HAND BOOK OF

"MATLAB"

Compiled

by

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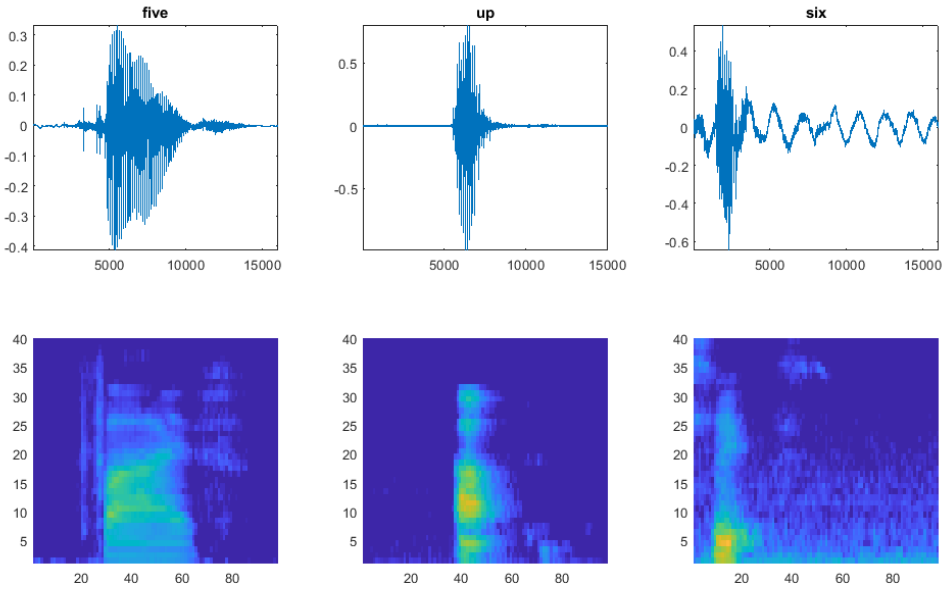

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MATLAB – Overview

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

Basic Features of MATLAB

- It is a high-level language for numerical computation, visualization and application development.
- It also provides an interactive environment for iterative 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

MATLAB - 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,

```
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
```

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 −

S. No	Operator	Purpose
1	+	Plus; addition operator.
2	-	Minus; subtraction operator.
3	*	Scalar and matrix multiplication operator.
4	.*	Array multiplication operator.
5	^	Scalar and matrix exponentiation operator.
6	.^	Array exponentiation operator.

S. No	Operator	Purpose
7	\	Left-division operator.
8	/	Right-division operator.
9	.\	Array left-division operator.
10	./	Array right-division operator.
11	:	Colon; generates regularly spaced elements and represents an entire row or column.
12	( )	Parentheses; encloses function arguments and array indices; overrides precedence.
13	[ ]	Brackets; enclosures array elements.
14	.	Decimal point.
15	…	Ellipsis; line-continuation operator
16	,	Comma; separates statements and elements in a row
17	;	Semicolon; separates columns and suppresses display.
18	%	Percent sign; designates a comment and specifies formatting.
19	_	Quote sign and transpose operator.
20	._	Nonconjugated transpose operator.
21	=	Assignment operator.

Special Variables and Constants

MATLAB supports the following special variables and constants −

S. No	Name	Meaning
1	**ans**	Most recent answer.
2	**eps**	Accuracy of floating-point precision.
3	**i,j**	The imaginary unit √-1.
4	**Inf**	Infinity.
5	**NaN**	Undefined numerical result (not a number).
6	**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
```

MATLAB - 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** −

```
sqrt(78);
9876/ans
```

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

```
ans =  1118.2
```

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 =  441.84
```

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
```

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 −

```
Attr Name        Size        Bytes      Class
==== ====        ====        ====       =====
  a              1x1             8      double
  ans            1x70          757        cell
  b              1x1             8      double
  c              1x1             8      double

Total is 73 elements using 781 bytes
```

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 = 17.2319816406394
```

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
```

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 = 34177/1491
```

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 =7    8    9   10   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 =  9    11    13    15    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
```

MATLAB - 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 −

S. No	Command	Purpose
1	clc	Clears command window.
2	clear	Removes variables from memory.
3	exist	Checks for existence of file or variable.
4	global	Declares variables to be global.
5	he p	Searches for a help topic.
6	lookfor	Searches help entries for a keyword.
7	quit	Stops MATLAB.
8	who	Lists current variables.
9	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 −

S. No	Command	Purpose
1	cd	Changes current directory.
2	date	Displays current date.
3	delete	Deletes a file.
4	diary	Switches on/off diary file recording.
5	dir	Lists all files in current directory.
6	load	Loads workspace variables from a file.
7	path	Displays search path.
8	pwd	Displays current directory.
9	save	Saves workspace variables in a file.
10	type	Displays contents of a file.
11	what	Lists all MATLAB files in the current directory.
12	wklread	Reads .wk1 spreadsheet file.

Input and Output Commands

MATLAB provides the following input and output related commands −

S. No	Command	Purpose
1	disp	Displays contents of an array or string.
2	fscanf	Read formatted data from a file.
3	format	Controls screen-display format.
4	fprintf	Performs formatted writes to screen or file.
5	input	Displays prompts and waits for input.
6	;	Suppresses screen printing.

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

S. No	Format Code	Purpose
1	**%s**	Format as a string.
2	**%d**	Format as an integer.
3	**%f**	Format as a floating point value.
4	**%e**	Format as a floating point value in scientific notation.
5	**%g**	Format in the most compact form: %f or %e.
6	**\n**	Insert a new line in the output string.
7	**\t**	Insert a tab in the output string.

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

S. No	Format Function	Display up to
1	format short	Four decimal digits (default).
2	format long	16 decimal digits.
3	format short e	Five digits pl s exponent.
4	format long e	16 digits plus exponents.
5	format bank	Two decimal digits.
6	format +	Positive, negative, or zero.
7	format rat	Rational approximation.
8	format compact	Suppresses some line feeds.
9	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 −

S. No	Command	Purpose
1	cat	Concatenates arrays.
2	find	Finds indices of nonzero elements.
3	length	Computes number of elements.
4	linspace	Creates regularly spaced vector.
5	logspace	Creates logarithmically spaced vector.
6	max	Returns largest element.
7	min	Returns smallest element.
8	prod	Product of each column.
9	reshape	Changes size.
10	size	Computes array size.
11	sort	Sorts each column.
12	sum	Sums each column.
13	eye	Creates an identity matrix.
14	ones	Creates an array of ones.
15	zeros	Creates an array of zeros.
16	cross	Computes matrix cross products.
17	dot	Computes matrix dot products.
18	det	Computes determinant of an array.
19	inv	Computes inverse of a matrix.
20	pinv	Computes pseudoinverse of a matrix.
21	rank	Computes rank of a matrix.
22	rref	Computes reduced row echelon form.
23	cell	Creates cell array.
24	celldisp	Displays cell array.
25	cellplot	Displays graphical representation of cell array.
26	num2cell	Converts numeric array to cell array.
27	deal	Matches input and output lists.
28	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 –

S. No	Command	Purpose
1	axis	Sets axis limits.
2	fplot	Intelligent plotting of functions.
3	grid	Displays gridlines.
4	plot	Generates xy plot.
5	print	Prints plot or saves plot to a file.
6	title	Puts text at top of plot.
7	xlabel	Adds text label to x-axis.
8	ylabel	Adds text label to y-axis.
9	axes	Creates axes objects.
10	close	Closes the current plot.
11	close all	Closes all plots.
12	figure	Opens a new figure window.
13	gtext	Enables label placement by mouse.
14	hold	Freezes current plot.
15	legend	Legend placement by mouse.
16	refresh	Redraws current figure window.
17	set	Specifies properties of objects such as axes.
18	subplot	Creates plots in subwindows.
19	text	Places string in figure.
20	bar	Creates bar chart.
21	loglog	Creates log-log plot.
22	polar	Creates polar plot.
23	semilogx	Creates semilog plot. (logarithmic abscissa).
24	semilogy	Creates semilog plot. (logarithmic ordinate).
25	stairs	Creates stairs plot.
26	stem	Creates stem plot.

MATLAB - 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 −

S. No.	Data Type	Description
1	**int8**	8-bit signed integer
2	**uint8**	8-bit unsigned integer
3	**int16**	16-bit signed integer
4	**uint16**	16- it unsigned integer
5	**int32**	32-bit signed integer
6	**uint32**	32-bit unsigned integer
7	**int64**	64-bit signed integer
8	**uint64**	64-bit unsigned integer
9	**Single**	single precision numerical data
10	**Double**	double precision numerical data
11	**Logical**	logical values of 1 or 0, represent true and false respectively
12	**char**	character data (strings are stored as vector of characters)
13	**cell array**	array of indexed cells, each capable of storing an array of a different dimension and data type
14	**Structure**	C-like structures, each structure having named fields capable of storing an array of a different dimension and data type
15	**function handle**	pointer to a function
16	**user classes**	objects constructed from a user-defined class
17	**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 = 5678.9
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 −

S. No	Function	Purpose
1	char	Convert to character array (string)
2	int2str	Convert integer data to string
3	mat2str	Convert matrix to string
4	num2str	Convert number to string
5	str2double	Convert string to double-precision value
6	str2num	Convert string to number
7	native2unicode	Convert numeric bytes to Unicode characters
8	unicode2native	Convert Unicode characters to numeric bytes
9	base2dec	Convert base N number string to decimal number
10	bin2dec	Convert binary number string to decimal number
11	dec2base	Convert decimal to base N number in string
12	dec2bin	Convert decimal to binary number in string
13	dec2hex	Convert decimal to hexadecimal number in string
14	hex2dec	Convert hexadecimal number string to decimal number
15	hex2num	Convert hexadecimal number string to double-precision number
16	num2hex	Convert singles and doubles to IEEE hexadecimal strings
17	cell2mat	Convert cell array to numeric array
18	cell2struct	Convert cell array to structure array
19	cellstr	Create cell array of strings from character array
20	mat2cell	Convert array to cell array with potentially different sized cells
21	num2cell	Convert array to cell array with consistently sized cells
22	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 −

S. No	Function	Purpose
1	is	Detect state
2	isa	Determine if input is object of specified class
3	iscell	Determine whether input is cell array
4	iscellstr	Determine whether input is cell array of strings
5	ischar	Determine whether item is character array
6	isfield	Determine whether input is structure array field
7	isfloat	Determine if input is floating-point array
8	ishghandle	True for Handle Graphics object handles
9	isinteger	Determine if input is integer array
10	isjava	Determine if input is Java object
11	islogical	Determine if input is logical array
12	isnumeric	Determine if input is numeric array
13	isobject	Determine if input is MATLAB object
14	isreal	Check if input is real array
15	isscalar	Determine whether input is scalar
16	isstr	Determine whether input is character array
17	isstruct	Determine whether input is structure array
18	isvector	Determine whether input is vector

19	class	Determine class of object
20	validateattributes	Check validity of array
21	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 = 23.540
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
```

MATLAB - 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 −

Show Examples

S. No	Operators	Purpose
1	+	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.
2	-	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.
3	*	Matrix multiplication. C = A*B is the linear algebraic product of the matrices A and B. More precisely,
4	.*	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.
5	/	Slash or matrix right division. B/A is roughly the same as B*inv(A). More precisely, B/A = (A'\B')'.
6	./	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.
7	\	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.
8	.\	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.

9	^	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.
10	.^	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.
11	'	Matrix transpose. A' is the linear algebraic transpose of A. For complex matrices, this is the complex conjugate transpose.
12	.'	Array transpose. A.' is the array transpose of A. For complex matrices, this does not involve conjugation.

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 −

Show Examples

S. No.	Operator	Purpose
1	<	Less than
2	<=	Less than or equal to
3	>	Greater than
4	>=	Greater than or equal to
5	==	Equal to
6	~=	Not equal to

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.

Show Examples

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 −

Show Examples

S. No.	Function	Purpose
1	bitand(a, b)	Bit-wise AND of integers *a* and *b*
2	bitcmp(a)	Bit-wise complement of *a*
3	bitget(a,pos)	Get bit at specified position *pos*, in the integer array *a*
4	bitor(a, b)	Bit-wise OR of integers *a* and *b*
5	bitset(a, pos)	Set bit at specific location *pos* of *a*
6	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.
7	bitxor(a, b)	Bit-wise XOR of integers *a* and *b*
8	swapbytes	Swap byte ordering

Set Operations

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

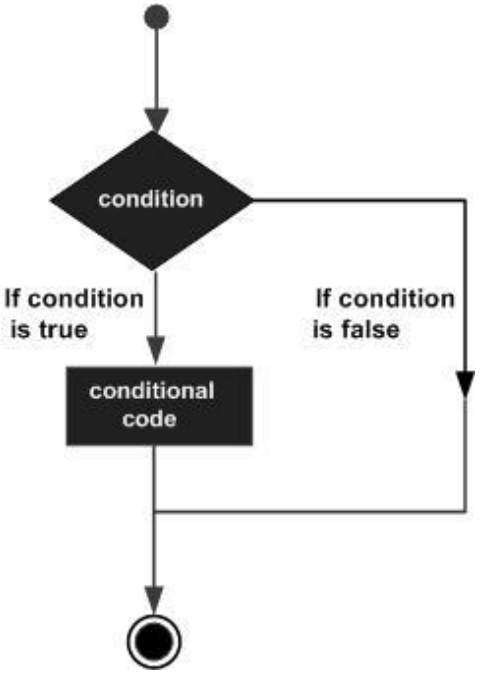
The following table shows some commonly used set operations −

Show Examples

S. No.	Function	Description
1	**intersect(A,B)**	Set intersection of two arrays; returns the values common to both A and B. The values returned are in sorted order.
2	**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.
3	**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).
4	**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).
5	**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.
6	**issorted(A, 'rows')**	Returns logical 1 (true) if the rows of two-dimensional matrix A is 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.
7	**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.
8	**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.
9	**Setxor**	Sets exclusive OR of two arrays
10	**Union**	Sets union of two arrays
11	**Unique**	Unique values in array

MATLAB - 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 −

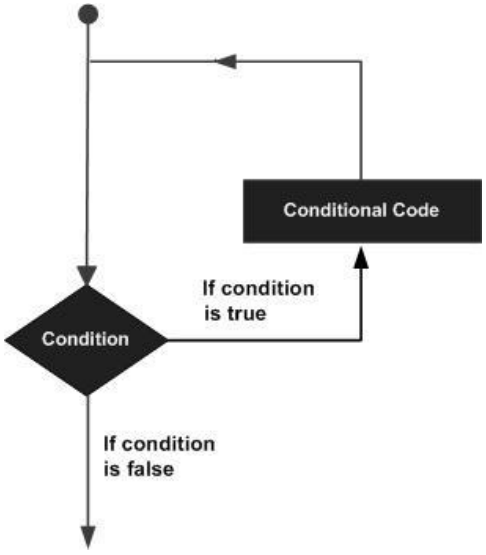
S. No.	Statement	Description
1	if ... end statement	An **if ... end statement** consists of a boolean expression followed by one or more statements.
2	if...else...end statement	An **if statement** can be followed by an optional **else statement**, which executes when the boolean expression is false.
3	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.
4	nested if statements	You can use one **if** or **elseif** statement inside another **if** or **elseif** statement(s).
5	switch statement	A **switch** statement allows a variable to be tested for equality against a list of values.
6	nested switch statements	You can use one **switch** statement inside another **switch** statement(s).

MATLAB - 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 −

S. No.	Loop Type	Description
1	while loop	Repeats a statement or group of statements while a given condition is true. It tests the condition before executing the loop body.
2	for loop	Executes a sequence of statements multiple times and abbreviates the code that manages the loop variable.
3	nested loops	You can use one or more loops inside any another loop.

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.

S. No.	Control Statement	Description
1	break statement	Terminates the **loop** statement and transfers execution to the statement immediately following the loop.
2	continue statement	Causes the loop to skip the remainder of its body and immediately retest its condition prior to reiterating.

MATLAB – 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 =

   7    8    9   10   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
```

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

MATLAB - 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 m^{th} row and n^{th} column, of a matrix *mx*, we write −

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

For example, to refer to the element in the 2^{nd} row and 5^{th} 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 m^{th} column we type A(:,m).
Let us create a column vector v, from the elements of the 4^{th} 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 m^{th} through n^{th} 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
```

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

MATLAB - 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 =

ans(:,:,1) =

   0   0   0
   0   0   0
   0   0   0

ans(:,:,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
   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.

S. No	Function	Purpose
1	length	Length of vector or largest array dimension
2	ndims	Number of array dimensions
3	numel	Number of array elements
4	size	Array dimensions
5	iscolumn	Determines whether input is column vector
6	isempty	Determines whether array is empty
7	ismatrix	Determines whether input is matrix
8	isrow	Determines whether input is row vector
9	isscalar	Determines whether input is scalar
10	isvector	Determines whether input is vector
11	blkdiag	Constructs block diagonal matrix from input arguments
12	circshift	Shifts array circularly
13	ctranspose	Complex conjugate transpose
14	diag	Diagonal matrices and diagonals of matrix
15	flipdim	Flips array along specified dimension
16	fliplr	Flips matrix from left to right
17	flipud	Flips matrix up to down
18	ipermute	Inverses permute dimensions of N-D array
19	permute	Rearranges dimensions of N-D array
20	repmat	Replicates and tile array
21	reshape	Reshapes array
22	rot90	Rotates matrix 90 degrees
23	shiftdim	Shifts dimensions
24	issorted	Determines whether set elements are in sorted order
25	sort	Sorts array elements in ascending or descending order
26	sortrows	Sorts rows in ascending order
27	squeeze	Removes singleton dimensions
28	transpose	Transpose
29	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]  % horizontal 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}
```

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

```
c =
{
  [1,1] = Red
  [2,1] =  1
  [1,2] = Blue
  [2,2] =  2
  [1,3] = Green
  [2,3] =  3
  [1,4] = Yellow
  [2,4] =  4
  [1,5] = White
  [2,5] =  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 =
{
  [1,1] = Red
  [2,1] =  1
  [1,2] = Blue
  [2,2] =  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, 2:3}
```

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

```
ans = Blue
ans = Green
```

MATLAB - 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 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
```

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) −

S. No	Format	Purpose
1	**A(:,j)**	is the jth column of A.
2	**A(i,:)**	is the ith row of A.
3	**A(:,:)**	is the equivalent two- imensional array. For matrices this is the same as A.
4	**A(j:k)**	is A(j), A(j+1),...,A(k).
5	**A(:,j:k)**	is A(:,j), A(:,j+1),...,A(:,k).
6	**A(:,:,k)**	is the k^{th} page of three-dimensional array A.
7	**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.
8	**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
```

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
```

MATLAB - 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 −

S. No	Function	Purpose
1	double	Converts to double precision number
2	single	Converts to single precision number
3	int8	Converts to 8-bit signed integer
4	int16	Converts to 16-bit signed integer
5	int32	Converts to 32-bit signed integer
6	int64	Converts to 64-bit signed integer
7	uint8	Converts to 8-bit unsigned integer
8	uint16	Converts to 16-bit unsigned integer
9	uint32	Converts to 32-bit unsigned integer
10	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 =

  39.900   26.025   47.100

x =

  39.900   26.025   47.100

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
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 =
{
  [1,1] = 38
  [1,2] = 23
  [1,3] = 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:
```

```
            0 to 0
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 -1
ans = The range for uint64 is:
            0 to 18446744073709551616
```

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
```

MATLAB - 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 = 'Tutorials Point'
```

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

```
my_string = Tutorials 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 =

  84  117  116  111  114  105   97  108   39  115   32   80  111  105  110  116

str_back_to_char = Tutorial's Point
str_16bit =

  84  117  116  111  114  105   97  108   39  115   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 –

```
{
  [1,1] = Zara Ali
  [2,1] = Sr. Surgeon
  [3,1] = 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 −

Examples

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

S. No	Function	Purpose
	Functions for storing text in character arrays, combine character arrays, etc.	
1	blanks	Create string of blank characters
2	cellstr	Create cell array of strings from character array
3	char	Convert to character array (string)
4	iscellstr	Determine whether input is cell array of strings
5	ischar	Determine whether item is character array
6	sprintf	Format data into string
7	strcat	Concatenate strings horizontally
8	strjoin	Join strings in cell array into single string
	Functions for identifying parts of strings, find and replace substrings	
9	ischar	Determine whether item is character array
10	isletter	Array elements that are alphabetic letters
11	isspace	Array elements that are space characters
12	isstrprop	Determine whether string is of specified category
13	sscanf	Read formatted data from string
14	strfind	Find one string within another
15	strrep	Find and replace substring
16	strsplit	Split string at specified delimiter
17	strtok	Selected parts of string
18	validatestring	Check validity of text string
19	symvar	Determine symbolic variables in expression
20	regexp	Match regular expression (case sensitive)
21	regexpi	Match regular expression (case insensitive)
22	regexprep	Replace string using regular expression
23	regexptranslate	Translate string into regular expression
	Functions for string comparison	
24	strcmp	Compare strings (case sensitive)
25	strcmpi	Compare strings (case insensitive)
26	strncmp	Compare first n characters of strings (case sensitive)
27	strncmpi	Compare first n characters of strings (case insensitive)
	Functions for changing string to upper- or lowercase, creating or removing white space	
28	deblank	Strip trailing blanks from end of string
29	strtrim	Remove leading and trailing white space from string
30	lower	Convert string to lowercase
31	upper	Convert string to uppercase
32	strjust	Justify character array

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
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 −

```
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 =
{
  [1,1] = Poulomi Dutta
}
first_names =
{
  [1,1] = Zara
  [1,2] = Neha
  [1,3] = Monica
  [1,4] = Madhu
  [1,5] = Madhu
  [1,6] = Bhawna
  [1,7] = Nuha
  [1,8] = Reva
  [1,9] = Sunaina
  [1,10] = 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
```

MATLAB - 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;
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 return 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 following 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 =  0.73205
```

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-efficient 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 =  0.73205
```

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 =  35.500
```

MATLAB - 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. No.	Function	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(___)**	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  SaturDay
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
SaturDay
   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
```

MATLAB – Plotting

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

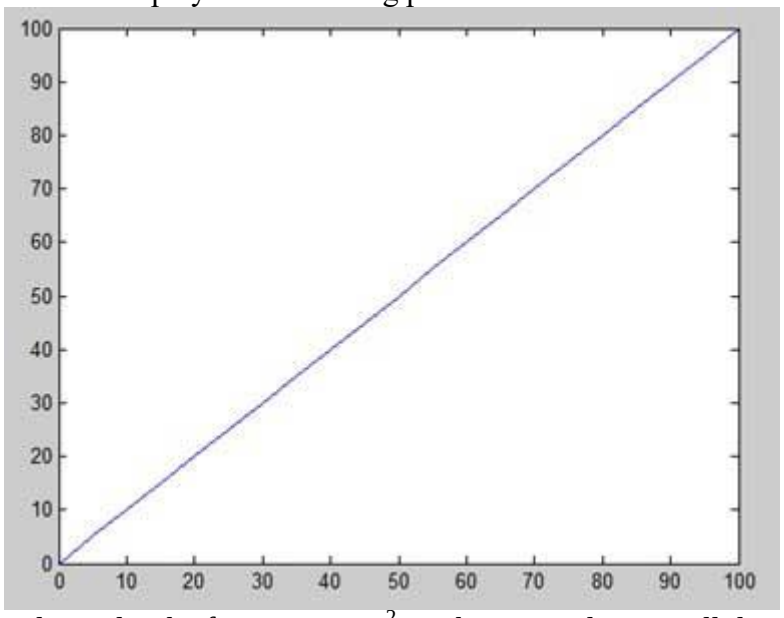
- Define **x**, by specifying the **range of values** for the variable **x**, for which the function is to be plotted
- Define the function, **y = f(x)**
- Call the **plot** command, as **plot(x, y)**

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 −

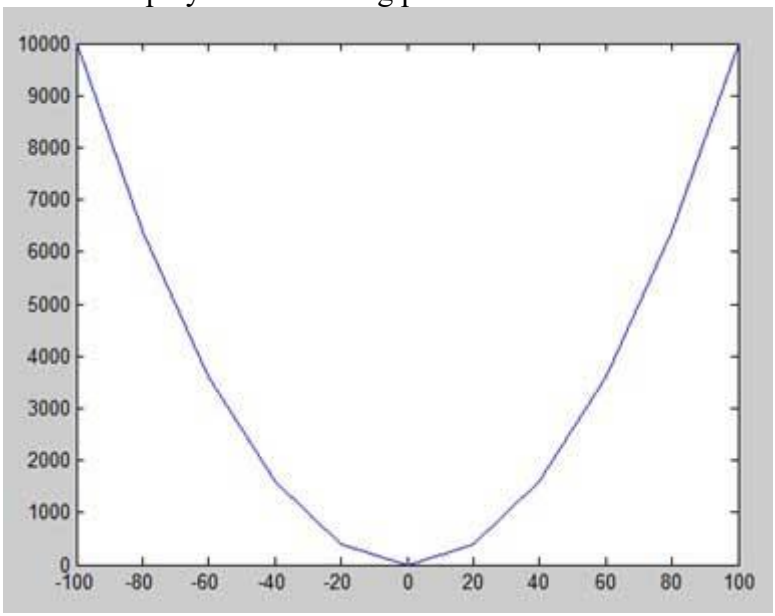


Let us take one more example to plot the function $y = x^2$. In this example, we will draw two graphs with the same function, but in second time, we will reduce the value of increment. Please note that as we decrease the increment, the graph becomes smoother.

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)
```

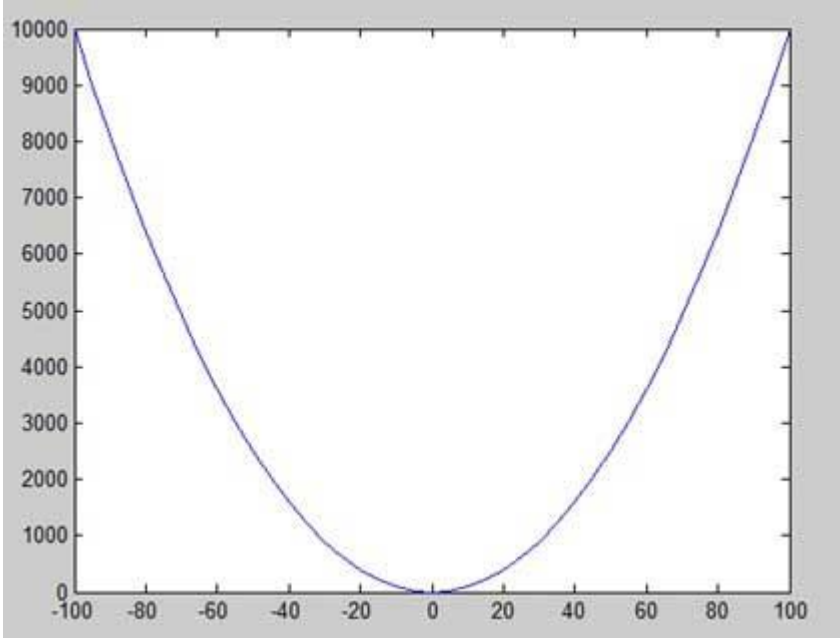
When you run the file, MATLAB displays the following plot −



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.

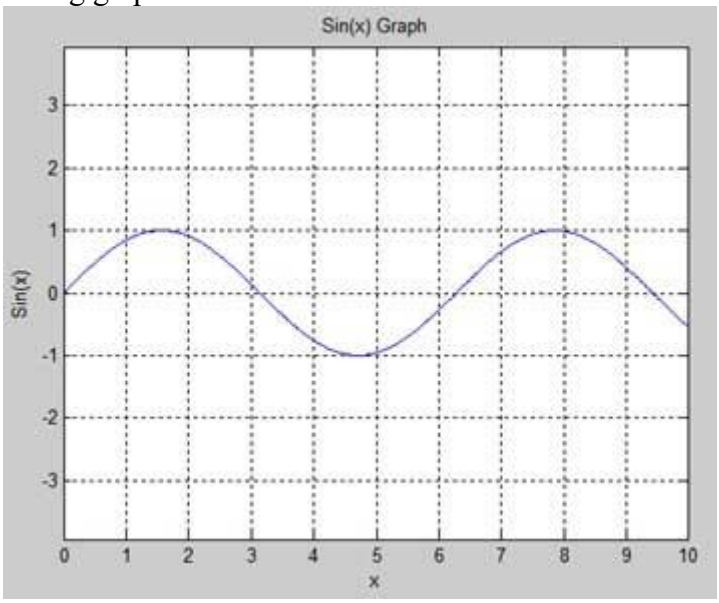
- The **xlabel** and **ylabel** commands generate labels along x-axis and y-axis.
- The **title** command allows you to put a title on the graph.
- The **grid on** command allows you to put the grid lines on the graph.
- The **axis equal** command allows generating the plot with the same scale factors 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

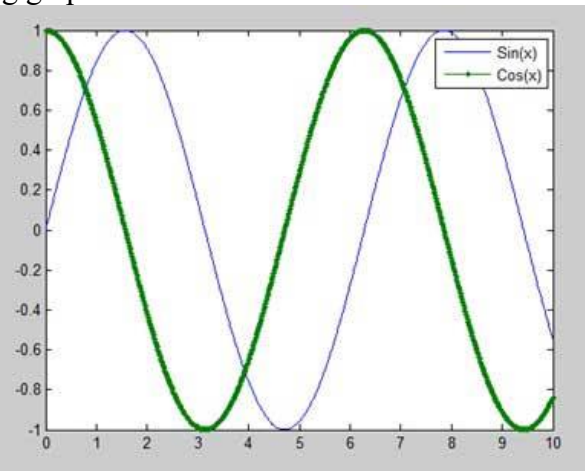
You can draw multiple graphs on the same plot. The following example demonstrates the concept −

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

Example

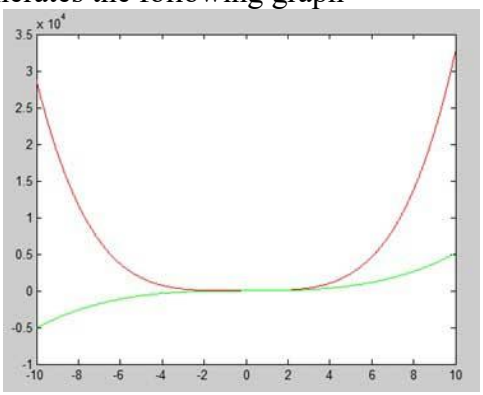
Let us draw the graph of two polynomials

- $f(x) = 3x^4 + 2x^3 + 7x^2 + 2x + 9$ and
- $g(x) = 5x^3 + 9x + 2$

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] )
```

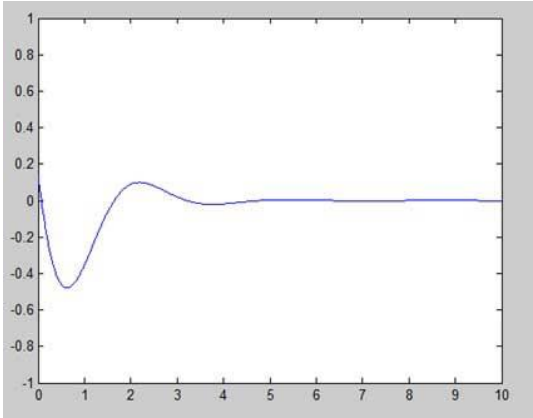
The following example shows this −

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 −

Example

Let us generate two plots −

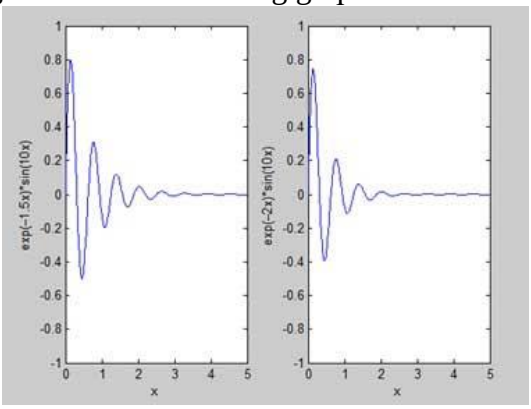
$y = e^{-1.5x}\sin(10x)$

$y = e^{-2x}\sin(10x)$

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 −



MATLAB - 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.

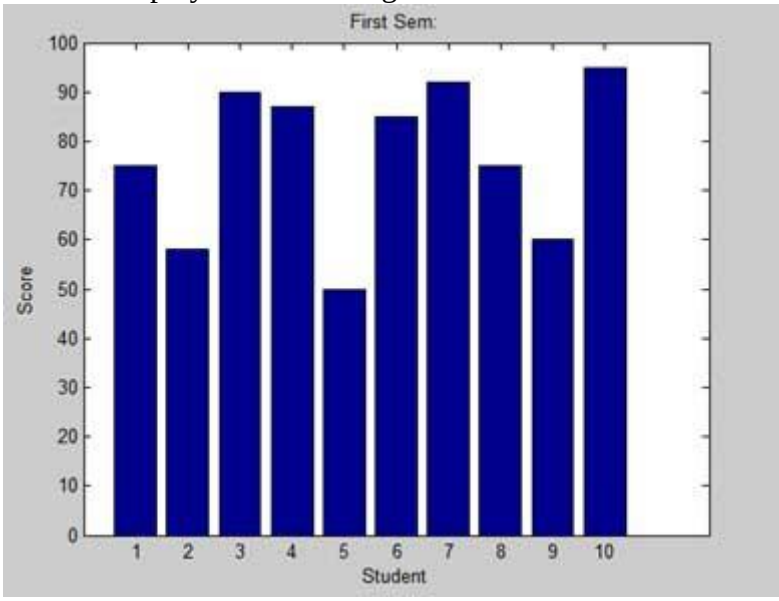
Example

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 $-5 \le x \le 5$, $-3 \le y \le 3$. Let us take an increment of 0.1 for both the values. The variables are set as −

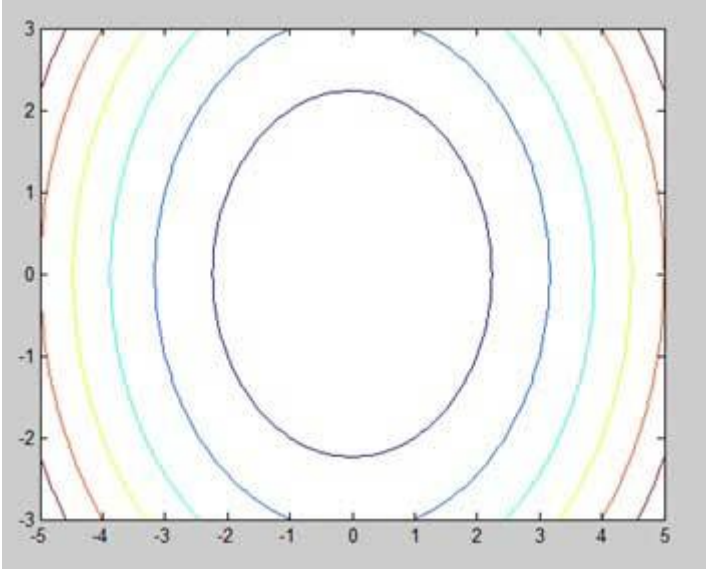
```
[x,y] = meshgrid(–5:0.1:5, –3:0.1:3);
```

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
g = x.^2 + y.^2;                       % our function
contour(x,y,g)                         % call the contour function
print -deps graph.eps
```

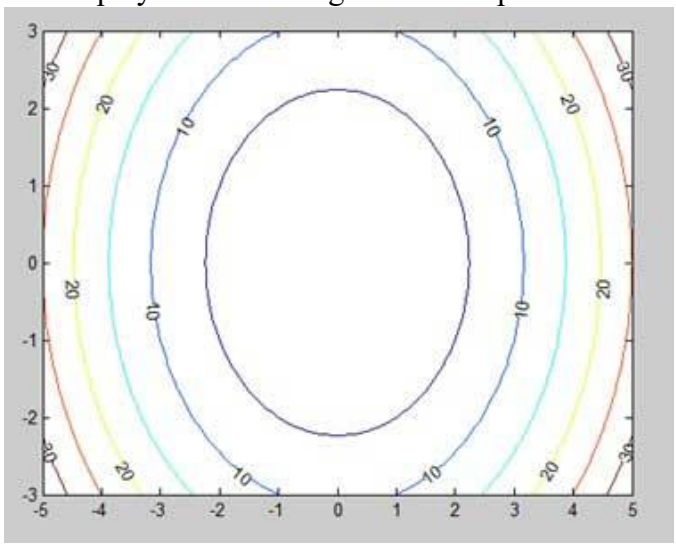
When you run the file, MATLAB displays the following contour map −



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 −

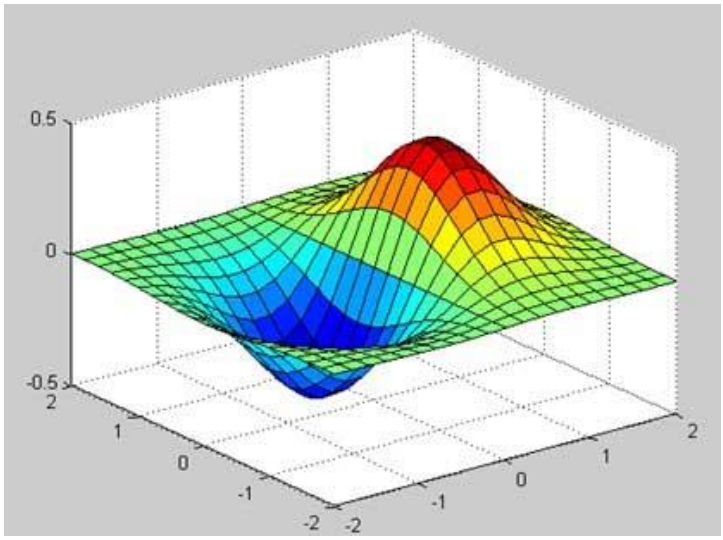
Example

Let us create a 3D surface map for the function $g = xe^{-(x2 + y^2)}$

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.

MATLAB - 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 function 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 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 Higher Order Equations in MATLAB

The **solve** function 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:
6.630396332390718431485053218985
 The second root is:
1.059780463302589629168277249988 5
 The third root is:
- 0.345088397846654030326665234486 75 - 1.077836295463017659683110926979 3*i
 The fourth root is:
- 0.345088397846654030326665234486 75 + 1.077836295463017659683110926979 3*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 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 −

$x + 3y -2z = 5$

$3x + 5y + 6z = 7$

$2x + 4y + 3z = 8$

Expanding and Collecting Equations in MATLAB

The **expand** and the **collect** function 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
```

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
```

MATLAB - 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** function for calculating limits. In its most basic form, the **limit** function 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
```

Verification of Basic Properties of Limits

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) = x^2 + 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
```

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 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.

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 $\lim_{x->3} f(x)$ 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.

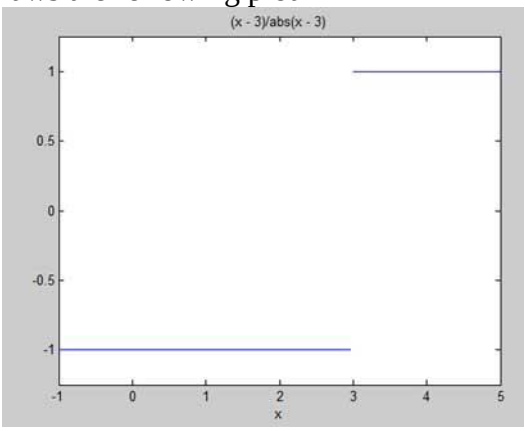
The left-handed and right-handed limits are computed by passing the character strings 'left' and 'right' to the limit command as the last argument.

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



After this following output is displayed −

```
l =
   -1

r =
   1
```

MATLAB - 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
```

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,

$(f/g)' = (f'.g - g'.f)/g^2$

Rule 5

The **polynomial** or elementary power rule states that, if **$y = f(x) = x^n$**, then **$f' = n.\ x^{(n-1)}$**

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, 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
```

Derivatives of Exponential, Logarithmic and Trigonometric Functions

The following table provides the derivatives of commonly used exponential, logarithmic and trigonometric functions −

Function	Derivative
$\mathbf{c^{a.x}}$	$c^{a.x}$.ln c.a (ln is natural logarithm)
$\mathbf{e^x}$	e^x
ln x	1/x
$\mathbf{ln_c x}$	1/x.ln c
$\mathbf{x^x}$	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
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
```

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 .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)
```

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;        %evaluting 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)
```

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

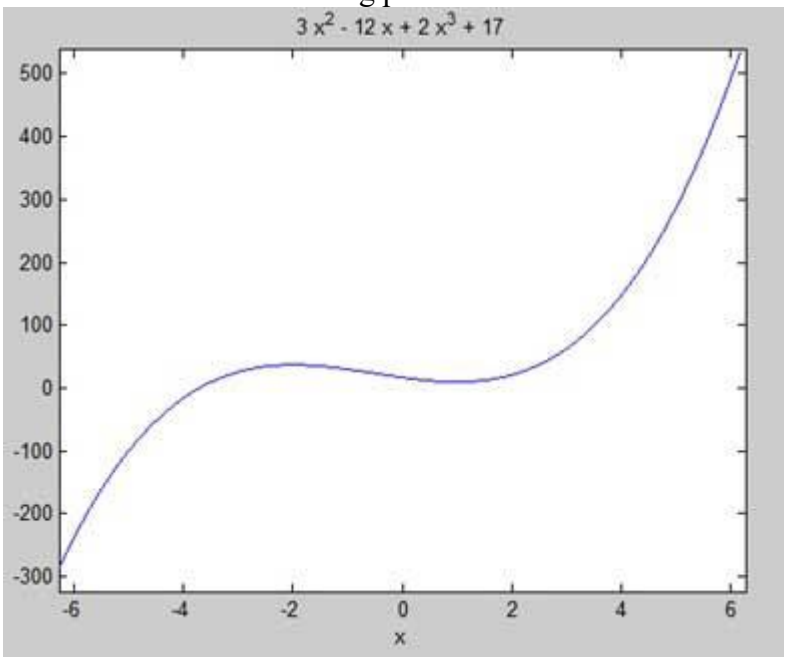
Let us find the stationary points of the function $f(x) = 2x^3 + 3x^2 - 12x + 17$

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)
```

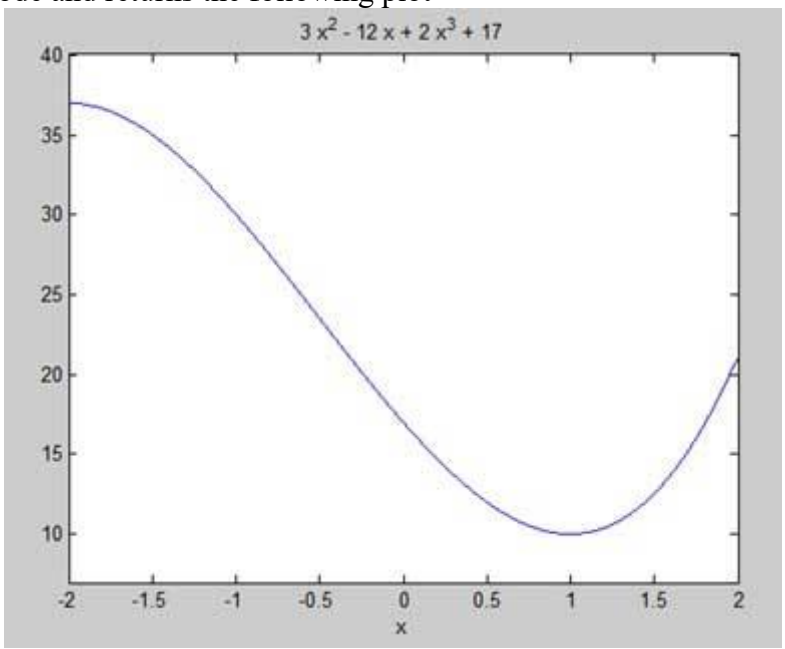
MATLAB executes the code and returns the following plot −



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 −



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
```

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
```

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
```

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
```

MATLAB - 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,

$\int 2xdx = x^2$.

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 −

$\int 2xdx = x^2 + c$.

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

To calculate

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

we write,

```
int(x, a, b)
```

For example, to calculate the value of $\int_4^9 xdx$ we write −

```
int(x, 4, 9)
```

MATLAB executes the above statement and returns the following result −

```
ans =
   65/2
```

Example 1

Let us calculate the area enclosed between the x-axis, and the curve $y = x^3 - 2x + 5$ 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
```

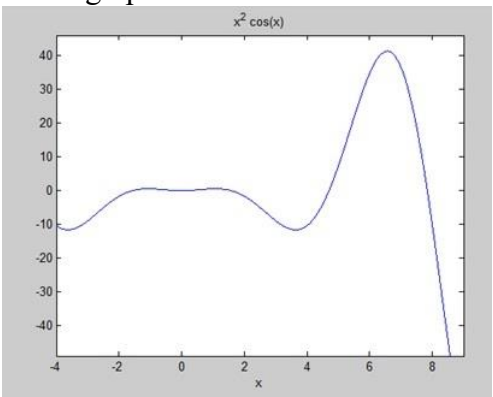
Example 2

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
```

MATLAB - 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 =

  Columns 1 through 3:

   1.00000 + 0.00000i   7.00000 + 0.00000i   0.00000 + 0.00000i

  Columns 4 and 5:

   -5.00000 - 0.00000i   9.00000 + 0.00000i
```

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 −

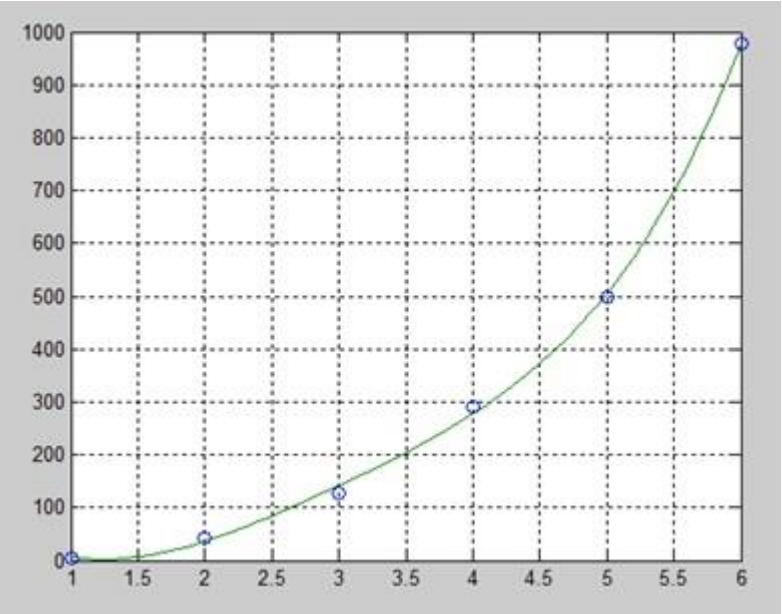
```
x = [1 2 3 4 5 6]; y = [5.5 43.1 128 290.7 498.4 978.67];   %data
p = polyfit(x,y,4)   %get the polynomial

% 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
```

And plots the following graph –



MATLAB - 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))
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

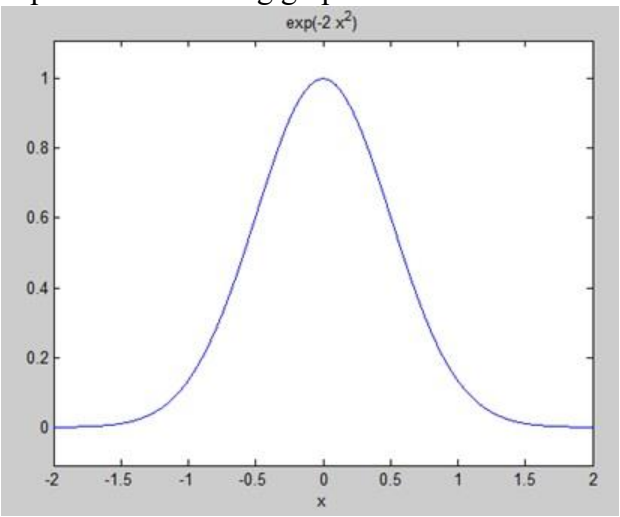
Fourier transforms commonly transforms a mathematical function of time, f(t), into a new function, sometimes denoted by or F, whose argument is frequency with units of cycles/s (hertz) or radians per second. The new function is then known as the Fourier transform and/or the frequency spectrum of the 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 −



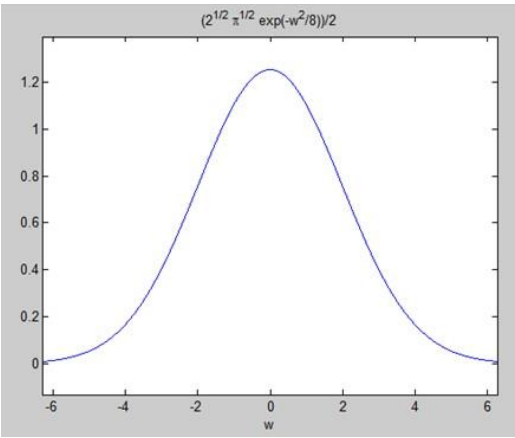
The following result is displayed −

```
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)))
```

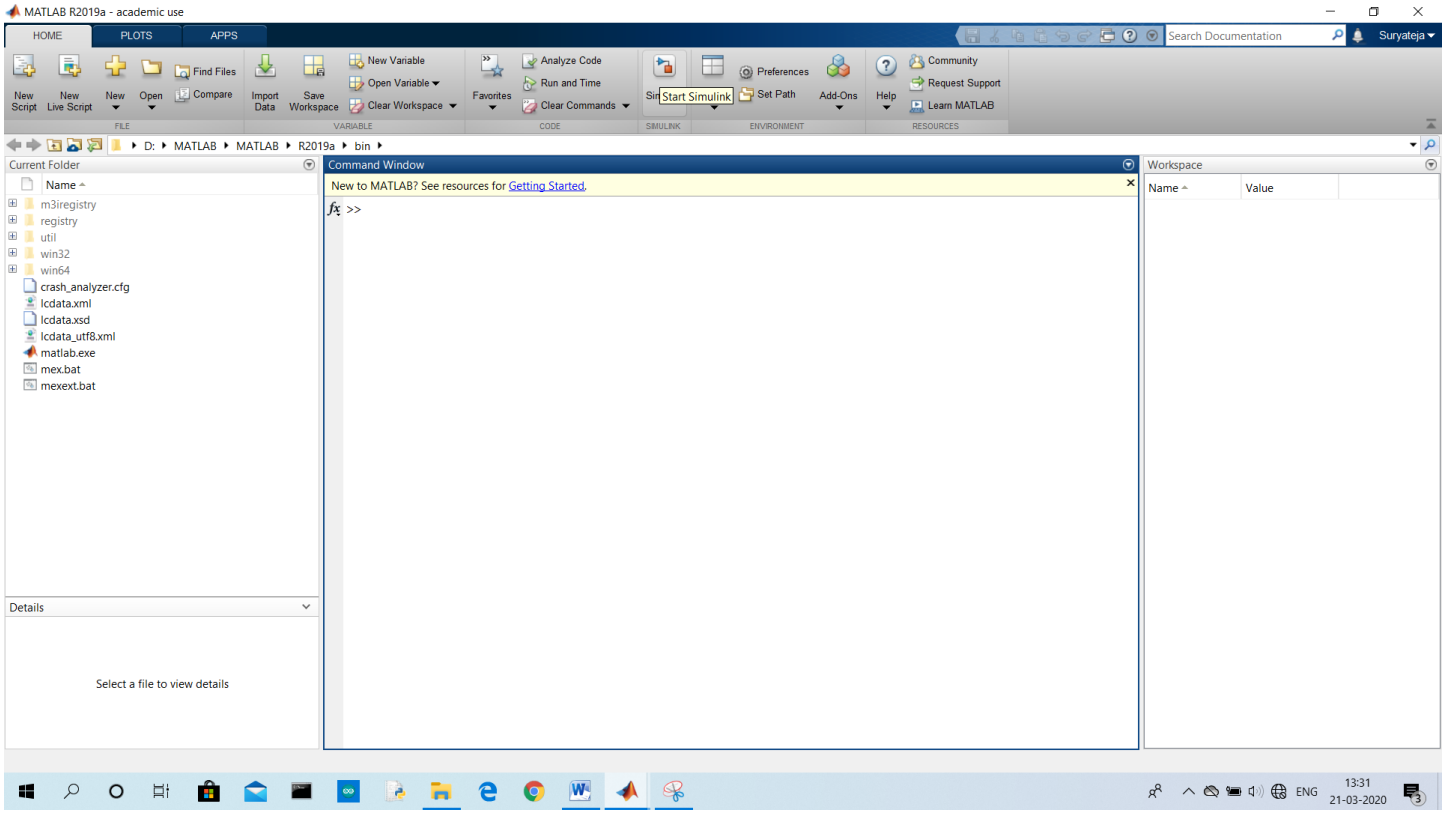
MATLAB will execute the above statement and display the result −

```
f =
  -2/(pi*(x^2 + 1))
```

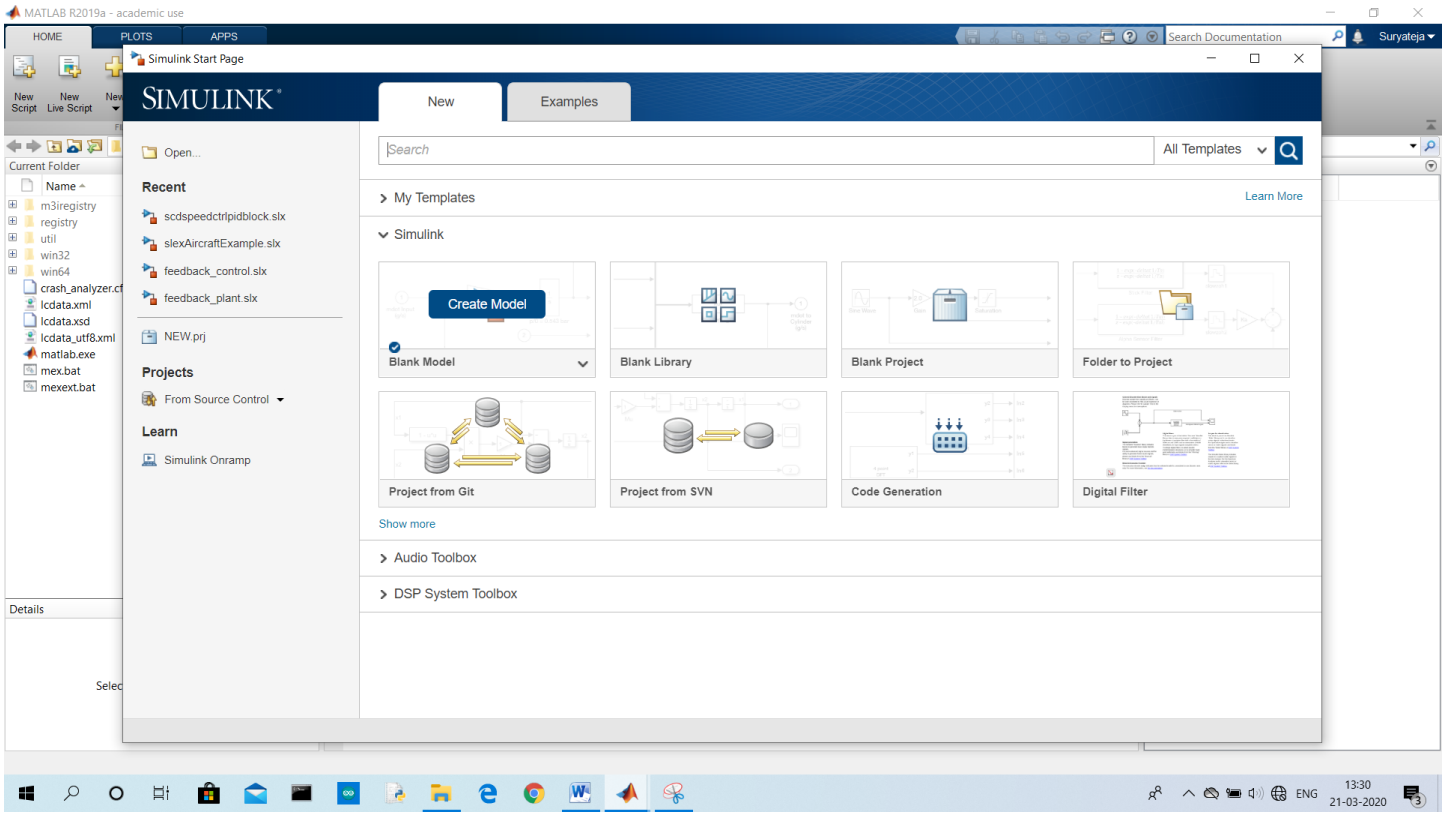
MATLAB – Simulink

Simulink provides the dataflow chart of a project and it defines the functions as a component of the project. The project is then created in the following procedure

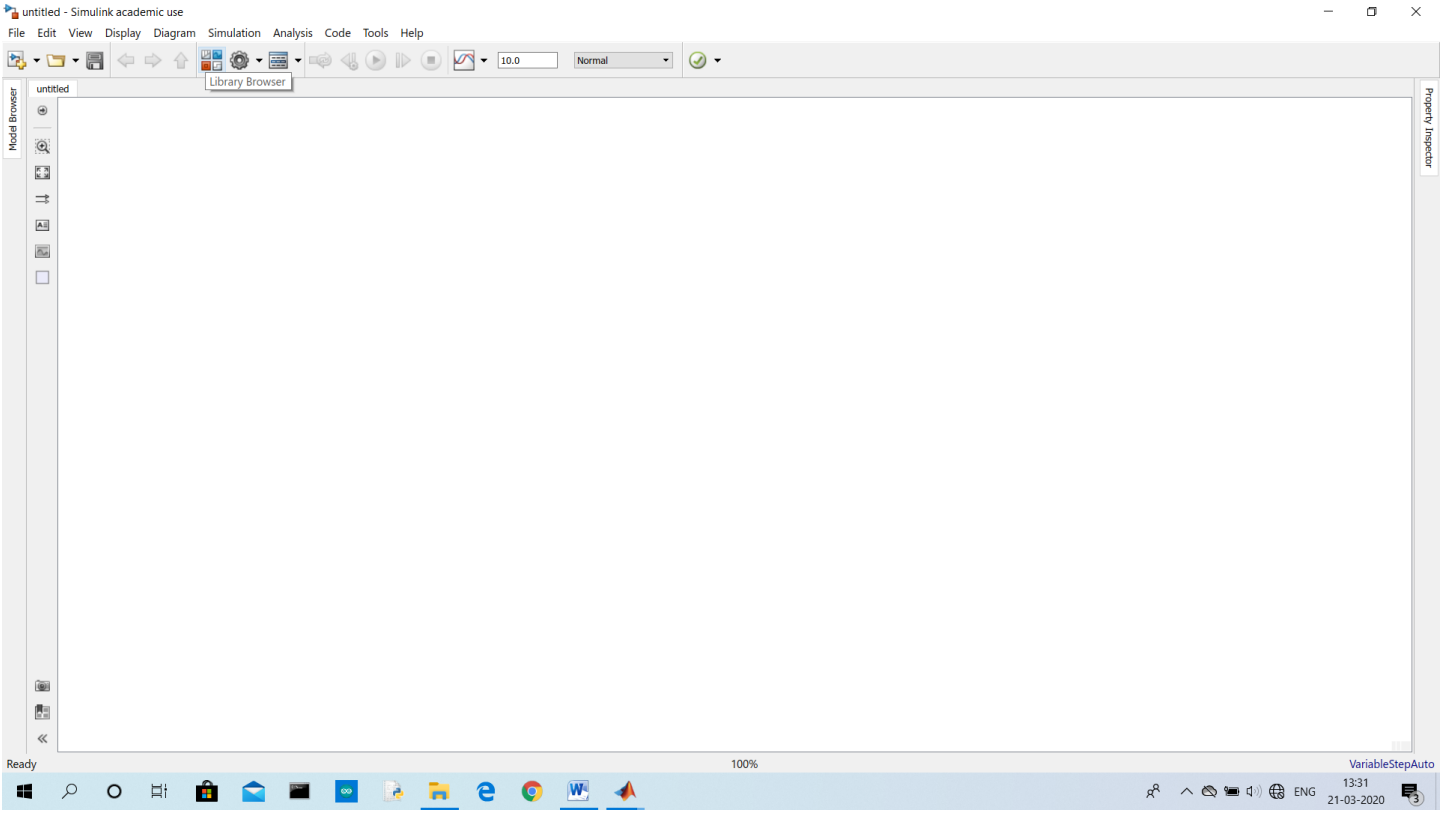
- Click on ‘Simulink’ on the Home page of the MATLAB.



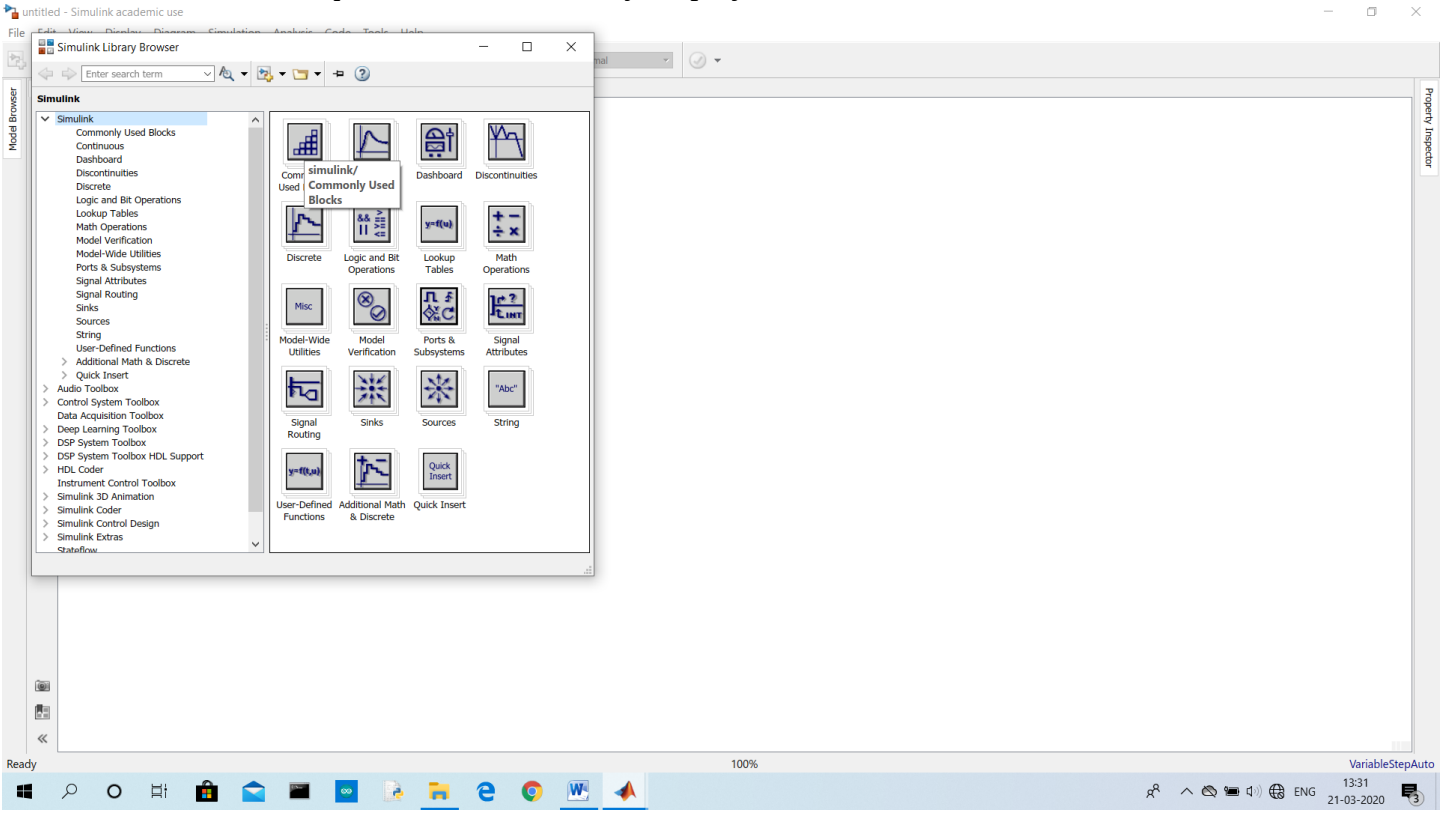
- Then under the class of ‘New’ select the ‘Blank Model’ to create a new project.



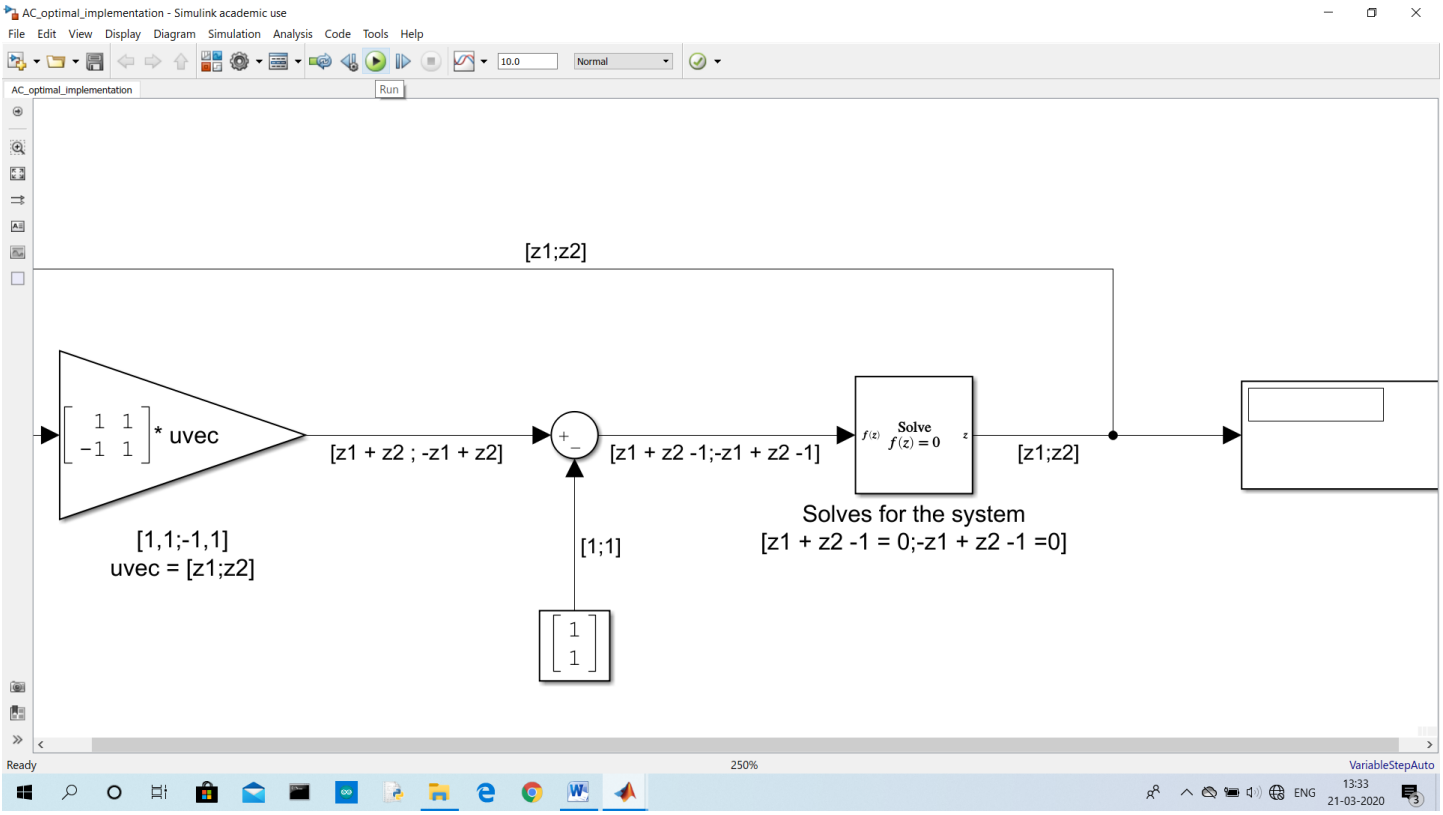
- Then click on the ‘Library Browser’ in the New created model through Simulink.



- Then select the required blocks to create your project



- For Example:


AC_optimal_implementation - Simulink academic use
File Edit View Display Diagram Simulation Analysis Code Tools Help
Run
[z1;z2]
1 1
-1 1
* uvec
[1,1;-1,1]
uvec = [z1;z2]
[z1 + z2 ; -z1 + z2]
[1;1]
1
1
[z1 + z2 -1;-z1 + z2 -1]
Solve
f(z) = 0
Solves for the system
[z1 + z2 -1 = 0;-z1 + z2 -1 =0]
[z1;z2]
Ready
250%
VariableStepAuto
ENG
13:33
21-03-2020