http://web.eecs.umich.edu/~aey/eecs451/matlab.pdf

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 = 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
```

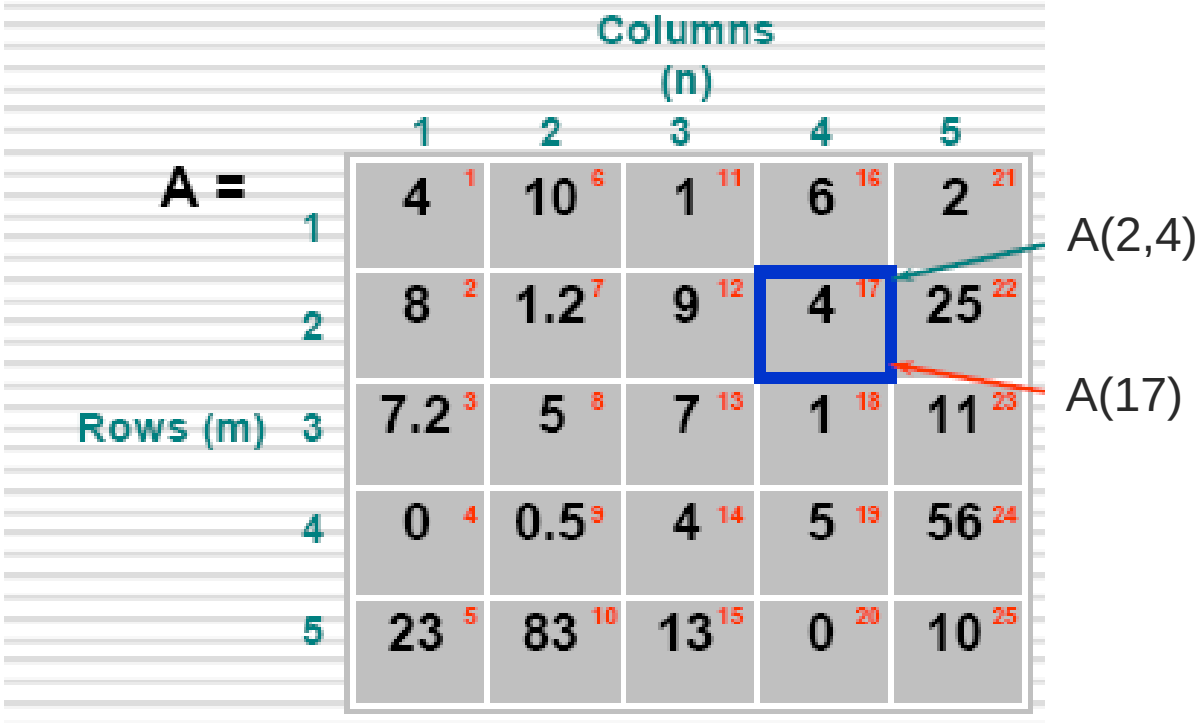
Generating Matrices

- 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



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 = [1,½;1/3,¼];
>> 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,… - Trignometric functions
- asin,acos… - Inverse trignometric 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…

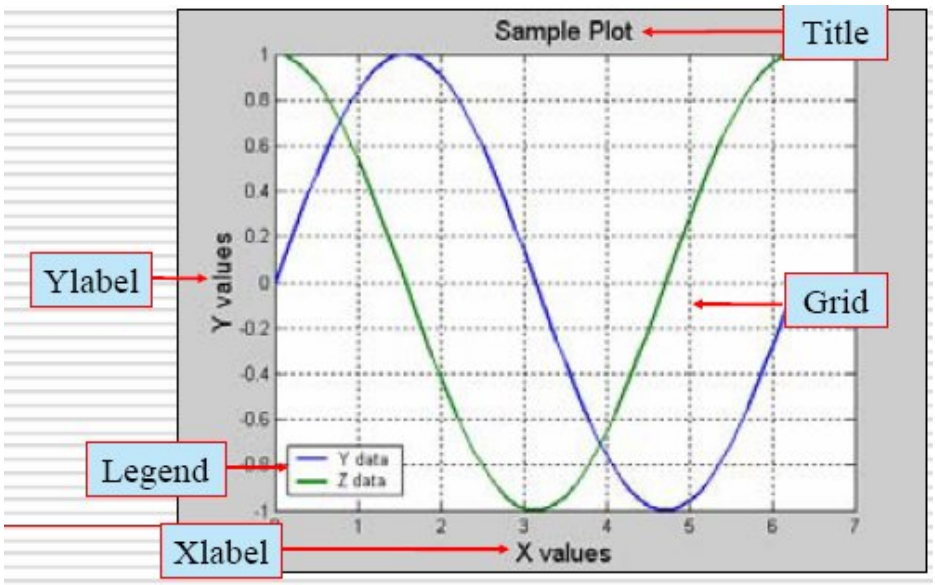
Graphics Fundamentals

2D Plotting

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

Method 1:

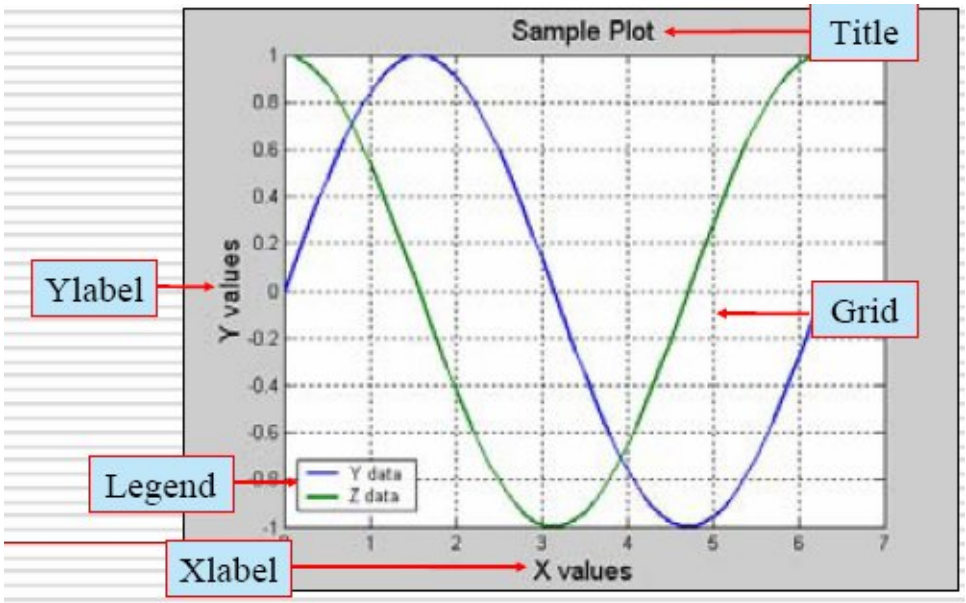
```
>> x = linspace(0,2*pi,1000);
>> y = sin(x);
>> z = cos(x);
>> hold on;
>> plot(x,y,'b');
>> plot(x,z,'g');
>> xlabel 'X values';
>> ylabel 'Y values';
>> title 'Sample Plot';
>> legend ('Y data','Z data');
>> hold off;
```



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;
```

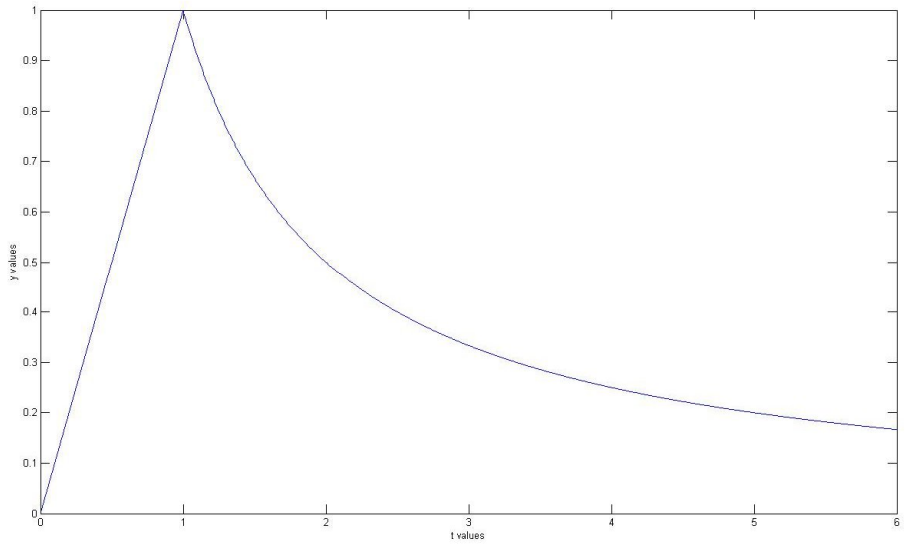


2D Plotting

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

Method 1:

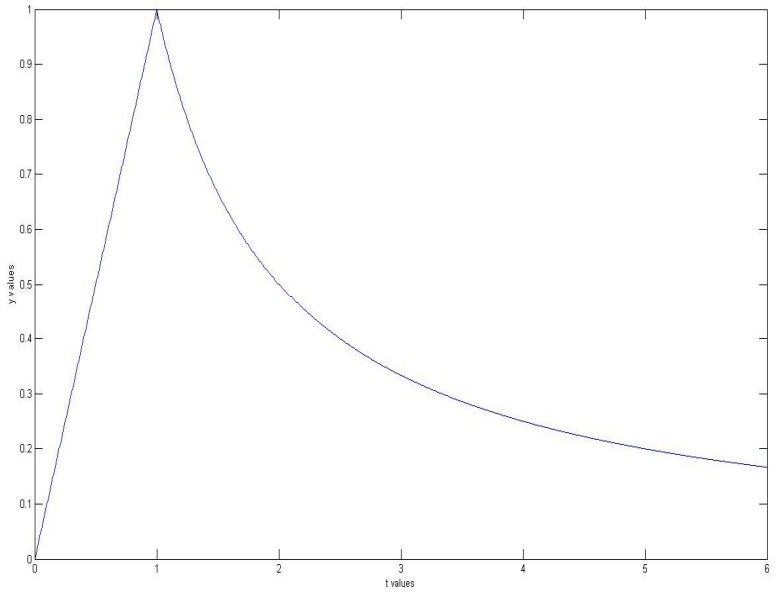
```
>> t1 = linspace(0,1,1000);
>> t2 = linspace(1,6,1000);
>> y1 = t1;
>> y2 = 1./ t2;
>> t = [t1,t2];
>> y = [y1,y2];
>> figure
>> plot(t,y);
>> xlabel ‘t values’, ylabel ‘y values’;
```



2D Plotting

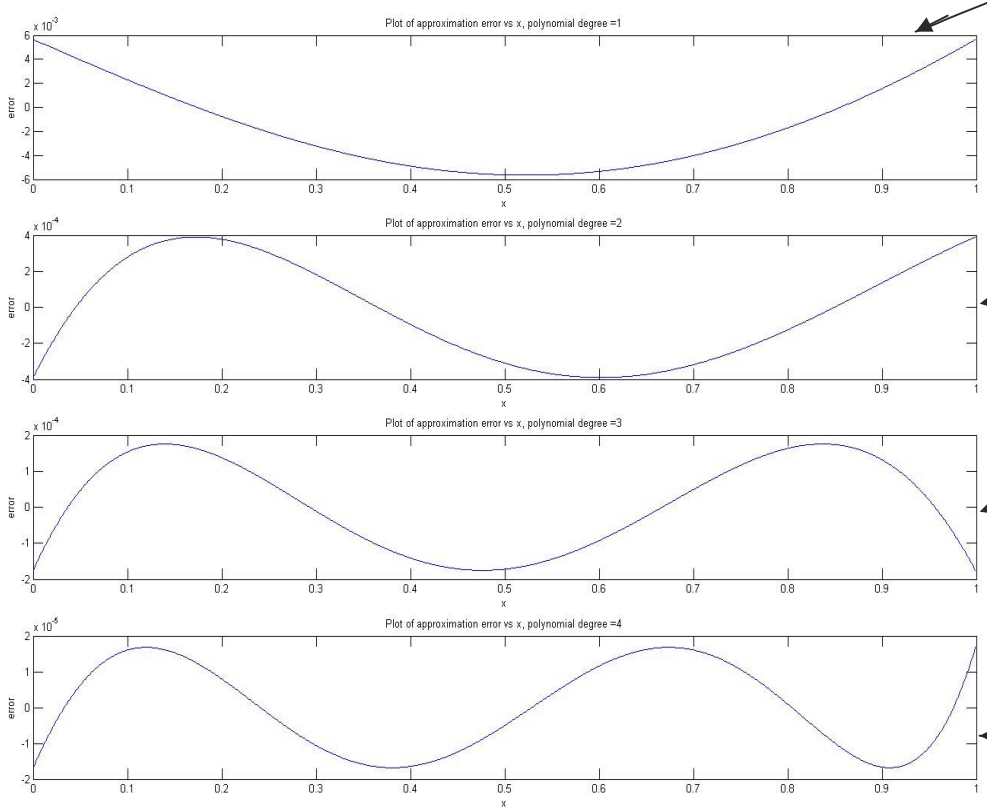
Method 2:

```
>> 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

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

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