it:

```
filename = '/data/myfile.txt';

rows = 7;

cols = 5;


% open the file

fid = fopen(filename);


% read the file headers, find M (number of months)

M = fscanf(fid, '%*s %*s\n%*s %*s %*s %*s\nM=%d\n\n', 1);


% read each set of measurements
```

```
for n = 1:M

    mydata(n).time = fscanf(fid, '%s', 1);

    mydata(n).month = fscanf(fid, '%s', 1);


    % fscanf fills the array in column order,

    % so transpose the results

    mydata(n).raindata  = ...

      fscanf(fid, '%f', [rows, cols]);

end

for n = 1:M

    disp(mydata(n).time), disp(mydata(n).month)

    disp(mydata(n).raindata)

end


% close the file

fclose(fid);
```

When you run the file, it displays the following result:

```
12:00:00

June-2012

   17.2100   17.5700   11.0900   13.1700   14.4500

   28.5200       NaN    9.5900       NaN   14.0000

   39.7800   12.0100    9.3300   14.8900   18.2300

   16.5500   17.9200       NaN   19.3300   10.3400

   23.6700   28.4900    0.3100   20.9700   17.9500

   19.1500   17.4000    0.2300   19.5000   16.4600

    0.3500   17.0600   10.4600   17.6500   19.3400
```

```
09:10:02

July-2012

   12.7600        NaN  34.0000  33.1700  24.4500

   16.9400  24.8900  18.2300        NaN  34.0000

   14.3800  19.3300  30.3400  34.8900  28.6700

   11.8600  30.9700  27.9500  29.3300  30.3400

   16.8900  49.5000  16.4600  30.9700  27.9500

   20.4600  47.6500  19.3400  49.5000  36.4600

   23.1700  24.4500  30.4600  47.6500  29.3400


15:03:40

August-2012

   17.0900  13.4800  27.2100  11.4500  25.0500

   16.5500  22.5500  26.7900  13.4800  27.2100

   19.5900  24.0100  24.9800  22.5500  26.7900

   17.2500        NaN  12.2300  24.0100  24.9800

   19.2200  21.1900  16.9900        NaN  12.2300

   17.5400  25.8500  18.6700  21.1900  16.9900

   11.4500  25.0500  17.5400  25.8500  18.6700
```

Data export in MATLAB means to write into files. MATLAB allows you to use your data in another application that reads ASCII files. For this, MATLAB provides several data export options.

You can create the following type of files:

Rectangular, delimited ASCII data file from an array.

Diary (or log) file of keystrokes and the resulting text output.

Specialized ASCII file using low-level functions such as fprintf.

MEX-file to access your C/C++ or FORTRAN routine that writes to a particular text file format.

Apart from this, you can also export data to spreadsheets.

There are two ways to export a numeric array as a delimited ASCII data file:

Using the **save** function and specifying the **-ASCII** qualifier

Using the **dlmwrite** function

Syntax for using the save function is:

```
save my_data.out num_array -ASCII
```

where, *my_data.out* is the delimited ASCII data file created, *num_array* is a numeric array and **�ASCII** is the specifier.

Syntax for using the **dlmwrite** function is:

```
dlmwrite('my_data.out', num_array, 'dlm_char')
```

where, *my_data.out* is the delimited ASCII data file created, *num_array* is a numeric array and *dlm_char* is the delimiter character.

Example

The following example demonstrates the concept. Create a script file and type the following code:

```
num_array = [ 1 2 3 4 ; 4 5 6 7; 7 8 9 0];

save array_data1.out num_array -ASCII;

type array_data1.out
```

```
dlmwrite('array_data2.out', num_array, ' ');

type array_data2.out
```

When you run the file, it displays the following result:

```
   1.0000000e+00   2.0000000e+00   3.0000000e+00   4.0000000e+00

   4.0000000e+00   5.0000000e+00   6.0000000e+00   7.0000000e+00

   7.0000000e+00   8.0000000e+00   9.0000000e+00   0.0000000e+00


1 2 3 4

4 5 6 7

7 8 9 0
```

Please note that the save -ascii command and the dlmwrite function does not work with cell arrays as input. To create a delimited ASCII file from the contents of a cell array, you can

Either, convert the cell array to a matrix using the **cell2mat** function

Or export the cell array using low-level file I/O functions.

If you use the **save** function to write a character array to an ASCII file, it writes the ASCII equivalent of the characters to the file.

For example, let us write the word 'hello' to a file:

```
h = 'hello';

save textdata.out h -ascii

type textdata.out
```

MATLAB executes the above statements and displays the following result which is the characters of the string 'hello' in 8-digit ASCII format.

```
1.0400000e+02   1.0100000e+02   1.0800000e+02   1.0800000e+02
1.1100000e+02
```

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Writing to Diary Files

Diary files are activity logs of your MATLAB session. The diary function creates an exact copy of your session in a disk file, excluding graphics.

To turn on the diary function, type:

```
diary
```

Optionally, you can give the name of the log file, say:

```
diary logdata.out
```

To turn off the diary function:

```
diary off
```

You can open the diary file in a text editor.

Exporting Data to Text Data Files with Low-Level I/O

So far, we have exported numeric arrays. However, you may need to create other text files, including combinations of numeric and character data, nonrectangular output files, or files with non-ASCII encoding schemes. For these purposes, MATLAB provides the low-level **fprintf** function.

As in low-level I/O file activities, before exporting, you need to open or create a file with the **fopen** function and get the file identifier. By default, fopen opens a file for read-only access. You should specify the permission to write or append, such as 'w' or 'a'.

After processing the file, you need to close it with **fclose(fid)** function.

The following example demonstrates the concept:

Example

Create a script file and type the following code in it:

```
% create a matrix y, with two rows

x = 0:10:100;

y = [x; log(x)];
```

```
% open a file for writing

fid = fopen('logtable.txt', 'w');



% Table Header

fprintf(fid, 'Log      Function\n\n');



% print values in column order

% two values appear on each row of the file

fprintf(fid, '%f    %f\n', y);

fclose(fid);

% display the file created

type logtable.txt
```

When you run the file, it displays the following result:

```
Log      Function

0.000000     -Inf

10.000000    2.302585

20.000000    2.995732

30.000000    3.401197

40.000000    3.688879

50.000000    3.912023

60.000000    4.094345

70.000000    4.248495

80.000000    4.382027

90.000000    4.499810

100.000000    4.605170
```

20. PLOTTING

To plot the graph of a function, you need to take the following steps:

Define **x**, by specifying the **range of values** for the variable **x**, for which the function is to be plotted

Define the function, **y = f(x)**

Call the **plot** command, as **plot(x, y)**

Following example would demonstrate the concept. Let us plot the simple function **y = x** for the range of values for x from 0 to 100, with an increment of 5.

Create a script file and type the following code:

```
x = [0:5:100];

y = x;

plot(x, y)
```

When you run the file, MATLAB displays the following plot:
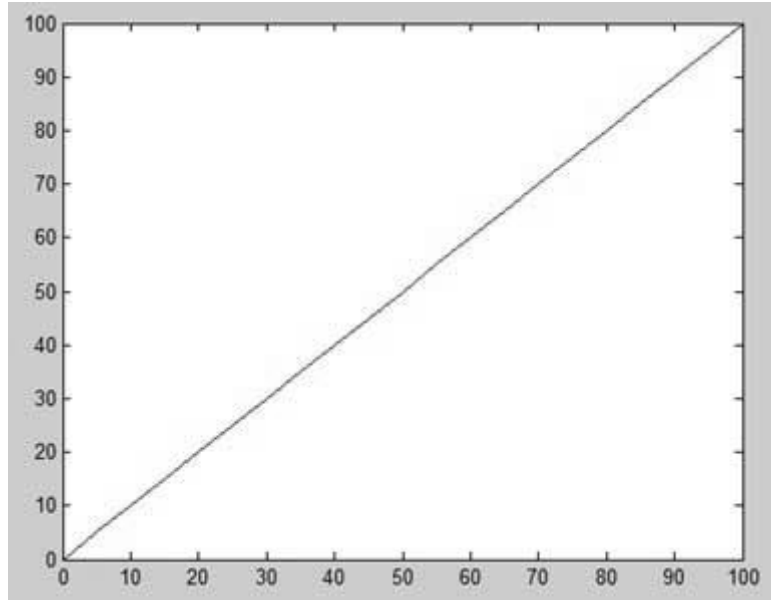
Let us take one more example to plot the function $y = x^2$. In this example, we will draw two graphs with the same function, but in second time, we will reduce the value of increment. Please note that as we decrease the increment, the graph becomes smoother.

Create a script file and type the following code:

```
x = [1 2 3 4 5 6 7 8 9 10];

x = [-100:20:100];

y = x.^2;

plot(x, y)
```

When you run the file, MATLAB displays the following plot:
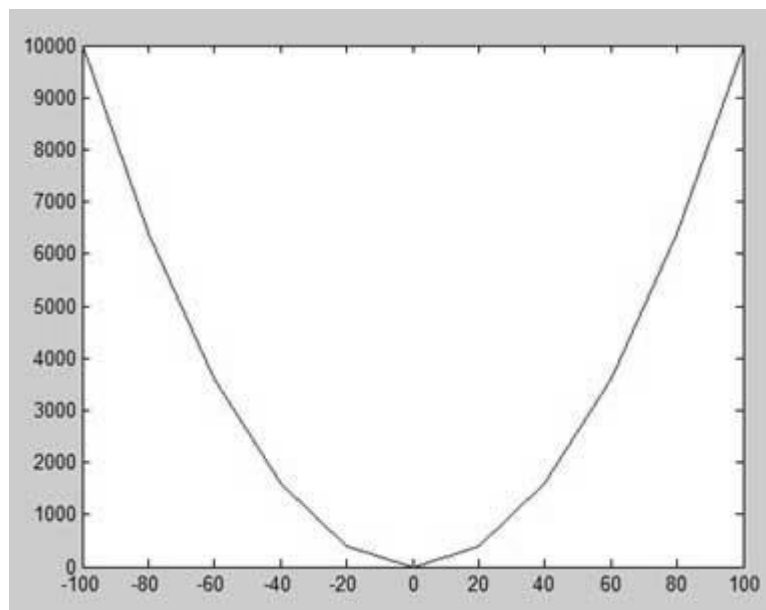
Change the code file a little, reduce the increment to 5:

```
x = [-100:5:100];

y = x.^2;

plot(x, y)
```

MATLAB draws a smoother graph:
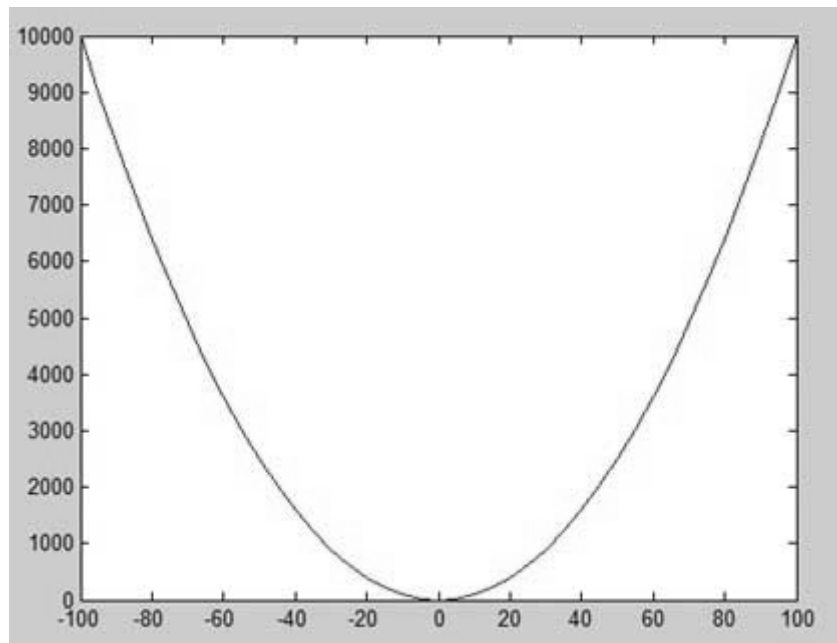
Adding Title, Labels, Grid Lines, and Scaling on the Graph

MATLAB allows you to add title, labels along the x-axis and y-axis, grid lines and also to adjust the axes to spruce up the graph.

The **xlabel** and **ylabel** commands generate labels along x-axis and y-axis.

The **title** command allows you to put a title on the graph.

The **grid on** command allows you to put the grid lines on the graph.

The **axis equal** command allows generating the plot with the same scale factors and the spaces on both axes.

The **axis square** command generates a square plot.

Example

Create a script file and type the following code:

```
x = [0:0.01:10];

y = sin(x);

plot(x, y), xlabel('x'), ylabel('Sin(x)'), title('Sin(x) Graph'),

grid on, axis equal
```

MATLAB generates the following graph:
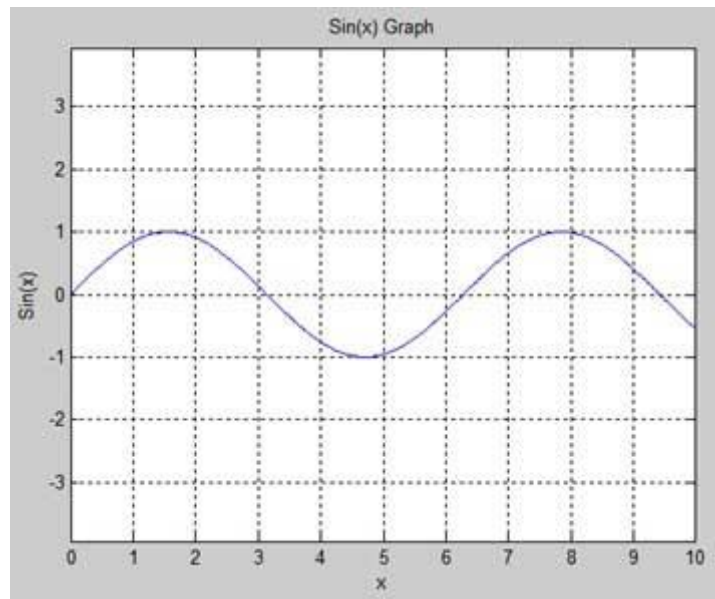
Drawing Multiple Functions on the Same Graph

You can draw multiple graphs on the same plot. The following example demonstrates the concept:

Example

Create a script file and type the following code:

```
x = [0 : 0.01: 10];

y = sin(x);

g = cos(x);

plot(x, y, x, g, '.-'), legend('Sin(x)', 'Cos(x)')
```

MATLAB generates the following graph:
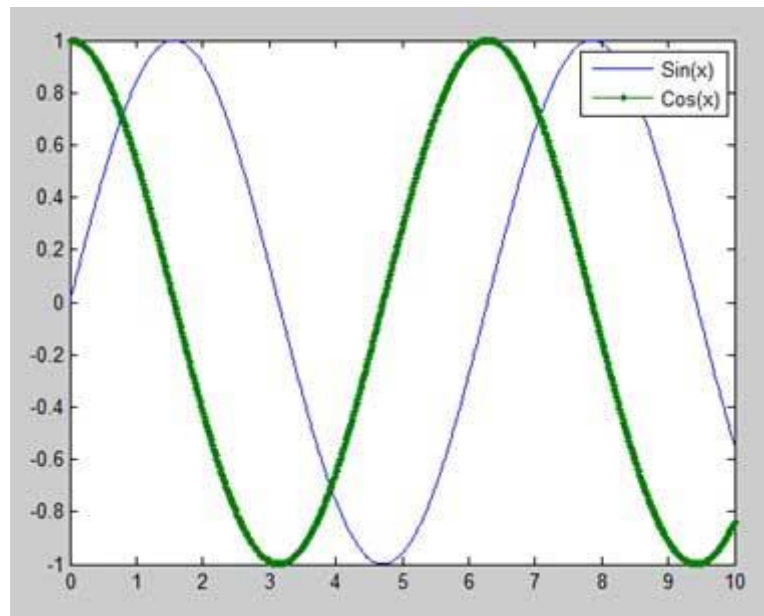
Setting Colors on Graph

MATLAB provides eight basic color options for drawing graphs. The following table shows the colors and their codes:

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

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Example

Let us draw the graph of two polynomials

f(x) = 3x⁴ + 2x³+ 7x² + 2x + 9 and

g(x) = 5x³ + 9x + 2

Create a script file and type the following code:

```
x = [-10 : 0.01: 10];

y = 3*x.^4 + 2 * x.^3 + 7 * x.^2 + 2 * x + 9;

g = 5 * x.^3 + 9 * x + 2;

plot(x, y, 'r', x, g, 'g')
```

When you run the file, MATLAB generates the following graph:
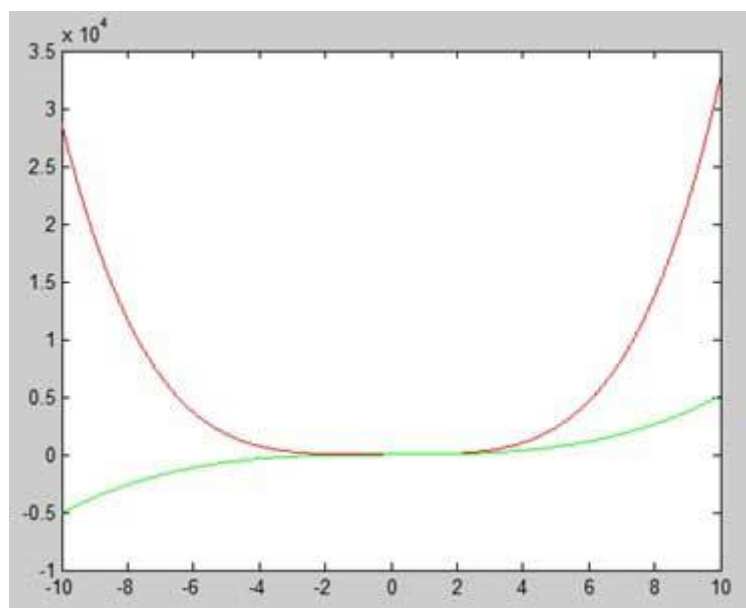
Setting Axis Scales

The **axis** command allows you to set the axis scales. You can provide minimum and maximum values for x and y axes using the axis command in the following way:

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

The following example shows this:

Example

Create a script file and type the following code:

```
x = [0 : 0.01: 10];

y = exp(-x).* sin(2*x + 3);

plot(x, y), axis([0 10 -1 1])
```

When you run the file, MATLAB generates the following graph:
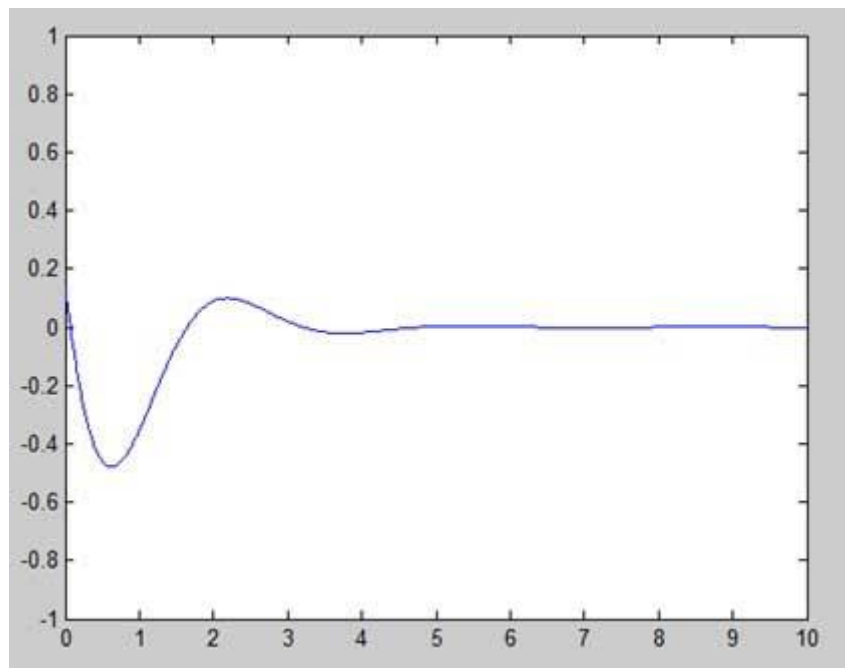
Generating Sub-Plots

When you create an array of plots in the same figure, each of these plots is called a subplot. The **subplot** command is used for creating subplots.

Syntax for the command is:

```
subplot(m, n, p)
```

where, *m* and *n* are the number of rows and columns of the plot array and *p* specifies where to put a particular plot.

Each plot created with the subplot command can have its own characteristics. Following example demonstrates the concept:

162

Example

Let us generate two plots:

$y = e^{-1.5x} \sin(10x)$

$y = e^{-2x} \sin(10x)$

Create a script file and type the following code:

```
x = [0:0.01:5];

y = exp(-1.5*x).*sin(10*x);

subplot(1,2,1)

plot(x,y), xlabel('x'),ylabel('exp(-1.5x)*sin(10x)'),axis([0 5 -1 1])

y = exp(-2*x).*sin(10*x);

subplot(1,2,2)

plot(x,y),xlabel('x'),ylabel('exp(-2x)*sin(10x)'),axis([0 5 -1 1])
```

When you run the file, MATLAB generates the following graph:
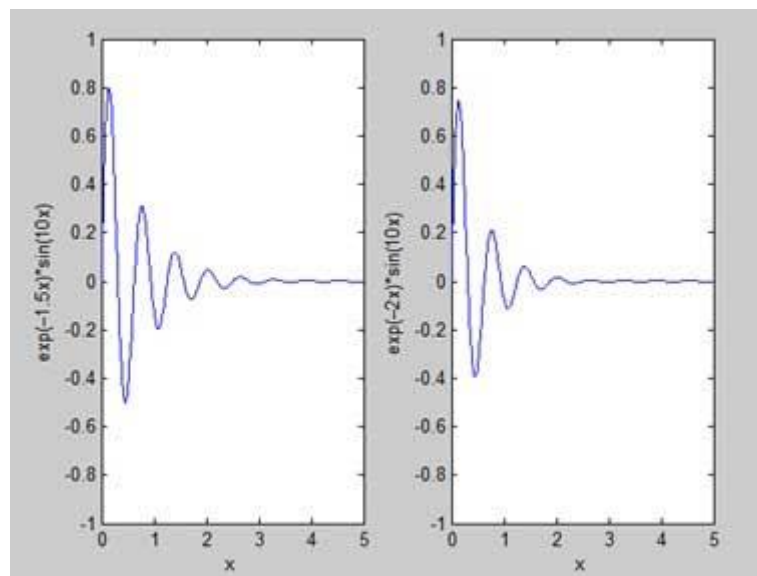
21. GRAPHICS

This chapter will continue exploring the plotting and graphics capabilities of MATLAB. We will discuss:

Drawing bar charts

Drawing contours

Three dimensional plots

Drawing Bar Charts

The **bar** command draws a two dimensional bar chart. Let us take up an example to demonstrate the idea.

Example

Let us have an imaginary classroom with 10 students. We know the percent of marks obtained by these students are 75, 58, 90, 87, 50, 85, 92, 75, 60 and 95. We will draw the bar chart for this data.

Create a script file and type the following code:

```
x = [1:10];

y = [75, 58, 90, 87, 50, 85, 92, 75, 60, 95];

bar(x,y), xlabel('Student'),ylabel('Score'),

title('First Sem:')

print -deps graph.eps
```

When you run the file, MATLAB displays the following bar chart:
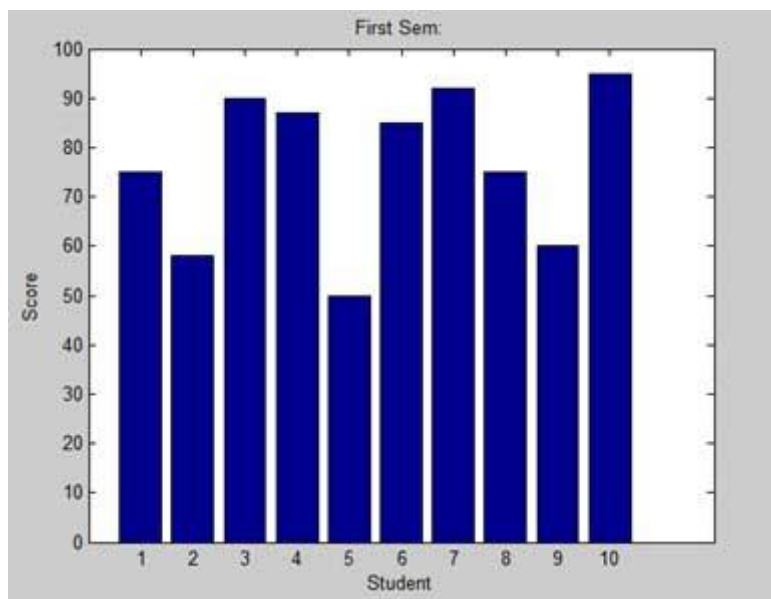
Drawing Contours

A contour line of a function of two variables is a curve along which the function has a constant value. Contour lines are used for creating contour maps by joining points of equal elevation above a given level, such as mean sea level.

MATLAB provides a **contour** function for drawing contour maps.

Example

Let us generate a contour map that shows the contour lines for a given function g = f(x, y). This function has two variables. So, we will have to generate two independent variables, i.e., two data sets x and y. This is done by calling the **meshgrid** command.

The **meshgrid** command is used for generating a matrix of elements that give the range over x and y along with the specification of increment in each case.

Let us plot our function g = f(x, y), where $-5 \leq x \leq 5$, $-3 \leq y \leq 3$. Let us take an increment of 0.1 for both the values. The variables are set as:

```
[x,y] = meshgrid(-5:0.1:5, -3:0.1:3);
```

Lastly, we need to assign the function. Let our function be: $x^2 + y^2$

Create a script file and type the following code:

```
[x,y] = meshgrid(-5:0.1:5,-3:0.1:3); %independent variables
```

165

```
g = x.^2 + y.^2;                        % our function

contour(x,y,g)                          % call the contour function

print -deps graph.eps
```

When you run the file, MATLAB displays the following contour map:
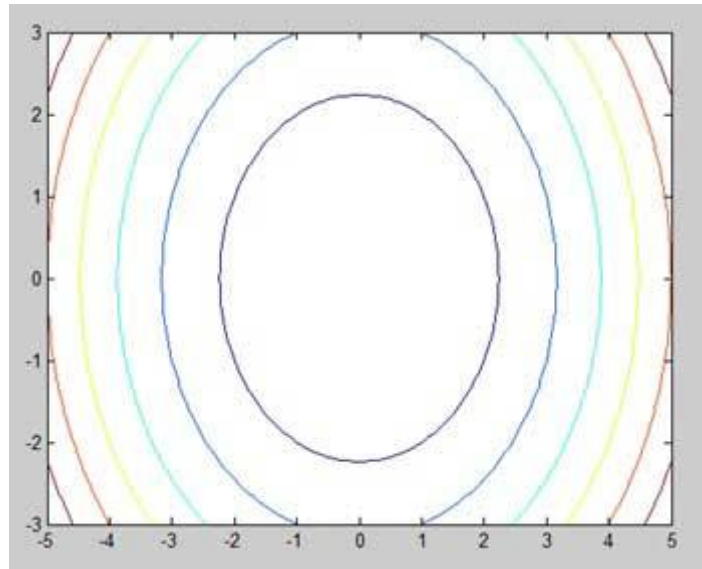
Let us modify the code a little to spruce up the map:

```
[x,y] = meshgrid(-5:0.1:5,-3:0.1:3); %independent variables

g = x.^2 + y.^2;                        % our function

[C, h] = contour(x,y,g);                % call the contour function

set(h,'ShowText','on','TextStep',get(h,'LevelStep')*2)

print -deps graph.eps
```

When you run the file, MATLAB displays the following contour map:
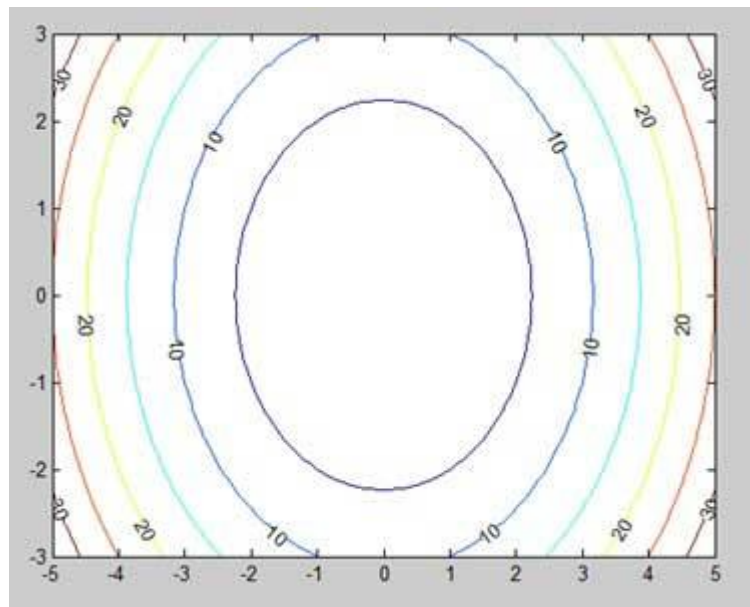
Three-Dimensional Plots

Three-dimensional plots basically display a surface defined by a function in two variables, g = f (x,y).

As before, to define g, we first create a set of (x,y) points over the domain of the function using the **meshgrid** command. Next, we assign the function itself. Finally, we use the **surf** command to create a surface plot.

The following example demonstrates the concept:

Example

Let us create a 3D surface map for the function $g = xe^{-(x^2 + y^2)}$

Create a script file and type the following code:

```
[x,y] = meshgrid(-2:.2:2);

g = x .* exp(-x.^2 - y.^2);

surf(x, y, g)

print -deps graph.eps
```

When you run the file, MATLAB displays the following 3-D map:
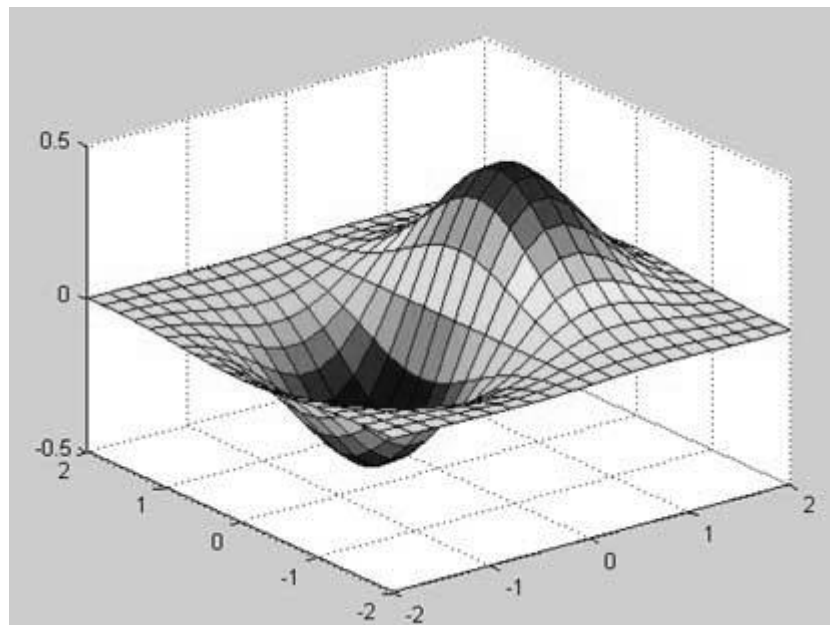
You can also use the **mesh** command to generate a three-dimensional surface. However, the **surf** command displays both the connecting lines and the faces of the surface in color, whereas, the **mesh** command creates a wireframe surface with colored lines connecting the defining points.

22. ALGEBRA

So far, we have seen that all the examples work in MATLAB as well as its GNU, alternatively called Octave. But for solving basic algebraic equations, both MATLAB and Octave are little different, so we will try to cover MATLAB and Octave in separate sections.

We will also discuss factorizing and simplification of algebraic expressions.

Solving Basic Algebraic Equations in MATLAB

The **solve** function is used for solving algebraic equations. In its simplest form, the solve function takes the equation enclosed in quotes as an argument.

For example, let us solve for x in the equation x-5 = 0

```
solve('x-5=0')
```

MATLAB will execute the above statement and return the following result:

```
ans =

 5
```

You can also call the solve function as:

```
y = solve('x-5 = 0')
```

MATLAB will execute the above statement and return the following result:

```
y =

 5
```

You may even not include the right hand side of the equation:

```
solve('x-5')
```

MATLAB will execute the above statement and return the following result:

```
ans =
```

```
5
```

If the equation involves multiple symbols, then MATLAB by default assumes that you are solving for x, however, the solve command has another form:

```
solve(equation, variable)
```

where, you can also mention the variable.

For example, let us solve the equation $v - u - 3t^2 = 0$, for v. In this case, we should write:

```
solve('v-u-3*t^2=0', 'v')
```

MATLAB will execute the above statement and return the following result:

```
ans =

 3*t^2 + u
```

Solving Basic Algebraic Equations in Octave

The **roots** command is used for solving algebraic equations in Octave and you can write above examples as follows:

For example, let us solve for x in the equation x-5 = 0

```
roots([1, -5])
```

Octave will execute the above statement and return the following result:

```
ans =

  5
```

You can also call the solve function as:

```
y = roots([1, -5])
```

Octave will execute the above statement and return the following result:

```
y =

  5
```

Solving Quadratic Equations in MATLAB

The **solve** function can also solve higher order equations. It is often used to solve quadratic equations. The function returns the roots of the equation in an array.

The following example solves the quadratic equation $x^2 -7x +12 = 0$. Create a script file and type the following code:

```
eq = 'x^2 -7*x + 12 = 0';

s = solve(eq);

disp('The first root is: '), disp(s(1));

disp('The second root is: '), disp(s(2));
```

When you run the file, it displays the following result:

```
The first root is:

3

The second root is:

4
```

Solving Quadratic Equations in Octave

The following example solves the quadratic equation $x^2 -7x +12 = 0$ in Octave. Create a script file and type the following code:

```
s = roots([1, -7, 12]);



disp('The first root is: '), disp(s(1));

disp('The second root is: '), disp(s(2));
```

When you run the file, it displays the following result:

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```
The first root is:

 4

The second root is:

 3
```

Solving Higher Order Equations in MATLAB

The **solve** command can also solve higher order equations. For example, let us solve a cubic equation as $(x-3)^2(x-7) = 0$

```
solve('(x-3)^2*(x-7)=0')
```

MATLAB will execute the above statement and return the following result:

```
ans =

   3

   3

   7
```

In case of higher order equations, roots are long containing many terms. You can get the numerical value of such roots by converting them to double. The following example solves the fourth order equation $x^4 - 7x^3 + 3x^2 - 5x + 9 = 0$.

Create a script file and type the following code:

```
eq = 'x^4 - 7*x^3 + 3*x^2 - 5*x + 9 = 0';

s = solve(eq);

disp('The first root is: '), disp(s(1));

disp('The second root is: '), disp(s(2));

disp('The third root is: '), disp(s(3));

disp('The fourth root is: '), disp(s(4));

% converting the roots to double type

disp('Numeric value of first root'), disp(double(s(1)));
```

```
disp('Numeric value of second root'), disp(double(s(2)));

disp('Numeric value of third root'), disp(double(s(3)));

disp('Numeric value of fourth root'), disp(double(s(4)));
```

When you run the file, it returns the following result:

```
The first root is:

6.6303963323907184314850532189985

  The second root is:

1.0597804633025896291682772499885

  The third root is:

- 0.34508839784665403032666523448675 -
1.0778362954630176596831109269793*i

  The fourth root is:

- 0.34508839784665403032666523448675 +
1.0778362954630176596831109269793*i

Numeric value of first root

    6.6304

Numeric value of second root

    1.0598

Numeric value of third root

  -0.3451 - 1.0778i

Numeric value of fourth root

  -0.3451 + 1.0778i
```

Please note that the last two roots are complex numbers.

Solving Higher Order Equations in Octave

The following example solves the fourth order equation $x^4 - 7x^3 + 3x^2 - 5x + 9 = 0$.

Create a script file and type the following code:

```
v = [1, -7,  3, -5, 9];



s = roots(v);

% converting the roots to double type

disp('Numeric value of first root'), disp(double(s(1)));

disp('Numeric value of second root'), disp(double(s(2)));

disp('Numeric value of third root'), disp(double(s(3)));

disp('Numeric value of fourth root'), disp(double(s(4)));
```

When you run the file, it returns the following result:

```
Numeric value of first root

 6.6304

Numeric value of second root

-0.34509 + 1.07784i

Numeric value of third root

-0.34509 - 1.07784i

Numeric value of fourth root

 1.0598
```

Solving System of Equations in MATLAB

The **solve** function can also be used to generate solutions of systems of equations involving more than one variables. Let us take up a simple example to demonstrate this use.

Let us solve the equations:

$5x + 9y = 5$

$3x - 6y = 4$

Create a script file and type the following code:

```
s = solve('5*x + 9*y = 5','3*x - 6*y = 4');
s.x
s.y
```

When you run the file, it displays the following result:

```
ans =

 22/19

ans =

-5/57
```

In same way, you can solve larger linear systems. Consider the following set of equations:

$x + 3y - 2z = 5$

$3x + 5y + 6z = 7$

$2x + 4y + 3z = 8$

Solving System of Equations in Octave

We have a little different approach to solve a system of 'n' linear equations in 'n' unknowns. Let us take up a simple example to demonstrate this use.

Let us solve the equations:

$5x + 9y = 5$

$3x - 6y = 4$

Such a system of linear equations can be written as the single matrix equation Ax = b, where A is the coefficient matrix, b is the column vector containing the right-hand side of the linear equations and x is the column vector representing the solution as shown in the below program:

Create a script file and type the following code:

```
A = [5, 9; 3, -6];

b = [5;4];

A \ b
```

When you run the file, it displays the following result:

```
ans =


   1.157895

  -0.087719
```

In same way, you can solve larger linear systems as given below:

x + 3y -2z = 5

3x + 5y + 6z = 7

2x + 4y + 3z = 8

Expanding and Collecting Equations in MATLAB

The **expand** and the **collect** commands expands and collects an equation respectively. The following example demonstrates the concepts:

When you work with many symbolic functions, you should declare that your variables are symbolic.

Create a script file and type the following code:

```
syms x %symbolic variable x

syms y %symbolic variable x

% expanding equations

expand((x-5)*(x+9))

expand((x+2)*(x-3)*(x-5)*(x+7))

expand(sin(2*x))

expand(cos(x+y))
```

```
% collecting equations

collect(x^3 *(x-7))

collect(x^4*(x-3)*(x-5))
```

When you run the file, it displays the following result:

```
ans =

 x^2 + 4*x - 45

 ans =

 x^4 + x^3 - 43*x^2 + 23*x + 210

 ans =

 2*cos(x)*sin(x)

 ans =

cos(x)*cos(y) - sin(x)*sin(y)

 ans =

 x^4 - 7*x^3

 ans =

 x^6 - 8*x^5 + 15*x^4
```

Expanding and Collecting Equations in Octave

You need to have **symbolic** package, which provides **expand** and **collect** command to expand and collect an equation, respectively. The following example demonstrates the concepts:

When you work with many symbolic functions, you should declare that your variables are symbolic but Octave has different approach to define symbolic variables. Notice the use of **Sin** and **Cos** which are also defined in symbolic package.

Create a script file and type the following code:

```
% first of all load the package, make sure it's installed.
```

```
pkg load symbolic


% make symbols module available

symbols


% define symbolic variables

x = sym ('x');

y = sym ('y');

z = sym ('z');


% expanding equations

expand((x-5)*(x+9))

expand((x+2)*(x-3)*(x-5)*(x+7))

expand(Sin(2*x))

expand(Cos(x+y))


% collecting equations

collect(x^3 *(x-7), z)

collect(x^4*(x-3)*(x-5), z)
```

When you run the file, it displays the following result:

```
ans =


-45.0+x^2+(4.0)*x

ans =


210.0+x^4-(43.0)*x^2+x^3+(23.0)*x
```

```
ans =


sin((2.0)*x)

ans =


cos(y+x)

ans =


x^(3.0)*(-7.0+x)

ans =


(-3.0+x)*x^(4.0)*(-5.0+x)
```

Factorization and Simplification of Algebraic Expressions

The **factor** function factorizes an expression and the **simplify** function simplifies an expression. The following example demonstrates the concept:

Example

Create a script file and type the following code:

```
syms x

syms y

factor(x^3 - y^3)

factor([x^2-y^2,x^3+y^3])

simplify((x^4-16)/(x^2-4))
```

When you run the file, it displays the following result:

```
ans =

(x - y)*(x^2 + x*y + y^2)
```

```
ans =

[ (x - y)*(x + y), (x + y)*(x^2 - x*y + y^2)]

ans =

x^2 + 4
```

23. 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.

This chapter will deal with problems of calculus.. In this chapter, we will discuss pre-calculus concepts i.e., calculating limits of functions and verifying the properties of limits.

In the next chapter *Differential*, we will compute derivative of an expression and find the local maxima and minima on a graph. We will also discuss solving differential equations.

Finally, in the *Integration* chapter, we will discuss integral calculus.

Calculating Limits

MATLAB provides the **limit** command for calculating limits. In its most basic form, the **limit** command takes expression as an argument and finds the limit of the expression as the independent variable goes to zero.

For example, let us calculate the limit of a function f(x) = $(x^3 + 5)/(x^4 + 7)$, as x tends to zero.

```
syms x

limit((x^3 + 5)/(x^4 + 7))
```

MATLAB will execute the above statement and return the following result:

```
ans =

 5/7
```

The **limit** function falls in the realm of symbolic computing; you need to use the **syms** function to tell MATLAB which symbolic variables you are using. You can also compute limit of a function, as the variable tends to some number other than zero. To calculate lim $_{x->a}$(f(x)), we use the limit command with arguments. The first being the expression and the second is the number, that *x* approaches, here it is *a*.

For example, let us calculate limit of a function f(x) = (x-3)/(x-1), as x tends to 1.

```
limit((x - 3)/(x-1),1)
```

MATLAB will execute the above statement and return the following result:

```
ans =

  NaN
```

Let's take another example,

```
limit(x^2 + 5, 3)
```

MATLAB will execute the above statement and return the following result:

```
ans =

  14
```

Calculating Limits using Octave

Following is Octave version of the above example using **symbolic** package, try to execute and compare the result:

```
pkg load symbolic

symbols

x=sym("x");


subs((x^3+5)/(x^4+7),x,0)
```

Octave will execute the above statement and return the following result:

```
ans =

0.7142857142857142857

Verification of Basic Properties of Limits
```

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

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

Let us consider two functions:

f(x) = (3x + 5)/(x - 3)

g(x) = x² + 1.

Let us calculate the limits of the functions as x tends to 5, of both functions and verify the basic properties of limits using these two functions and MATLAB.

Example

Create a script file and type the following code into it:

```
syms x

f = (3*x + 5)/(x-3);

g = x^2 + 1;

l1 = limit(f, 4)

l2 = limit (g, 4)

lAdd = limit(f + g, 4)

lSub = limit(f - g, 4)

lMult = limit(f*g, 4)

lDiv = limit (f/g, 4)
```

When you run the file, it displays:

```
l1 =

 17


l2 =
```

```
17


lAdd =

 34


lSub =

 0


lMult =

289


lDiv =

1
```

Verification of Basic Properties of Limits using Octave

Following is Octave version of the above example using **symbolic** package, try to execute and compare the result:

```
pkg load symbolic

symbols


x = sym("x");

f = (3*x + 5)/(x-3);

g = x^2 + 1;


l1=subs(f, x, 4)

l2 = subs (g, x, 4)

lAdd = subs (f+g, x, 4)
```

tutorialspoint
SIMPLYEASYLEARNING

```
lSub = subs (f-g, x, 4)

lMult = subs (f*g, x, 4)

lDiv = subs (f/g, x, 4)
```

Octave will execute the above statement and return the following result:

```
l1 =


17.0

l2 =


17.0

lAdd =


34.0

lSub =


0.0

lMult =


289.0

lDiv =


1.0
```

Left and Right Sided Limits

When a function has a discontinuity for some particular value of the variable, the limit does not exist at that point. In other words, limits of a function $f(x)$ has

tutorialspoint
SIMPLYEASYLEARNING

discontinuity at x = a, when the value of limit, as x approaches x from left side, does not equal the value of the limit as x approaches from right side.

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 limit are not equal, the limit does not exist.

Let us consider a function:

f(x) = (x - 3)/|x - 3|

We will show that $\lim_{x\to3} f(x)$ does not exist. MATLAB helps us to establish this fact in two ways:

By plotting the graph of the function and showing the discontinuity

By computing the limits and showing that both are different.

The left-handed and right-handed limits are computed by passing the character strings 'left' and 'right' to the limit command as the last argument.

Example

Create a script file and type the following code into it:

```
f = (x - 3)/abs(x-3);

ezplot(f,[-1,5])

l = limit(f,x,3,'left')

r = limit(f,x,3,'right')
```

When you run the file, MATLAB draws the following plot,
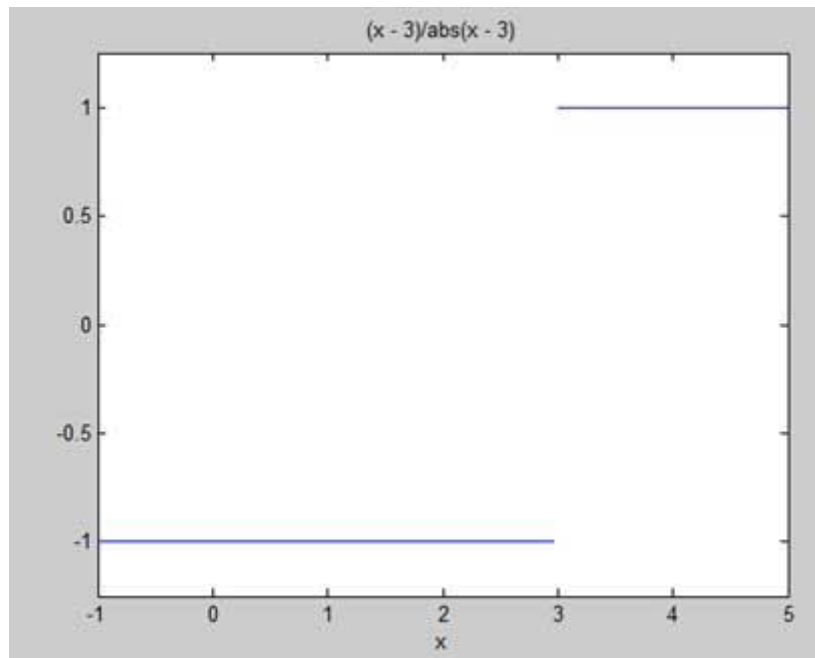
and displays the following output:

```
l =

  -1


r =

1
```

24. DIFFERENTIAL

MATLAB provides the **diff** command for computing symbolic derivatives. In its simplest form, you pass the function you want to differentiate to diff command as an argument.

For example, let us compute the derivative of the function $f(t) = 3t^2 + 2t^{-2}$

Example

Create a script file and type the following code into it:

```
syms t

f = 3*t^2 + 2*t^(-2);

diff(f)
```

When the above code is compiled and executed, it produces the following result:

```
ans =

6*t - 4/t^3
```

Following is Octave equivalent of the above calculation:

```
pkg load symbolic

symbols


t = sym("t");

f = 3*t^2 + 2*t^(-2);

differentiate(f,t)
```

Octave executes the code and returns the following result:

```
ans =



-(4.0)*t^(-3.0)+(6.0)*t
```

Verification of Elementary Rules of Differentiation

Let us briefly state various equations or rules for differentiation of functions and verify these rules. For this purpose, we will write f'(x) for a first order derivative and f"(x) for a second order derivative.

Following are the rules for differentiation:

Rule 1

For any functions f and g and any real numbers a and b are the derivative of the function:

h(x) = af(x) + bg(x) with respect to x is given by:

h'(x) = af'(x) + bg'(x)

Rule 2

The **sum** and **subtraction** rules state that if f and g are two functions, f' and g' are their derivatives respectively, then,

(f + g)' = f' + g'

(f - g)' = f' - g'

Rule 3

The **product** rule states that if f and g are two functions, f' and g' are their derivatives respectively, then,

(f.g)' = f'.g + g'.f

Rule 4

The **quotient** rule states that if f and g are two functions, f' and g' are their derivatives respectively, then,

(f/g)' = (f'.g - g'.f)/g²

Rule 5

The **polynomial** or elementary power rule states that, if **y = f(x) = x^n**, then **f' = n. x$^{(n-1)}$**

189

A direct outcome of this rule is that the derivative of any constant is zero, i.e., if **y = k**, any constant, then

> **f' = 0**

Rule 6

The **chain** rule states that, the derivative of the function of a function **h(x) = f(g(x))** with respect to x is,

> **h'(x)= f'(g(x)).g'(x)**

Example

Create a script file and type the following code into it:

```
syms x

syms t

f = (x + 2)*(x^2 + 3)

der1 = diff(f)

f = (t^2 + 3)*(sqrt(t) + t^3)

der2 = diff(f)

f = (x^2 - 2*x + 1)*(3*x^3 - 5*x^2 + 2)

der3 = diff(f)

f = (2*x^2 + 3*x)/(x^3 + 1)

der4 = diff(f)

f = (x^2 + 1)^17

der5 = diff(f)

f = (t^3 + 3* t^2 + 5*t -9)^(-6)

der6 = diff(f)
```

When you run the file, MATLAB displays the following result:

```
f =

 (x^2 + 3)*(x + 2)

```

```
 der1 =

 2*x*(x + 2) + x^2 + 3


f =

 (t^(1/2) + t^3)*(t^2 + 3)


 der2 =

 (t^2 + 3)*(3*t^2 + 1/(2*t^(1/2))) + 2*t*(t^(1/2) + t^3)


f =

 (x^2 - 2*x + 1)*(3*x^3 - 5*x^2 + 2)


der3 =

 (2*x - 2)*(3*x^3 - 5*x^2 + 2) - (- 9*x^2 + 10*x)*(x^2 - 2*x + 1)


 f =

 (2*x^2 + 3*x)/(x^3 + 1)


der4 =

 (4*x + 3)/(x^3 + 1) - (3*x^2*(2*x^2 + 3*x))/(x^3 + 1)^2


f =

 (x^2 + 1)^17


der5 =

 34*x*(x^2 + 1)^16
```

```
f =

1/(t^3 + 3*t^2 + 5*t - 9)^6



der6 =

 -(6*(3*t^2 + 6*t + 5))/(t^3 + 3*t^2 + 5*t - 9)^7
```

Following is Octave equivalent of the above calculation:

```
pkg load symbolic

symbols

x=sym("x");

t=sym("t");

f = (x + 2)*(x^2 + 3)

der1 = differentiate(f,x)

f = (t^2 + 3)*(t^(1/2) + t^3)

der2 = differentiate(f,t)

f = (x^2 - 2*x + 1)*(3*x^3 - 5*x^2 + 2)

der3 = differentiate(f,x)

f = (2*x^2 + 3*x)/(x^3 + 1)

der4 = differentiate(f,x)

f = (x^2 + 1)^17

der5 = differentiate(f,x)

f = (t^3 + 3* t^2 + 5*t -9)^(-6)

der6 = differentiate(f,t)
```

Derivatives of Exponential, Logarithmic, and Trigonometric Functions

The following table provides the derivatives of commonly used exponential, logarithmic and trigonometric functions:

Function	Derivative
$c^{a.x}$	$c^{a.x}.\ln c.a$ (ln is natural logarithm)
e^x	e^x
$\ln x$	$1/x$
$\ln_c x$	$1/x.\ln c$
x^x	$x^x.(1 + \ln x)$
sin(x)	cos(x)
cos(x)	-sin(x)
tan(x)	$\sec^2(x)$, or $1/\cos^2(x)$, or $1 + \tan^2(x)$
cot(x)	$-\csc^2(x)$, or $-1/\sin^2(x)$, or $-(1 + \cot^2(x))$
sec(x)	sec(x).tan(x)
csc(x)	-csc(x).cot(x)

Example

Create a script file and type the following code into it:

```
syms x

y = exp(x)

diff(y)

y = x^9
```

193

```
diff(y)

y = sin(x)

diff(y)

y = tan(x)

diff(y)

y = cos(x)

diff(y)

y = log(x)

diff(y)

y = log10(x)

diff(y)

y = sin(x)^2

diff(y)

y = cos(3*x^2 + 2*x + 1)

diff(y)

y = exp(x)/sin(x)

diff(y)
```

When you run the file, MATLAB displays the following result:

```
y =

 exp(x)

 ans =

 exp(x)




y =

x^9
```

```
ans =

9*x^8


y =

 sin(x)

 ans =

 cos(x)


y =

 tan(x)

ans =

 tan(x)^2 + 1


 y =

 cos(x)

 ans =

 -sin(x)


y =

 log(x)

 ans =

 1/x


y =

 log(x)/log(10)

 ans =
```

```
 1/(x*log(10))


y =

 sin(x)^2

  ans =

 2*cos(x)*sin(x)



 y =



cos(3*x^2 + 2*x + 1)

 ans =

 -sin(3*x^2 + 2*x + 1)*(6*x + 2)



y =

 exp(x)/sin(x)

 ans =

 exp(x)/sin(x) - (exp(x)*cos(x))/sin(x)^2
```

Following is Octave equivalent of the above calculation:

```
pkg load symbolic

symbols


x = sym("x");

y = Exp(x)

differentiate(y,x)


y = x^9
```

```
differentiate(y,x)


y = Sin(x)

differentiate(y,x)


y = Tan(x)

differentiate(y,x)


y = Cos(x)

differentiate(y,x)


y = Log(x)

differentiate(y,x)


% symbolic packages does not have this support
%y = Log10(x)
%differentiate(y,x)


y = Sin(x)^2

differentiate(y,x)


y = Cos(3*x^2 + 2*x + 1)

differentiate(y,x)


y = Exp(x)/Sin(x)

differentiate(y,x)
```

Computing Higher Order Derivatives

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

Let us compute the second derivative of the function $y = f(x) = x \cdot e^{-3x}$

```
f = x*exp(-3*x);

diff(f, 2)
```

MATLAB executes the code and returns the following result:

```
ans =

9*x*exp(-3*x) - 6*exp(-3*x)
```

Following is Octave equivalent of the above calculation:

```
pkg load symbolic

symbols


x = sym("x");

f = x*Exp(-3*x);


differentiate(f, x, 2)
```

Example

In this example, let us 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.

Create a script file and type the following code into it:

```
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(isequal(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);
```

When you run the file, it displays the following result:

```
No, the equation does not hold true

Value of LHS is:

-168*cos(5*x)
```

Following is Octave equivalent of the above calculation:

```
pkg load symbolic

symbols


x = sym("x");

y = 3*Sin(x)+7*Cos(5*x);          % defining the function

lhs = differentiate(y, x, 2) + y;  %evaluting 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);
```

Finding the Maxima and Minima of a Curve

If we are searching for the local maxima and minima for a graph, we are basically looking for the highest or lowest points on the graph of the function at a particular locality, or for a particular range of values of the symbolic variable.

For a function y = f(x) the points on the graph where the graph has zero slope are called **stationary points**. In other words stationary points are where f'(x) = 0.

To find the stationary points of a function we differentiate, we need to set the derivative equal to zero and solve the equation.

Example

Let us find the stationary points of the function $f(x) = 2x^3 + 3x^2 - 12x + 17$

Take the following steps:

First let us enter the function and plot its graph:

```
syms x

y = 2*x^3 + 3*x^2 - 12*x + 17;  % defining the function

ezplot(y)
```

MATLAB executes the code and returns the following plot:
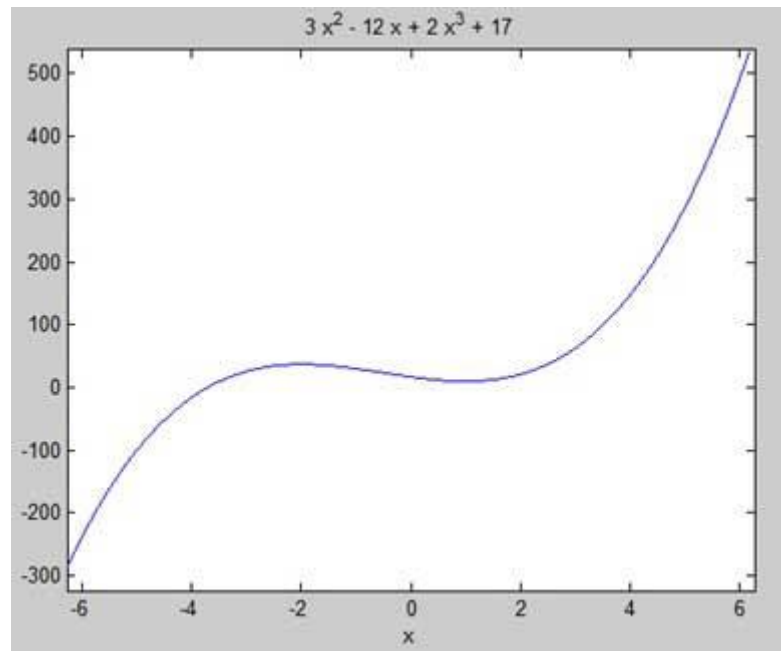
$3x^2 - 12x + 2x^3 + 17$

Here is Octave equivalent code for the above example:

```
pkg load symbolic

symbols


x = sym('x');

y = inline("2*x^3 + 3*x^2 - 12*x + 17");


ezplot(y)

print -deps graph.eps
```

Our aim is to find some local maxima and minima on the graph, so let us find the local maxima and minima for the interval [-2, 2] on the graph.

```
syms x

y = 2*x^3 + 3*x^2 - 12*x + 17;  % defining the function

ezplot(y, [-2, 2])
```

MATLAB executes the code and returns the following plot:
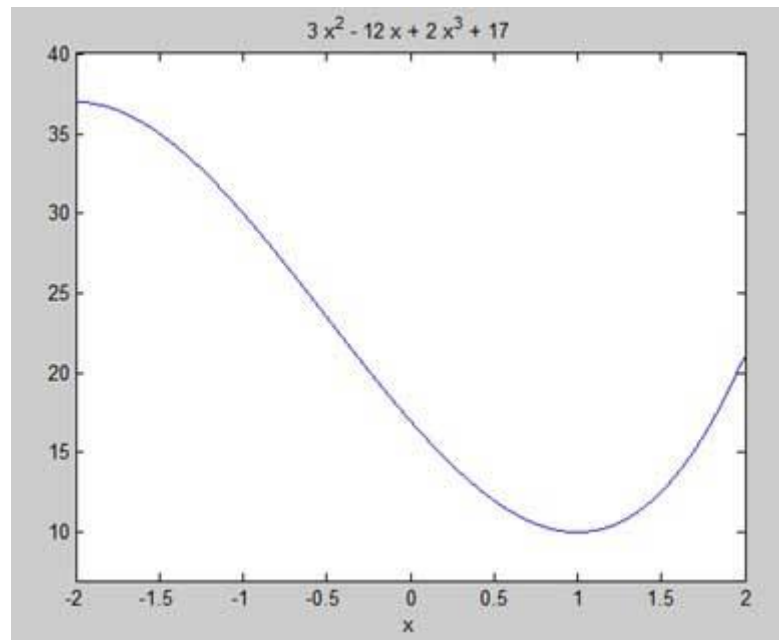
Here is Octave equivalent code for the above example:

```
pkg load symbolic

symbols

x = sym('x');

y = inline("2*x^3 + 3*x^2 - 12*x + 17");

ezplot(y, [-2, 2])

print -deps graph.eps
```

Next, let us compute the derivative

```
g = diff(y)
```

MATLAB executes the code and returns the following result:

```
g =

6*x^2 + 6*x - 12
```

Here is Octave equivalent of the above calculation:

```
pkg load symbolic

symbols


x = sym("x");


y = 2*x^3 + 3*x^2 - 12*x + 17;

g = differentiate(y,x)
```

Let us solve the derivative function, g, to get the values where it becomes zero.

```
s = solve(g)
```

MATLAB executes the code and returns the following result:

```
s =

     1

    -2
```

Following is Octave equivalent of the above calculation:

```
pkg load symbolic

symbols


x = sym("x");


y = 2*x^3 + 3*x^2 - 12*x + 17;

g = differentiate(y,x)

roots([6, 6, -12])
```

This agrees with our plot. So let us evaluate the function f at the critical points x = 1, -2. We can substitute a value in a symbolic function by using the **subs** command.

```
subs(y, 1), subs(y, -2)
```

MATLAB executes the code and returns the following result:

```
ans =

 10

ans =

 37
```

Following is Octave equivalent of the above calculation:

```
pkg load symbolic

symbols


x = sym("x");


y = 2*x^3 + 3*x^2 - 12*x + 17;

g = differentiate(y,x)


roots([6, 6, -12])


subs(y, x, 1), subs(y, x, -2)
```

Therefore, The minimum and maximum values on the function f(x) = $2x^3$ + $3x^2$ − 12x + 17, in the interval [-2,2] are 10 and 37.

Solving Differential Equations

MATLAB provides the **dsolve** command for solving differential equations symbolically.

The most basic form of the **dsolve** command 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 a set of arbitrary constants that MATLAB labels C1, C2, and so on.

You can also specify initial and boundary conditions for the problem, as comma-delimited list following the equation as:

```
dsolve('eqn','cond1',  'cond2',…)
```

For the purpose of using dsolve command, **derivatives are indicated with a D**. For example, an equation like f'(t) = -2*f + cost(t) is entered as:

'Df = -2*f + cos(t)'

Higher derivatives are indicated by following D by the order of the derivative.

For example the equation f"(x) + 2f'(x) = 5sin3x should be entered as:

'D2y + 2Dy = 5*sin(3*x)'

Let us take up a simple example of a first order differential equation: y' = 5y.

```
s = dsolve('Dy = 5*y')
```

MATLAB executes the code and returns the following result:

```
s =

 C2*exp(5*t)
```

Let us take up another example of a second order differential equation as: y" - y = 0, y(0) = -1, y'(0) = 2.

```
dsolve('D2y - y = 0','y(0) = -1','Dy(0) = 2')
```

MATLAB executes the code and returns the following result:

```
ans =

 exp(t)/2 - (3*exp(-t))/2
```

25. INTEGRATION

Integration deals with two essentially different types of problems.

In the first type, derivative of a function is given and we want to find the function. Therefore, we basically reverse the process of differentiation. This reverse process is known as anti-differentiation, or finding the primitive function, or finding an **indefinite integral**.

The second type of problems involve adding up a very large number of very small quantities and then taking a limit as the size of the quantities approaches zero, while the number of terms tend to infinity. This process leads to the definition of the **definite integral**.

Definite integrals are used for finding area, volume, center of gravity, moment of inertia, work done by a force, and in numerous other applications.

Finding Indefinite Integral Using MATLAB

By definition, if the derivative of a function f(x) is f'(x), then we say that an indefinite integral of f'(x) with respect to x is f(x). For example, since the derivative (with respect to x) of x^2 is 2x, we can say that an indefinite integral of 2x is x^2.

In symbols:

f'(x^2) = 2x, therefore,

∫ 2xdx = x^2.

Indefinite integral is not unique, because derivative of x^2 + c, for any value of a constant c, will also be 2x.

This is expressed in symbols as:

∫ 2xdx = x^2 + c.

Where, c is called an 'arbitrary constant'.

MATLAB provides an **int** command for calculating integral of an expression. To derive an expression for the indefinite integral of a function, we write:

```
int(f);
```

For example, from our previous example:

```
syms x
```

```
int(2*x)
```

MATLAB executes the above statement and returns the following result:

```
ans =

 x^2
```

Example 1

In this example, let us find the integral of some commonly used expressions. Create a script file and type the following code in it:

```
syms x n

int(sym(x^n))

f = 'sin(n*t)'

int(sym(f))

syms a t

int(a*cos(pi*t))

int(a^x)
```

When you run the file, it displays the following result:

```
ans =

 piecewise([n == -1, log(x)], [n ~= -1, x^(n + 1)/(n + 1)])

f =

sin(n*t)

ans =

 -cos(n*t)/n

 ans =

 (a*sin(pi*t))/pi

 ans =

 a^x/log(a)
```

Example 2

Create a script file and type the following code in it:

```
syms x n

int(cos(x))

int(exp(x))

int(log(x))

int(x^-1)

int(x^5*cos(5*x))

pretty(int(x^5*cos(5*x)))

int(x^-5)

int(sec(x)^2)

pretty(int(1 - 10*x + 9 * x^2))

int((3 + 5*x -6*x^2 - 7*x^3)/2*x^2)

pretty(int((3 + 5*x -6*x^2 - 7*x^3)/2*x^2))
```

Note that the **pretty** command returns an expression in a more readable format.

When you run the file, it displays the following result:

```
ans =


sin(x)




ans =


exp(x)


```

```
ans =

x*(log(x) - 1)


ans =

log(x)


ans =

(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



                                2              4
  24 cos(5 x)   24 x sin(5 x)   12 x  cos(5 x)   x  cos(5 x)
  ----------- + ------------- - -------------- + ----------- -
     3125            625             125              5


       3              5
    4 x  sin(5 x)   x  sin(5 x)
    ------------- + -----------
         25              5
```

```
ans =


-1/(4*x^4)



ans =


tan(x)



          2
  x (3 x  - 5 x + 1)



ans =


- (7*x^6)/12 - (3*x^5)/5 + (5*x^4)/8 + x^3/2



        6       5       4      3
    7 x     3 x     5 x      x
  - ---- - ---- + ---- + --
     12      5       8      2
```

Finding Definite Integral Using MATLAB

By definition, definite integral is basically the limit of a sum. We use definite integrals to find areas such as the area between a curve and the x-axis and the area between two curves. Definite integrals can also be used in other situations, where the quantity required can be expressed as the limit of a sum.

210

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

To calculate

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

we write,

```
int(x, a, b)
```

For example, to calculate the value of $\int_4^9 x\,dx$ we write:

```
int(x, 4, 9)
```

MATLAB executes the above statement and returns the following result:

```
ans =

 65/2
```

Following is Octave equivalent of the above calculation:

```
pkg load symbolic

symbols


x = sym("x");


f = x;


c = [1, 0];
integral = polyint(c);


a = polyval(integral, 9) - polyval(integral, 4);
```

```
display('Area: '), disp(double(a));

An alternative solution can be given using quad() function provided by
Octave as follows:

pkg load symbolic

symbols


f = inline("x");

[a, ierror, nfneval] = quad(f, 4, 9);


display('Area: '), disp(double(a));
```

Example 1

Let us calculate the area enclosed between the x-axis, and the curve y = x³−2x+5
and the ordinates x = 1 and x = 2.

The required area is given by:

$$A = \int_{1}^{2}(x^3 - 2x + 5)dx$$

Create a script file and type the following code:

```
f = x^3 - 2*x +5;

a = int(f, 1, 2)

display('Area: '), disp(double(a));
```

When you run the file, it displays the following result:

```
a =

23/4

Area:

   5.7500
```

Following is Octave equivalent of the above calculation:

```
pkg load symbolic

symbols


x = sym("x");


f = x^3 - 2*x +5;


c = [1, 0, -2, 5];
integral = polyint(c);


a = polyval(integral, 2) - polyval(integral, 1);


display('Area: '), disp(double(a));
```

An alternative solution can be given using quad() function provided by Octave as follows:

```
pkg load symbolic

symbols


x = sym("x");


f = inline("x^3 - 2*x +5");


[a, ierror, nfneval] = quad(f, 1, 2);

display('Area: '), disp(double(a));
```

Example 2

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

Create a script file and write the following code:

```
f = x^2*cos(x);

ezplot(f, [-4,9])

a = int(f, -4, 9)

disp('Area: '), disp(double(a));
```

When you run the file, MATLAB plots the graph:
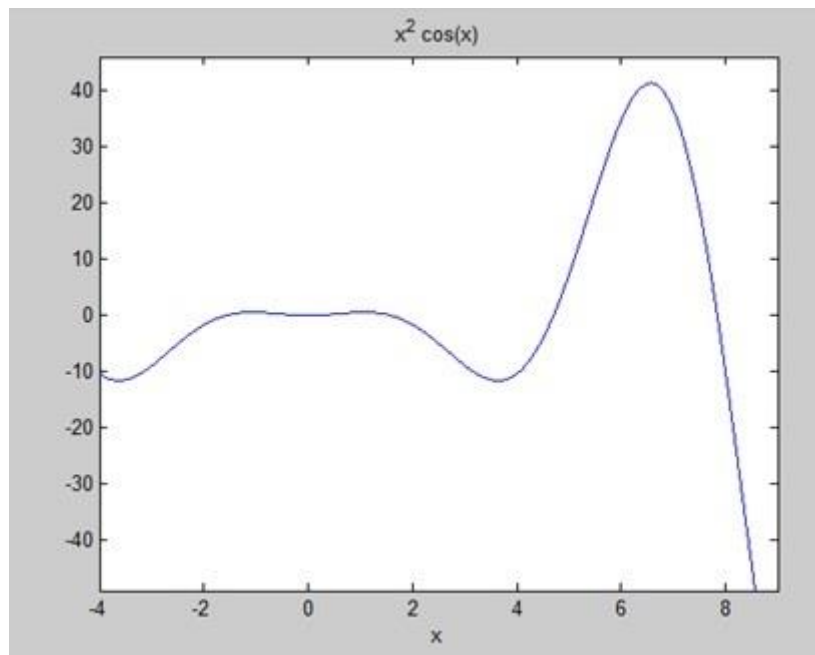
The output is given below:

```
a =



8*cos(4) + 18*cos(9) + 14*sin(4) + 79*sin(9)



Area:

   0.3326
```

Following is the Octave equivalent of the above calculation:

tutorialspoint
SIMPLYEASYLEARNING

```
pkg load symbolic

symbols


x = sym("x");


f = inline("x^2*cos(x)");


ezplot(f, [-4,9])
print -deps graph.eps


[a, ierror, nfneval] = quad(f, -4, 9);


display('Area: '), disp(double(a));
```

26. POLYNOMIALS

MATLAB represents polynomials as row vectors containing coefficients ordered by descending powers. For example, the equation $P(x) = x^4 + 7x^3 - 5x + 9$ could be represented as:

p = [1 7 0 -5 9];

Evaluating Polynomials

The **polyval** function is used for evaluating a polynomial at a specified value. For example, to evaluate our previous polynomial **p**, at x = 4, type:

```
p = [1 7 0  -5 9];

polyval(p,4)
```

MATLAB executes the above statements and returns the following result:

```
ans =

   693
```

MATLAB also provides the **polyvalm** function for evaluating a matrix polynomial. A matrix polynomial is a **polynomial** with matrices as variables.

For example, let us create a square matrix X and evaluate the polynomial p, at X:

```
p = [1 7 0  -5 9];

X = [1 2 -3 4; 2 -5 6 3; 3 1 0 2; 5 -7 3 8];

polyvalm(p, X)
```

MATLAB executes the above statements and returns the following result:

```
ans =

      2307        -1769        -939         4499

      2314        -2376        -249         4695

      2256        -1892        -549         4310
```

```
        4570        -4532        -1062        9269
```

Finding the Roots of Polynomials

The **roots** function calculates the roots of a polynomial. For example, to calculate the roots of our polynomial p, type:

```
p = [1 7 0  -5 9];

r = roots(p)
```

MATLAB executes the above statements and returns the following result:

```
r =

  -6.8661 + 0.0000i

  -1.4247 + 0.0000i

   0.6454 + 0.7095i

   0.6454 - 0.7095i
```

The function **poly** is an inverse of the roots function and returns to the polynomial coefficients. For example:

```
p2 = poly(r)
```

MATLAB executes the above statements and returns the following result:

```
p2 =

    1.0000    7.0000    0.0000    -5.0000    9.0000
```

Polynomial Curve Fitting

The **polyfit** function finds the coefficients of a polynomial that fits a set of data in a least-squares sense. If x and y are two vectors containing the x and y data to be fitted to a n-degree polynomial, then we get the polynomial fitting the data by writing:

```
p = polyfit(x,y,n)
```

Example

Create a script file and type the following code:

```
x = [1 2 3 4 5 6]; y = [5.5 43.1 128 290.7 498.4 978.67];  %data

p = polyfit(x,y,4)    %get the polynomial

% Compute the values of the polyfit estimate over a finer range,

% and plot the estimate over the real data values for comparison:

x2 = 1:.1:6;

y2 = polyval(p,x2);

plot(x,y,'o',x2,y2)

grid on
```

When you run the file, MATLAB displays the following result:

```
p =

    4.1056  -47.9607  222.2598 -362.7453  191.1250
```

The following graph will be plotted:
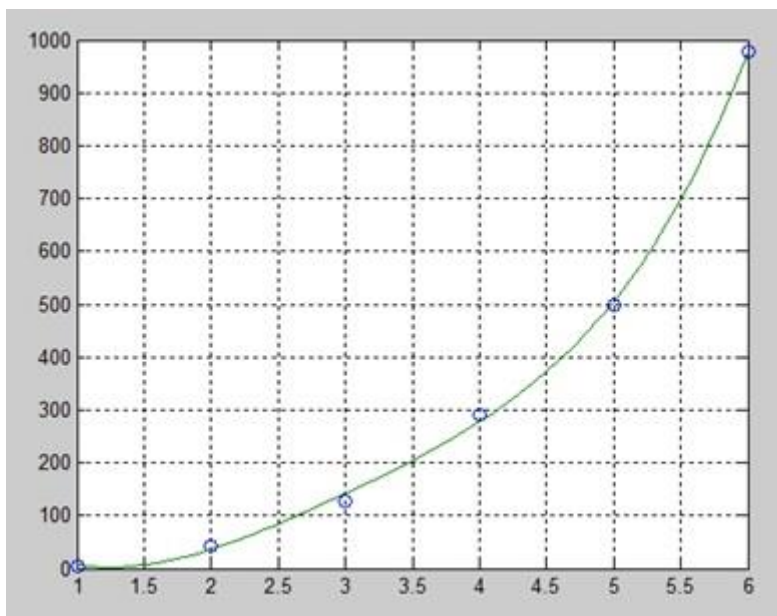
27. TRANSFORMS

MATLAB provides command for working with transforms, such as the Laplace and Fourier transforms. Transforms are used in science and engineering as a tool for simplifying analysis and look at data from another angle.

For example, the Fourier transform allows us to convert a signal represented as a function of time to a function of frequency. Laplace transform allows us to convert a differential equation to an algebraic equation.

MATLAB provides the **laplace**, **fourier** and **fft** commands to work with Laplace, Fourier and Fast Fourier transforms.

The Laplace Transform

The Laplace transform of a function of time f(t) is given by the following integral:

$$l\{f(t)\} = \int_0^\infty f(t).e^{-st}\,dt$$

Laplace transform is also denoted as transform of f(t) to F(s). You can see this transform or integration process converts f(t), a function of the symbolic variable t, into another function F(s), with another variable s.

Laplace transform turns differential equations into algebraic ones. To compute a Laplace transform of a function f(t), write:

```
laplace(f(t))
```

Example

In this example, we will compute the Laplace transform of some commonly used functions.

Create a script file and type the following code:

```
syms s t a b w

laplace(a)

laplace(t^2)

laplace(t^9)

laplace(exp(-b*t))
```

tutorialspoint
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```
laplace(sin(w*t))

laplace(cos(w*t))
```

When you run the file, it displays the following result:

```
ans =

 1/s^2


 ans =

 2/s^3


 ans =

 362880/s^10


 ans =

 1/(b + s)


ans =

 w/(s^2 + w^2)


ans =

 s/(s^2 + w^2)
```

The Inverse Laplace Transform

MATLAB allows us to compute the inverse Laplace transform using the command **ilaplace**.

For example,

```
ilaplace(1/s^3)
```

MATLAB will execute the above statement and display the result:

```
ans =

 t^2/2
```

Example

Create a script file and type the following code:

```
syms s t a b w

ilaplace(1/s^7)

ilaplace(2/(w+s))

ilaplace(s/(s^2+4))

ilaplace(exp(-b*t))

ilaplace(w/(s^2 + w^2))

ilaplace(s/(s^2 + w^2))
```

When you run the file, it displays the following result:

```
ans =

t^6/720


 ans =

 2*exp(-t*w)


 ans =

 cos(2*t)


 ans =

 ilaplace(exp(-b*t), t, x)
```

```
 ans =

 sin(t*w)



 ans =

 cos(t*w)
```

The Fourier Transforms

Fourier transforms commonly transforms a mathematical function of time, f(t), into a new function, sometimes denoted by or F, whose argument is frequency with units of cycles/s (hertz) or radians per second. The new function is then known as the Fourier transform and/or the frequency spectrum of the function f.

Example

Create a script file and type the following code in it:

```
syms x

f = exp(-2*x^2);  %our function

ezplot(f,[-2,2])  % plot of our function

FT = fourier(f)  % Fourier transform
```

When you run the file, MATLAB plots the following graph:
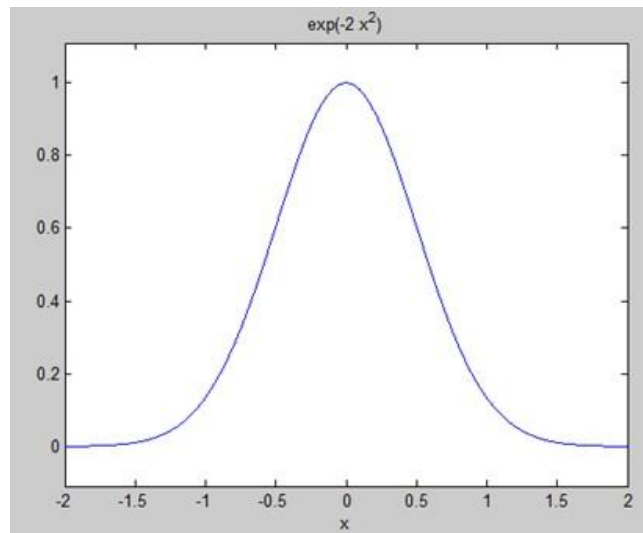
The following result is displayed:

```
FT =

 (2^(1/2)*pi^(1/2)*exp(-w^2/8))/2
```

Plotting the Fourier transform as:

```
ezplot(FT)
```

Gives the following graph:
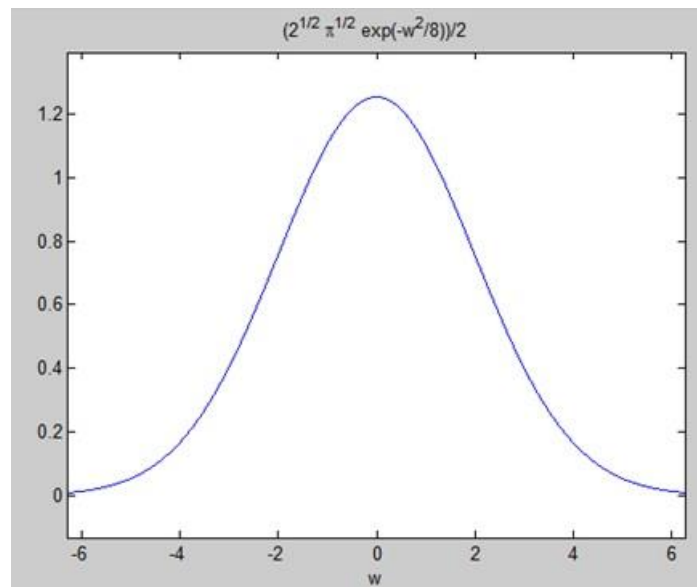
Inverse Fourier Transforms

MATLAB provides the **ifourier** command for computing the inverse Fourier transform of a function. For example,

```
f = ifourier(-2*exp(-abs(w)))
```

MATLAB will execute the above statement and display the result:

```
f =

-2/(pi*(x^2 + 1))
```

28. GNU OCTAVE TUTORIAL

GNU Octave is a high-level programming language like MATLAB and it is mostly compatible with MATLAB. It is also used for numerical computations.

Octave has the following common features with MATLAB:

- Matrices are fundamental data type.
- It has built-in support for complex numbers.
- It has built-in math functions and libraries.
- It supports user-defined functions.

GNU Octave is also freely redistributable software. You may redistribute it and/or modify it under the terms of the GNU General Public License (GPL) as published by the Free Software Foundation.

MATLAB vs Octave

Most MATLAB programs run in Octave, but some of the Octave programs may not run in MATLAB because, Octave allows some syntax that MATLAB does not.

For example, MATLAB supports single quotes only, but Octave supports both single and double quotes for defining strings. If you are looking for a tutorial on Octave, then kindly go through this tutorial from beginning which covers both MATLAB as well as Octave.

Compatible Examples

Almost all the examples covered in this tutorial are compatible with MATLAB as well as Octave. Let's try following example in MATLAB and Octave which produces same result without any syntax changes:

This example creates a 3D surface map for the function $g = xe^{-(x2 + y2)}$. Create a script file and type the following code:

```
[x,y] = meshgrid(-2:.2:2);

g = x .* exp(-x.^2 - y.^2);

surf(x, y, g)

print -deps graph.eps
```

When you run the file, MATLAB displays the following 3-D map:
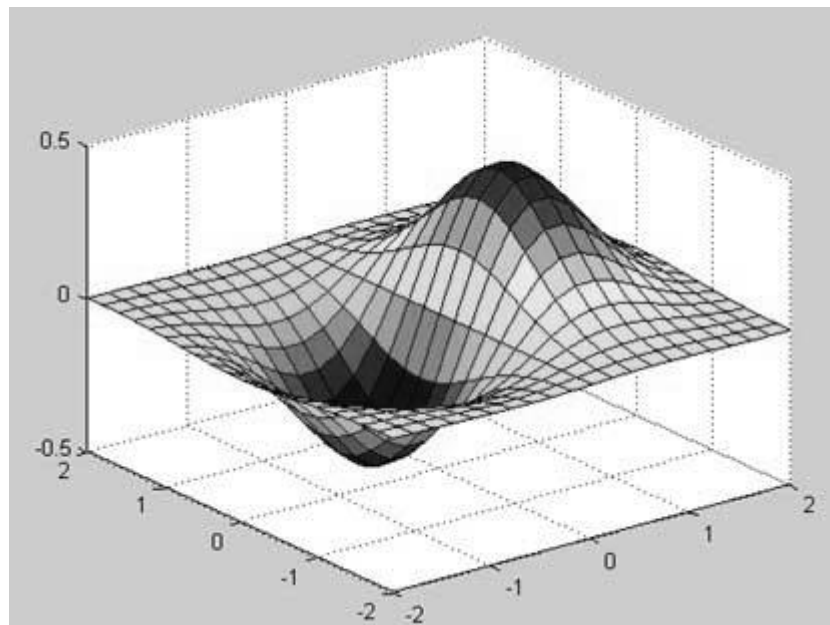

Non-compatible Examples

Though all the core functionality of MATLAB is available in Octave, there are some functionality for example, Differential & Integration Calculus, which does not match exactly in both the languages. This tutorial has tried to give both type of examples where they differed in their syntax.

Consider following example where MATLAB and Octave make use of different functions to get the area of a curve: $f(x) = x^2 \cos(x)$ for $-4 \leq x \leq 9$. Following is MATLAB version of the code:

```
f = x^2*cos(x);

ezplot(f, [-4,9])

a = int(f, -4, 9)

disp('Area: '), disp(double(a));
```

tutorialspoint
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When you run the file, MATLAB plots the graph:
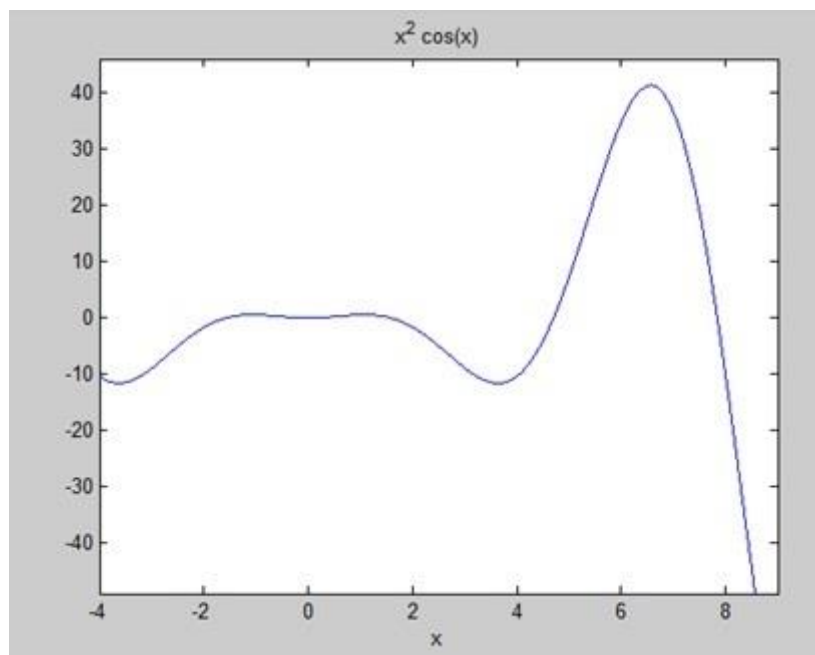
The following result is displayed:

```
a =


8*cos(4) + 18*cos(9) + 14*sin(4) + 79*sin(9)


Area:

     0.3326
```

But to give area of the same curve in Octave, you will have to make use of **symbolic** package as follows:

```
pkg load symbolic

symbols


x = sym("x");


f = inline("x^2*cos(x)");
```

```
ezplot(f, [-4,9])

print -deps graph.eps


[a, ierror, nfneval] = quad(f, -4, 9);


display('Area: '), disp(double(a));
```

29. SIMULINK

Simulink is a simulation and model-based design environment for dynamic and embedded systems, integrated with MATLAB. Simulink, also developed by MathWorks, is a data flow graphical programming language tool for modeling, simulating and analyzing multi-domain dynamic systems. It is basically a graphical block diagramming tool with customizable set of block libraries.

It allows you to incorporate MATLAB algorithms into models as well as export the simulation results into MATLAB for further analysis.

Simulink supports:

- system-level design
- simulation
- automatic code generation
- testing and verification of embedded systems

There are several other add-on products provided by MathWorks and third-party hardware and software products that are available for use with Simulink.

The following list gives a brief description of some of them:

- **Stateflow** allows developing state machines and flow charts.
- **Simulink Coder** allows the generation of C source code for real-time implementation of systems automatically.
- **xPC Target** together with **x86-based real-time systems** provide an environment to simulate and test Simulink and Stateflow models in real-time on the physical system.
- **Embedded Coder** supports specific embedded targets.
- **HDL Coder** allows to automatically generate synthesizable VHDL and Verilog.
- **SimEvents** provides a library of graphical building blocks for modelling queuing systems.

Simulink is capable of systematic verification and validation of models through modelling style checking, requirements traceability and model coverage analysis.
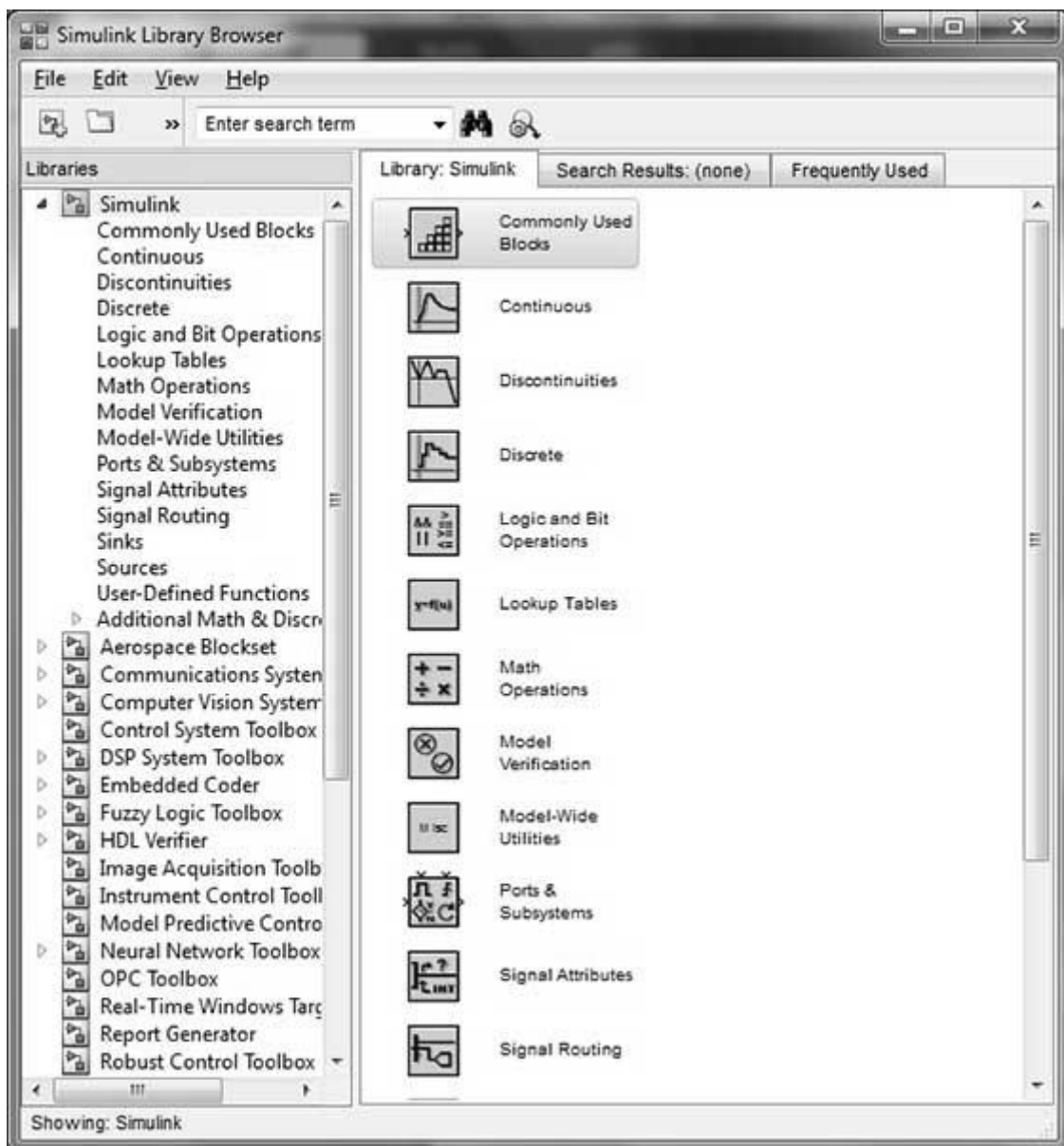
Simulink Design Verifier allows you to identify design errors and to generate test case scenarios for model checking.

229

Using Simulink

To open Simulink, type in the MATLAB work space:

```
simulink
```

Simulink opens with the **Library Browser**. The Library Browser is used for building simulation models.

On the left side window pane, you will find several libraries categorized on the basis of various systems, clicking on each one will display the design blocks on the right window pane.

Building Models

To create a new model, click the **New** button on the Library Browser's toolbar. This opens a new untitled model window
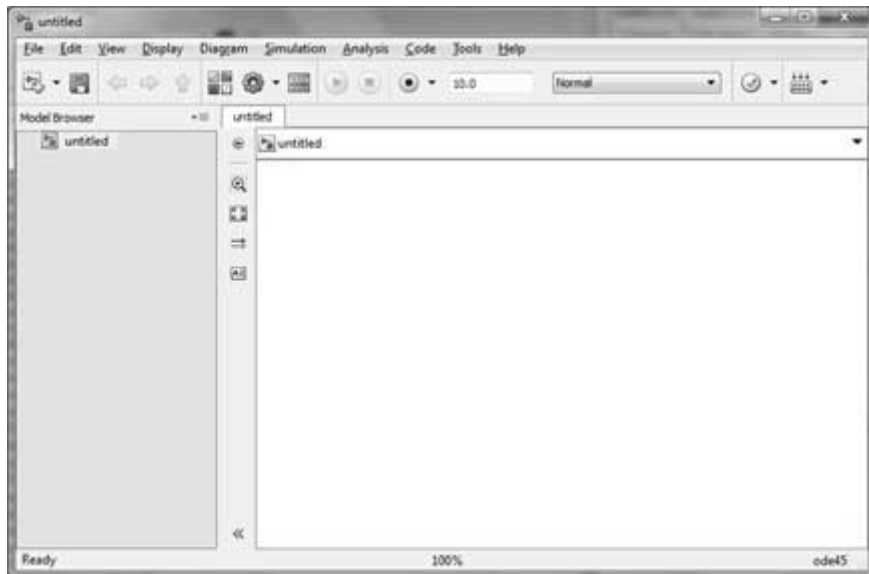
A Simulink model is a block diagram.

Model elements are added by selecting the appropriate elements from the Library Browser and dragging them into the Model window.

Alternately, you can copy the model elements and paste them into the model window.

Examples

Drag and drop items from the Simulink library to make your project.

For the purpose of this example, two blocks will be used for the simulation - A **Source** (a signal) and a **Sink** (a scope). A signal generator (the source) generates an analog signal, which will then be graphically visualized by the scope(the sink).
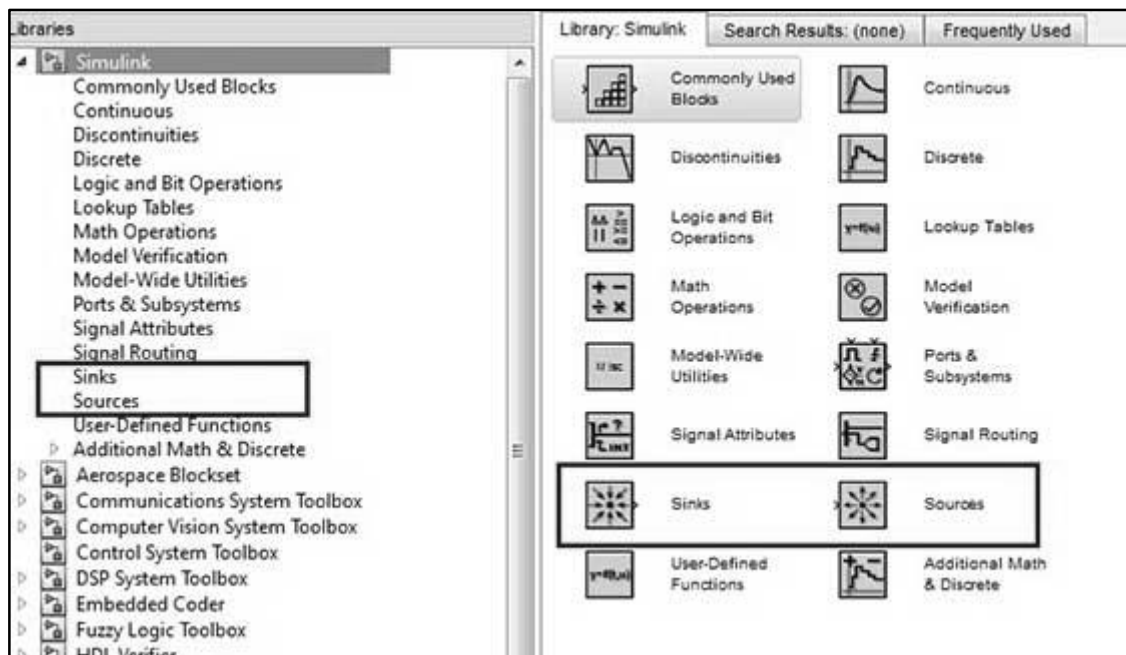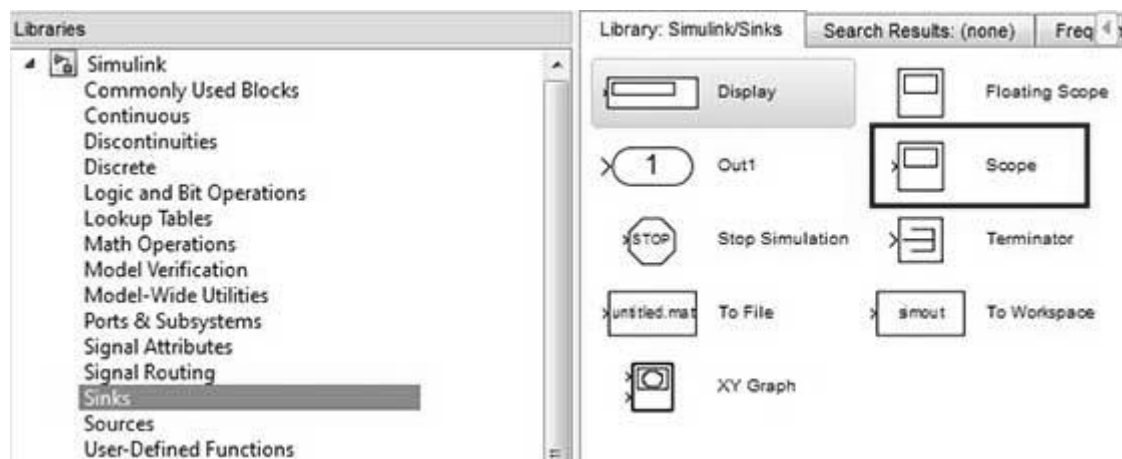
Begin by dragging the required blocks from the library to the project window. Then, connect the blocks together which can be done by dragging connectors from connection points on one block to those of another.
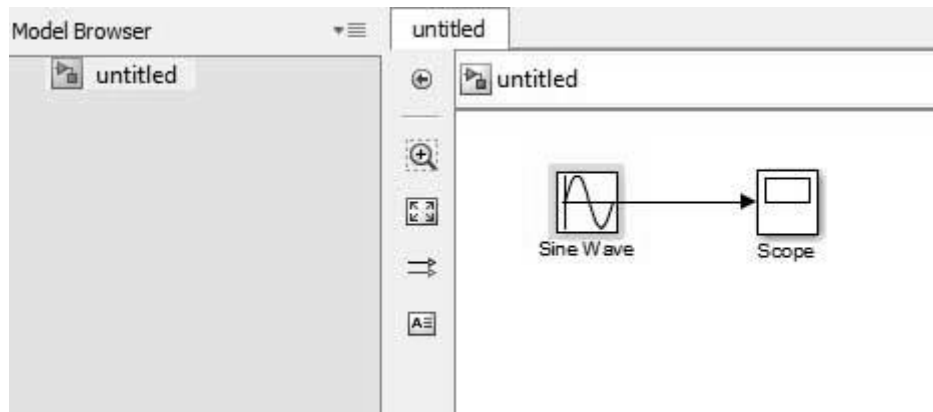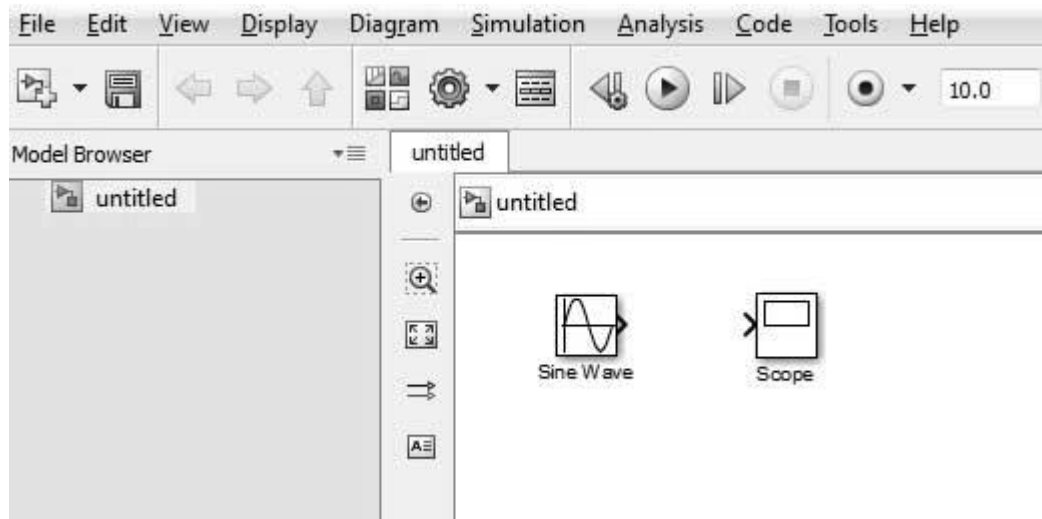
Let us drag a 'Sine Wave' block into the model.
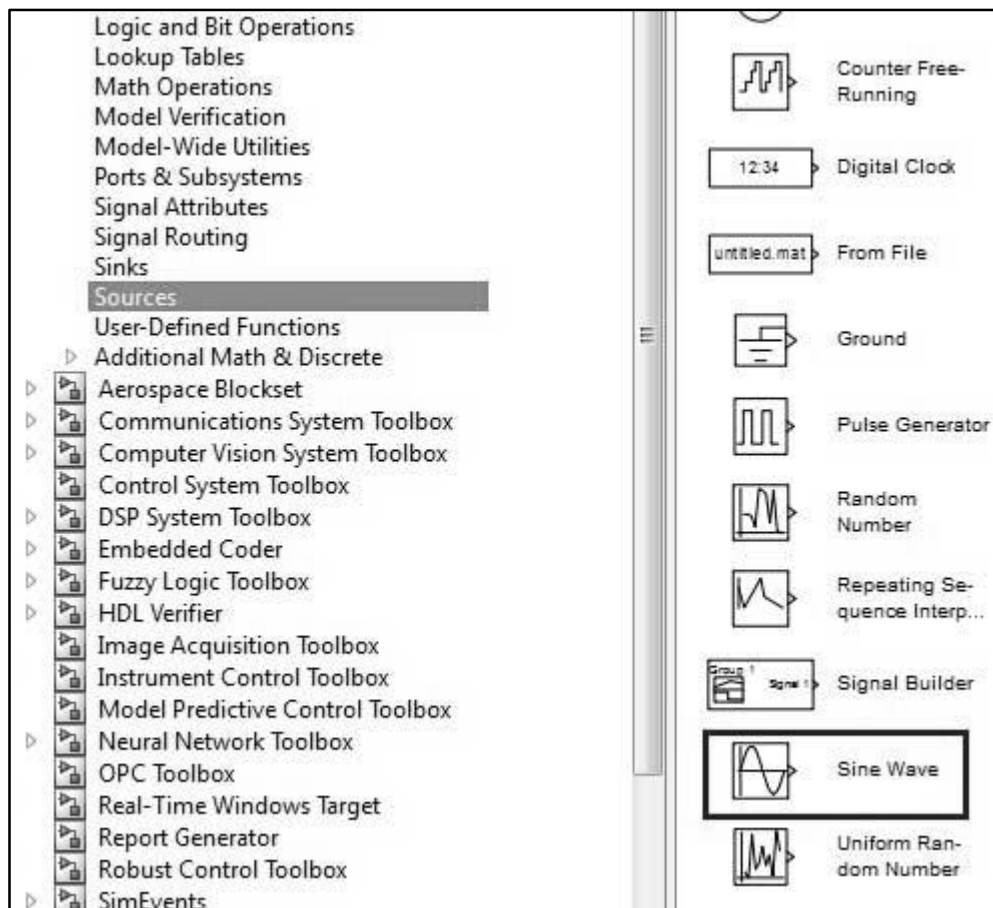
Select 'Sinks' from the library and drag a 'Scope' block into the model.

Drag a signal line from the output of the Sine Wave block to the input of the Scope block.

Run the simulation by pressing the '**Run**' button, keeping all parameters default (you can change them from the Simulation menu)

You should get the below graph from the scope.