A decorative graphic consisting of a thin gold circle on the left side. A thick black bracket is positioned on the left side of the circle, and a thick gold bracket is on the right side. A horizontal bar with a gold-to-white gradient is centered across the middle of the circle.

A Quick Tutorial on MATLAB

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[MATLAB]

- MATLAB is a software package for doing numerical computation. It was originally designed for solving linear algebra type problems using matrices. It's name is derived from MATrix LABoratory.
- MATLAB has since been expanded and now has built-in functions for solving problems requiring data analysis, signal processing, optimization, and several other types of scientific computations. It also contains functions for 2-D and 3-D graphics and animation.

MATLAB Variable names

- Variable names are case sensitive.
- Variable names can contain up to 63 characters (as of MATLAB 6.5 and newer).
- Variable names must start with a letter and can be followed by letters, digits and underscores.

Examples :

```
>> x = 2;
```

```
>> abc_123 = 0.005;
```

```
>> 1ab = 2;
```

Error: Unexpected MATLAB expression

[MATLAB Special Variables]

- pi Value of π
- eps Smallest incremental number
- inf Infinity
- NaN Not a number e.g. 0/0
- i and j $i = j = \text{square root of } -1$
- realmin The smallest usable positive real number
- realmax The largest usable positive real number

[MATLAB Relational operators]

- MATLAB supports six relational operators.

Less Than	<
Less Than or Equal	<=
Greater Than	>
Greater Than or Equal	>=
Equal To	==
Not Equal To	~= (NOT != like in C)

[MATLAB Logical Operators]

MATLAB supports three logical operators.

not	~	% highest precedence
and	&	% equal precedence with or
or		% equal precedence with and



Matrices and MATLAB

[MATLAB Matrices]

- MATLAB treats all variables as matrices. For our purposes a matrix can be thought of as an array, in fact, that is how it is stored.
- Vectors are special forms of matrices and contain only one row OR one column.
- Scalars are matrices with only one row AND one column

[Generating Matrices]

- A scalar can be created in MATLAB as follows:

```
>> x = 23;
```

- A matrix with only one row is called a row vector. A row vector can be created in MATLAB as follows (note the commas):

```
>> y = [12,10,-3]
```

```
y =
```

```
    12    10    -3
```

- A matrix with only one column is called a column vector. A column vector can be created in MATLAB as follows:

```
>> z = [12;10;-3]
```

```
z =
```

```
    12
```

```
    10
```

```
    -3
```

[Generating Matrices]

- MATLAB treats row vector and column vector very differently
- A matrix can be created in MATLAB as follows (note the commas and semicolons)

```
>> X = [1,2,3;4,5,6;7,8,9]
```

```
X =
```

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

Matrices must be rectangular!

[The Matrix in MATLAB]

		Columns (n)				
		1	2	3	4	5
A =	1	4 ¹	10 ⁶	1 ¹¹	6 ¹⁶	2 ²¹
	2	8 ²	1.2 ⁷	9 ¹²	4 ¹⁷	25 ²²
	3	7.2 ³	5 ⁸	7 ¹³	1 ¹⁸	11 ²³
	4	0 ⁴	0.5 ⁹	4 ¹⁴	5 ¹⁹	56 ²⁴
	5	23 ⁵	83 ¹⁰	13 ¹⁵	0 ²⁰	10 ²⁵

Rows (m)

A(2,4)

A(17)

Note: Unlike C, MATLAB's indices start from 1

[Extracting a Sub-matrix]

- A portion of a matrix can be extracted and stored in a smaller matrix by specifying the names of both matrices and the rows and columns to extract. The syntax is:

```
sub_matrix = matrix ( r1 : r2 , c1 : c2 ) ;
```

where **r1** and **r2** specify the beginning and ending rows and **c1** and **c2** specify the beginning and ending columns to be extracted to make the new matrix.

[Extracting a Sub-matrix]

- Example :

```
>> X = [1,2,3;4,5,6;7,8,9]
```

```
X =
```

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

```
>> X22 = X(1:2 , 2:3)
```

```
X22 =
```

```
    2    3
    5    6
```

```
>> X13 = X(3,1:3)
```

```
X13 =
```

```
    7    8    9
```

```
>> X21 = X(1:2,1)
```

```
X21 =
```

```
    1
    4
```

[Matrix Extension]

- ```
>> a = [1,2i,0.56]
a =
 1 0+2i 0.56
>> a(2,4) = 0.1
a =
 1 0+2i 0.56 0
 0 0 0 0.1
```

- **repmat** – replicates and tiles a matrix  

```
>> b = [1,2;3,4]
b =
 1 2
 3 4
>> b_rep = repmat(b,1,2)
b_rep =
 1 2 1 2
 3 4 3 4
```

- **Concatenation**  

```
>> a = [1,2;3,4]
a =
 1 2
 3 4
>> a_cat = [a,2*a;3*a,2*a]
a_cat =
 1 2 2 4
 3 4 6 8
 3 6 2 4
 9 12 6 8
```

**NOTE: The resulting matrix must be rectangular**

# [ Matrix Addition ]

- Increment all the elements of a matrix by a single value

```
>> x = [1,2;3,4]
```

```
x =
```

```
 1 2
```

```
 3 4
```

```
>> y = x + 5
```

```
y =
```

```
 6 7
```

```
 8 9
```

- Adding two matrices

```
>> xsy = x + y
```

```
xsy =
```

```
 7 9
```

```
 11 13
```

```
>> z = [1,0.3]
```

```
z =
```

```
 1 0.3
```

```
>> xsz = x + z
```

??? Error using => plus  
Matrix dimensions must  
agree

# [ Matrix Multiplication ]

- Matrix multiplication

```
>> a = [1,2;3,4]; (2x2)
```

```
>> b = [1,1]; (1x2)
```

```
>> c = b*a
```

```
c =
```

```
 4 6
```

```
>> c = a*b
```

```
??? Error using ==> mtimes
```

```
Inner matrix dimensions
must agree.
```

- Element wise multiplication

```
>> a = [1,2;3,4];
```

```
>> b = [1,1/2;1/3,1/4];
```

```
>> c = a.*b
```

```
c =
```

```
 1 1
```

```
 1 1
```

# Matrix Element wise operations

```
■ >> a = [1,2;1,3];
>> b = [2,2;2,1];
```

## ■ Element wise division

```
>> c = a./b
c =
 0.5 1
 0.5 3
```

## ■ Element wise multiplication

```
>> c = a.*b
c =
 2 4
 2 3
```

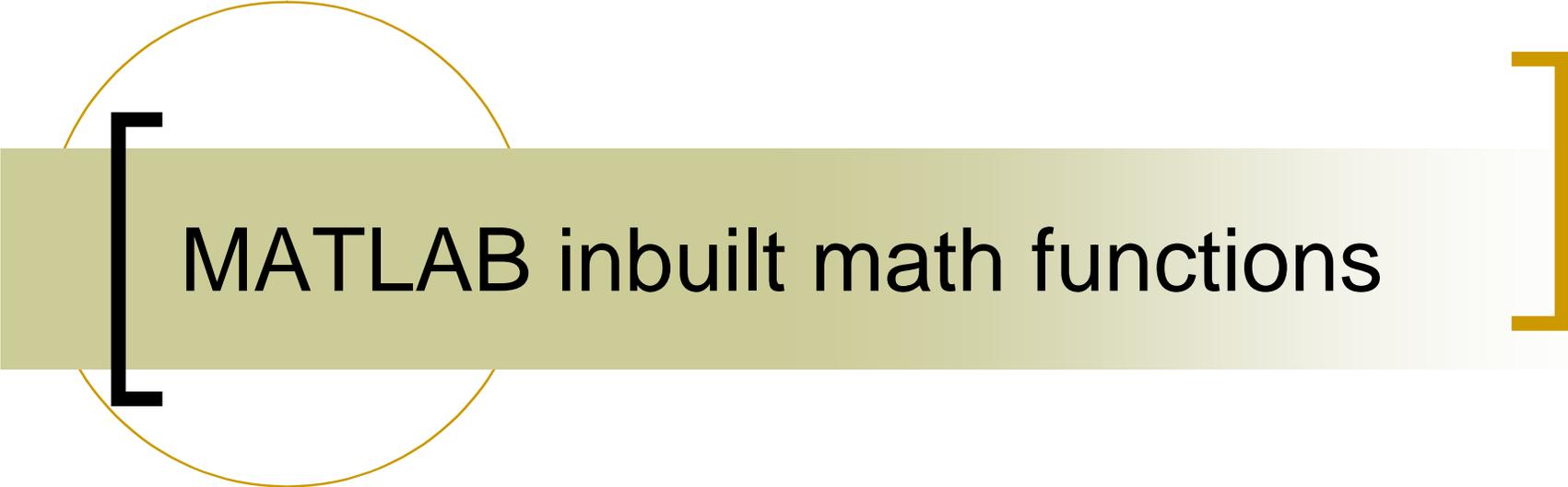
## ■ Element wise power operation

```
>> c = a.^2
c =
 1 4
 1 9
```

```
>> c = a.^b
c =
 1 4
 1 3
```

# Matrix Manipulation functions

- zeros : creates an array of all zeros, Ex: `x = zeros(3,2)`
- ones : creates an array of all ones, Ex: `x = ones(2)`
- eye : creates an identity matrix, Ex: `x = eye(3)`
- rand : generates uniformly distributed random numbers in [0,1]
- diag : Diagonal matrices and diagonal of a matrix
- size : returns array dimensions
- length : returns length of a vector (row or column)
- det : Matrix determinant
- inv : matrix inverse
- eig : evaluates eigenvalues and eigenvectors
- rank : rank of a matrix
- find : searches for the given values in an array/matrix.



# MATLAB inbuilt math functions

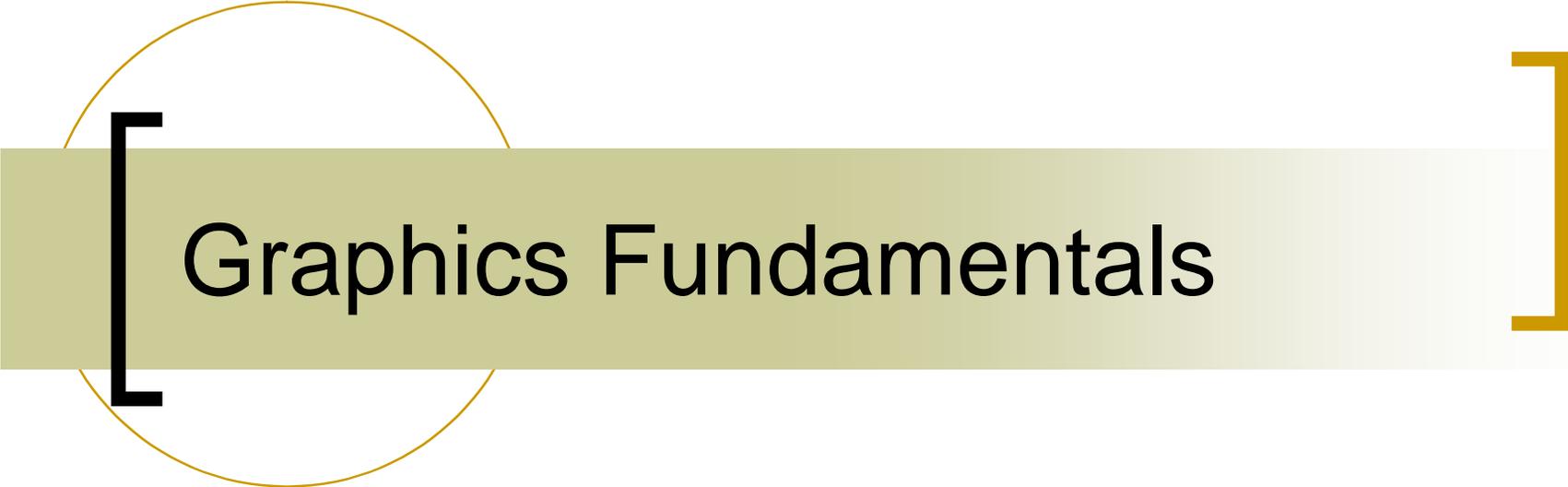
# [ Elementary Math functions ]

- abs - finds absolute value of all elements in the matrix
- sign - signum function
- sin,cos,... - Trigonometric functions
- asin,acos... - Inverse trigonometric functions
- exp - Exponential
- log,log10 - natural logarithm, logarithm (base 10)
- ceil,floor - round towards +infinity, -infinity respectively
- round - round towards nearest integer
- real,imag - real and imaginary part of a complex matrix
- sort - sort elements in ascending order

# [ Elementary Math functions ]

- sum,prod - summation and product of elements
- max,min - maximum and minimum of arrays
- mean,median – average and median of arrays
- std,var - Standard deviation and variance

*and many more...*



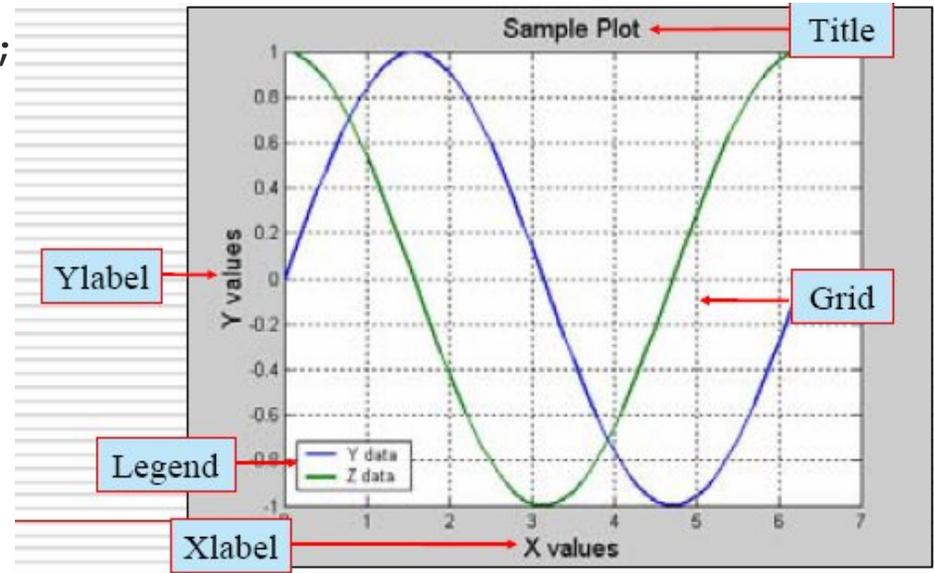
# Graphics Fundamentals

# [ 2D Plotting ]

- Example 1: Plot  $\sin(x)$  and  $\cos(x)$  over  $[0, 2\pi]$ , on the same plot with different colours

Method 1:

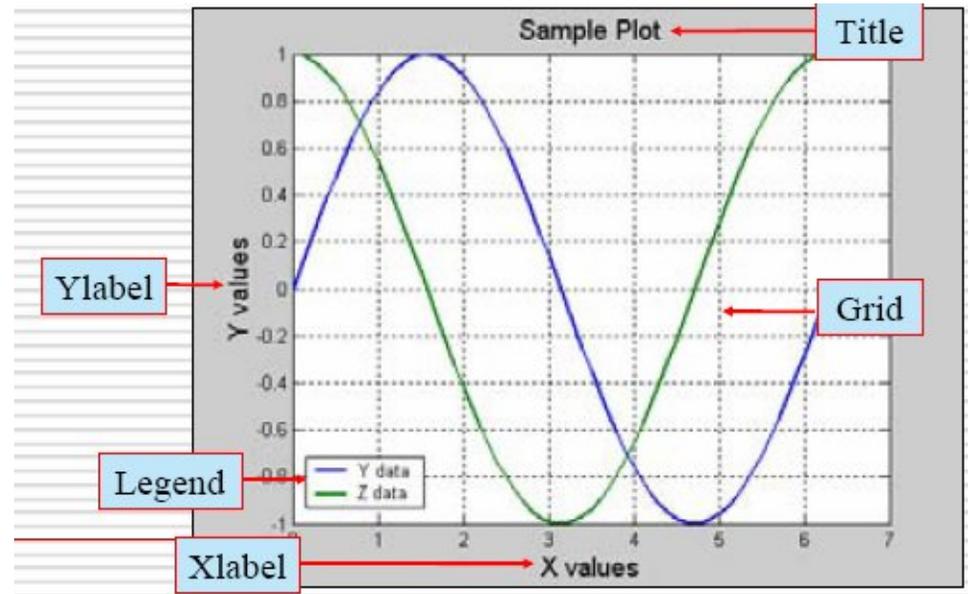
```
>> x = linspace(0, 2*pi, 1000);
>> y = sin(x);
>> z = cos(x);
>> hold on;
>> plot(x, y, 'b');
>> plot(x, z, 'g');
>> xlabel 'X values';
>> ylabel 'Y values';
>> title 'Sample Plot';
>> legend('Y data', 'Z data');
>> hold off;
```



# [ 2D Plotting ]

Method 2:

```
>> x = 0:0.01:2*pi;
>> y = sin(x);
>> z = cos(x);
>> figure
>> plot (x,y,x,z);
>> xlabel 'X values';
>> ylabel 'Y values';
>> title 'Sample Plot';
>> legend ('Y data', 'Z data');
>> grid on;
```

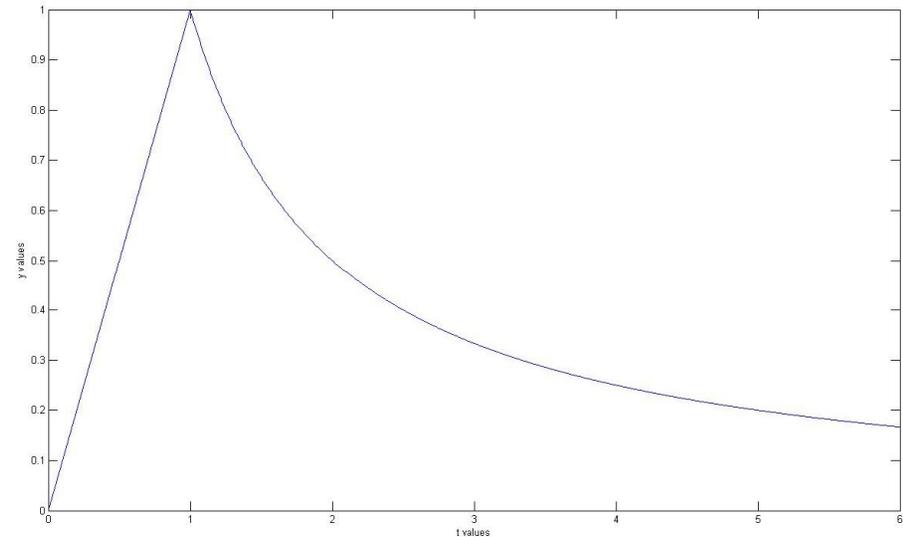


# [ 2D Plotting ]

- Example 2: Plot the following function  $y = \begin{cases} t & 0 \leq t \leq 1 \\ 1/t & 1 \leq t \leq 6 \end{cases}$

Method 1:

```
>> t1 = linspace(0,1,1000);
>> t2 = linspace(1,6,1000);
>> y1 = t1;
>> y2 = 1./ t2;
>> t = [t1,t2];
>> y = [y1,y2];
>> figure
>> plot(t,y);
>> xlabel 't values', ylabel 'y values';
```

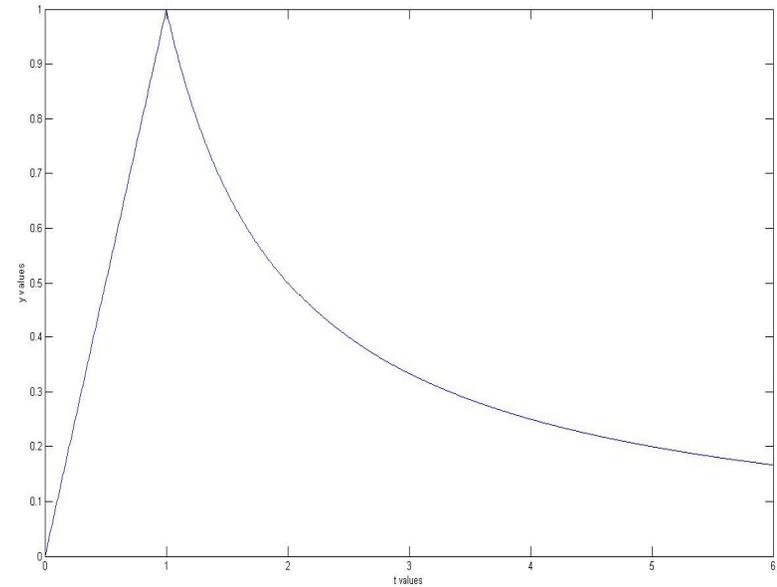


# [ 2D Plotting ]



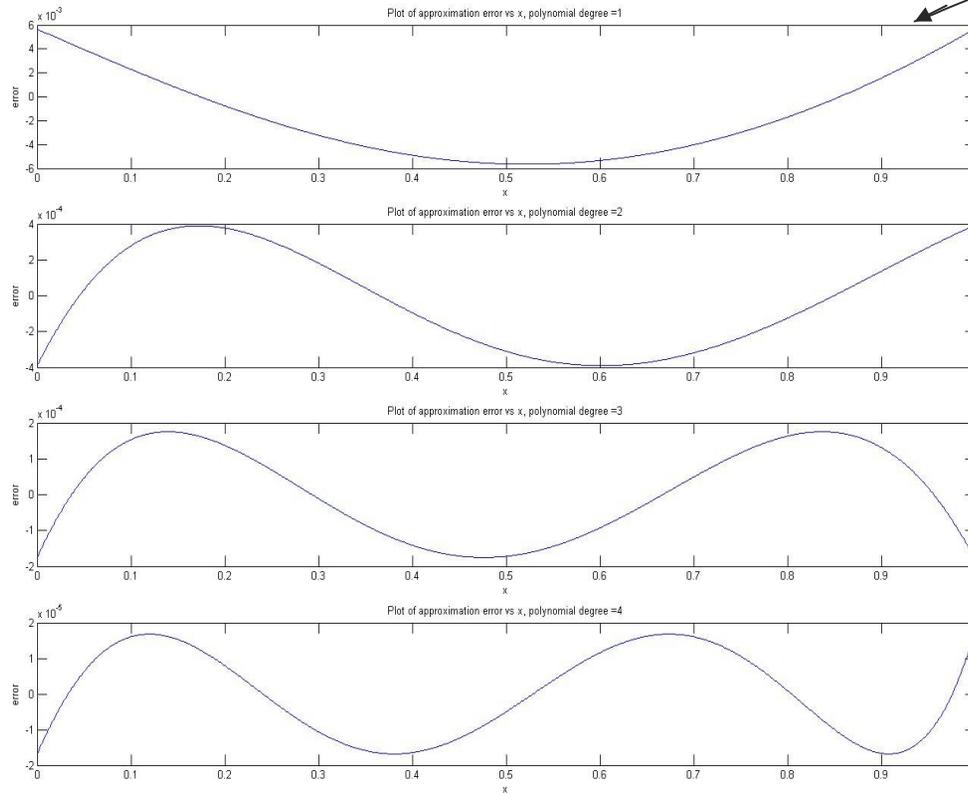
Method 2:

```
>> t = linspace(0,6,1000);
>> y = zeros(1,1000);
>> y(t()<=1) = t(t()<=1);
>> y(t()>1) = 1./ t(t()>1);
>> figure
>> plot(t,y);
>> xlabel't values';
>> ylabel'y values';
```



# [ Subplots ]

- Syntax: subplot (rows, columns, index)



```
>> subplot(4,1,1)
```

```
>> ...
```

```
>> subplot(4,1,2)
```

```
>> ...
```

```
>> subplot(4,1,3)
```

```
>> ...
```

```
>> subplot(4,1,4)
```

```
>> ...
```



Importing/Exporting Data

# [ Load and Save ]

- Using load and save

load filename - loads all variables from the file “filename”

load filename x - loads only the variable x from the file

load filename a\* - loads all variables starting with ‘a’

*for more information, type **help load** at command prompt*

save filename - saves all workspace variables to a binary  
.mat file named filename.mat

save filename x,y - saves variables x and y in filename.mat

*for more information, type **help save** at command prompt*

# Import/Export from Excel sheet

- Copy data from an excel sheet

```
>> x = xlsread(filename);
```

% if the file contains numeric values, text and raw data values, then

```
>> [numeric,txt,raw] = xlsread(filename);
```

- Copy data to an excel sheet

```
>>x = xlswrite('c:\matlab\work\data.xls',A,'A2:C4')
```

% will write A to the workbook file, data.xls, and attempt to fit the elements of A into the rectangular worksheet region, A2:C4. On success, 'x' will contain '1', while on failure, 'x' will contain '0'.

*for more information, type **help xlswrite** at command prompt*

# [ Read/write from a text file ]

- Writing onto a text file

```
>> fid = fopen('filename.txt', 'w');
>> count = fwrite(fid, x);
>> fclose(fid);
```

% creates a file named 'filename.txt' in your workspace and stores the values of variable 'x' in the file. 'count' returns the number of values successfully stored. **Do not forget to close the file at the end.**

- Read from a text file

```
>> fid = fopen('filename.txt', 'r');
>> X = fscanf(fid, '%5d');
>> fclose(fid);
```

% opens the file 'filename.txt' which is in your workspace and loads the values in the format '%5d' into the variable x.

*Other useful commands: fread, fprintf*



# Flow Control in MATLAB

# [ Flow control ]

---

- MATLAB has five flow control statements
  - **if** statements
  - **switch** statements
  - **for** loops
  - **while** loops
  - **break** statements

# [ 'if' statement ]

- The general form of the 'if' statement is

```
>> if expression
>> ...
>> elseif expression
>> ...
>> else
>> ...
>> end
```

- Example 1:

```
>> if i == j
>> a(i,j) = 2;
>> elseif i >= j
>> a(i,j) = 1;
>> else
>> a(i,j) = 0;
>> end
```

- Example 2:

```
>> if (attn>0.9)&(grade>60)
>> pass = 1;
>> end
```

# ['switch' statement]

- **switch** Switch among several cases based on expression

- The general form of the **switch** statement is:

```
>> switch switch_expr
>> case case_expr1
>> ...
>> case case_expr2
>> ...
>> otherwise
>> ...
>> end
```

- Example :

```
>> x = 2, y = 3;
>> switch x
>> case x==y
>> disp('x and y are equal');
>> case x>y
>> disp('x is greater than y');
>> otherwise
>> disp('x is less than y');
>> end
x is less than y
```

**Note: Unlike C, MATLAB doesn't need BREAKs in each case**

# [ 'for' loop ]

- **for** Repeat statements a specific number of times
- The general form of a **for** statement is

```
>> for variable=expression
>> ...
>> ...
>> end
```

- Example 1:

```
>> for x = 0:0.05:1
>> printf('%d\n',x);
>> end
```

- Example 2:

```
>> a = zeros(n,m);
>> for i = 1:n
>> for j = 1:m
>> a(i,j) = 1/(i+j);
>> end
>> end
```

# [ 'while' loop ]

- **while** Repeat statements an indefinite number of times
- The general form of a **while** statement is

```
>> while expression
>> ...
>> ...
>> end
```

- Example 1:  
>> n = 1;  
>> y = zeros(1,10);  
>> while n <= 10  
>> y(n) = 2\*n/(n+1);  
>> n = n+1;  
>> end

- Example 2:  
>> x = 1;  
>> while x  
>> %execute statements  
>> end

**Note:** In MATLAB '1' is synonymous to TRUE and '0' is synonymous to 'FALSE'

# [ 'break' statement ]

- **break** terminates the execution of **for** and **while** loops
- In nested loops, **break** terminates from the innermost loop only

- Example:

```
>> y = 3;
>> for x = 1:10
>> printf('%5d' ,x);
>> if (x>y)
>> break;
>> end
>> end
1 2 3 4
```



# Efficient Programming

# [ Efficient Programming in MATLAB ]

- Avoid using nested loops as far as possible
- In most cases, one can replace nested loops with efficient matrix manipulation.
- Preallocate your arrays when possible
- MATLAB comes with a huge library of in-built functions, use them when necessary
- Avoid using your own functions, MATLAB's functions are more likely to be efficient than yours.

# [ Example 1 ]

- Let  $x[n]$  be the input to a non causal FIR filter, with filter coefficients  $h[n]$ . Assume both the input values and the filter coefficients are stored in column vectors  $x, h$  and are given to you. Compute the output values  $y[n]$  for  $n = 1, 2, 3$  where

$$y[n] = \sum_{k=0}^{19} h[k]x[n+k]$$

# [ Solution ]

- Method 1:

```
>> y = zeros(1,3);
>> for n = 1:3
>> for k = 0:19
>> y(n) = y(n) + h(k) * x(n+k);
>> end
>> end
```

- Method 2 (avoids inner loop):

```
>> y = zeros(1,3);
>> for n = 1:3
>> y(n) = h' * x(n:(n+19));
>> end
```

- Method 3 (avoids both the loops):

```
>> X = [x(1:20), x(2:21), x(3:22)];
>> y = h' * X;
```

# [ Example 2 ]

- Compute the value of the following function

$$y(n) = 1^3 * (1^3 + 2^3) * (1^3 + 2^3 + 3^3) * \dots * (1^3 + 2^3 + \dots + n^3)$$

for n = 1 to 20

# [ Solution ]

- Method 1:

```
>> y = zeros(20,1);
>> y(1) = 1;
>> for n = 2:20
>> for m = 1:n
>> temp = temp + m^3;
>> end
>> y(n) = y(n-1)*temp;
>> temp = 0
>> end
```

- Method 2 (avoids inner loop):

```
>> y = zeros(20,1);
>> y(1) = 1;
>> for n = 2:20
>> temp = 1:n;
>> y(n) = y(n-1)*sum(temp.^3);
>> end
```

- Method 3 (avoids both the loops):

```
>> X = tril(ones(20)*diag(1:20));
>> x = sum(X.^3,2);
>> Y = tril(ones(20)*diag(x))+ ...
 triu(ones(20)) - eye(20);
>> y = prod(Y,2);
```

# [ Getting more help ]

Where to get help?

- In MATLAB's prompt type :  
**help, lookfor, helpwin, helpdesk, demos**
- On the Web :  
<http://www.mathworks.com/support>  
<http://www.mathworks.com/products/demos/#>  
<http://www.math.siu.edu/MATLAB/tutorials.html>  
<http://math.ucsd.edu/~driver/21d-s99/MATLAB-primer.html>  
<http://www.mit.edu/~pwb/cssm/>  
<http://www.eecs.umich.edu/~aey/eecs216/.html>