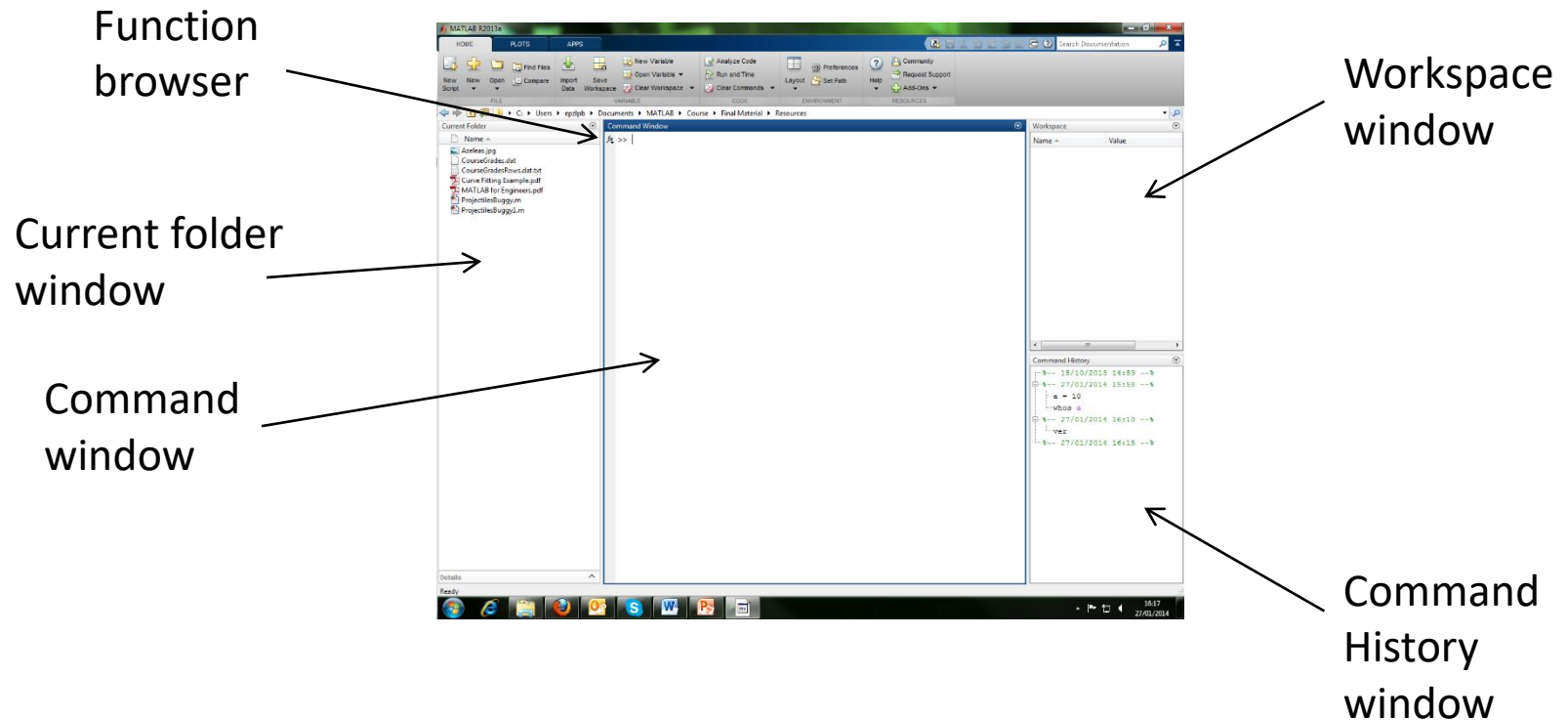


# Introduction to MATLAB for Engineers

Louise Brown

<http://moodle.nottingham.ac.uk/course/view.php?id=12439>

# The MATLAB Desktop



To change path use dialog given by Environment->SetPath  
`path('Folder',path)` or `path(path,'Folder')`

# Changing the desktop configuration



At top right hand corner of window gives drop down menu with options:



Dock and undock windows



Slide window to tabbed position at side of window



Restore maximised window to tiled position

Stack windows by dragging the title bars over each other

Save setup: Desktop -> Save Layout.

Restore default layout: Desktop->Desktop Layout->Default

# Version Control

Does this look familiar?

TestCode.m

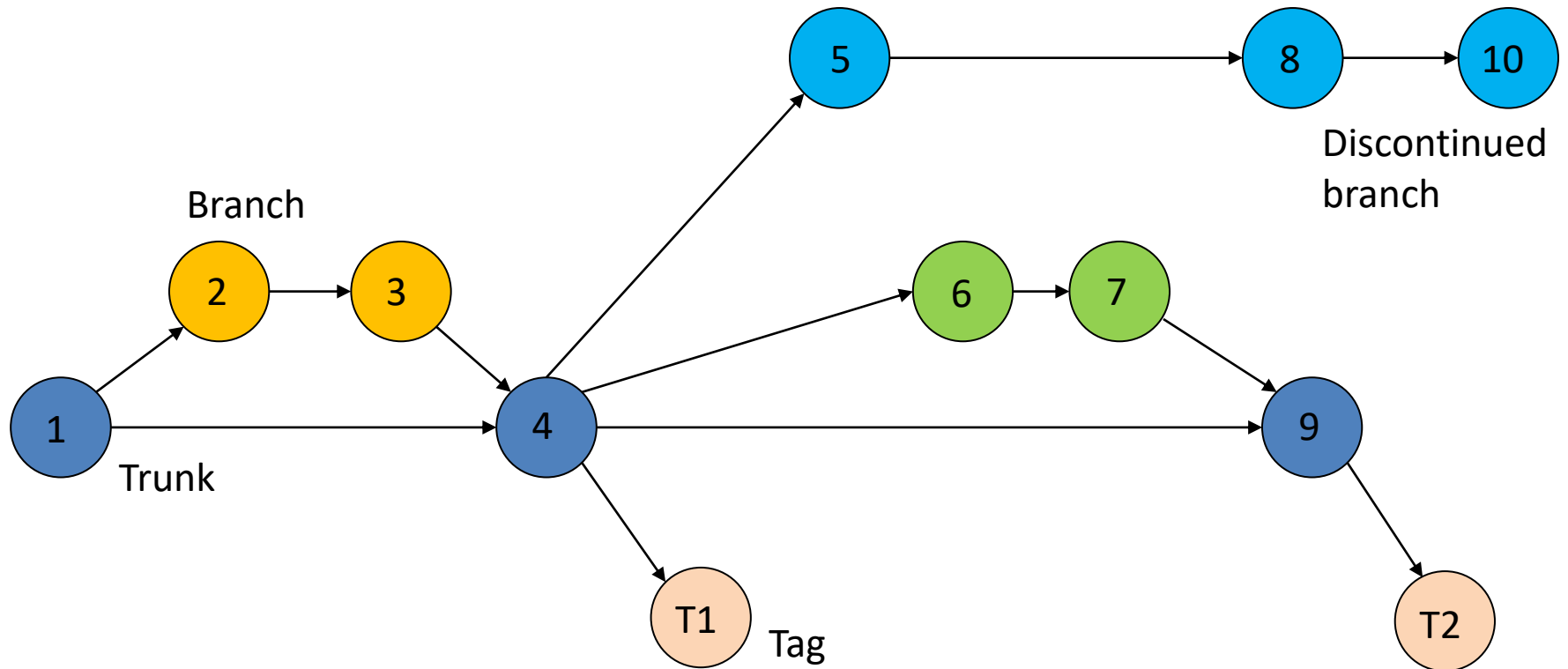
TestCode\_data\_set1.m

TestCode\_data\_set1\_v2.m

TestCode\_data\_set1\_v2\_with\_output.m

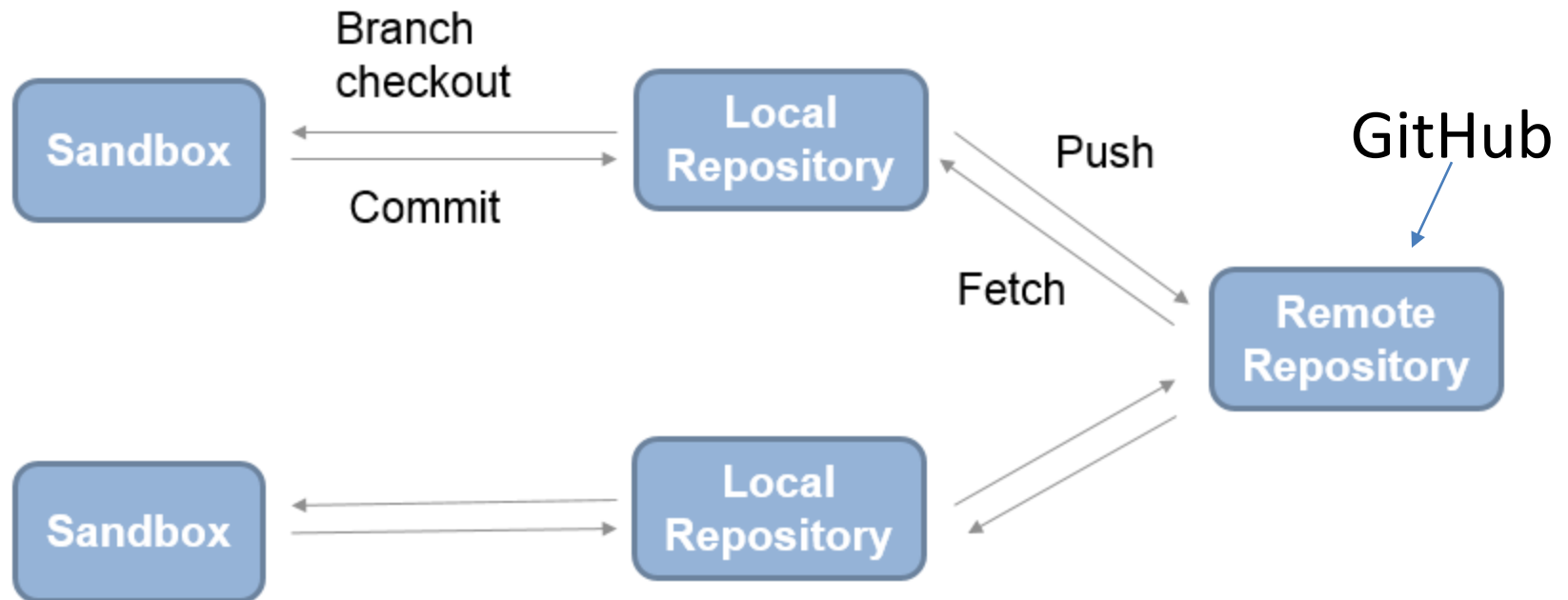
Use version control, eg Git, Subversion or Mercurial

# Git Workflow



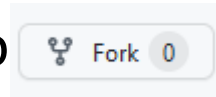
Tags can correspond to code producing results for research papers

# Git Workflow



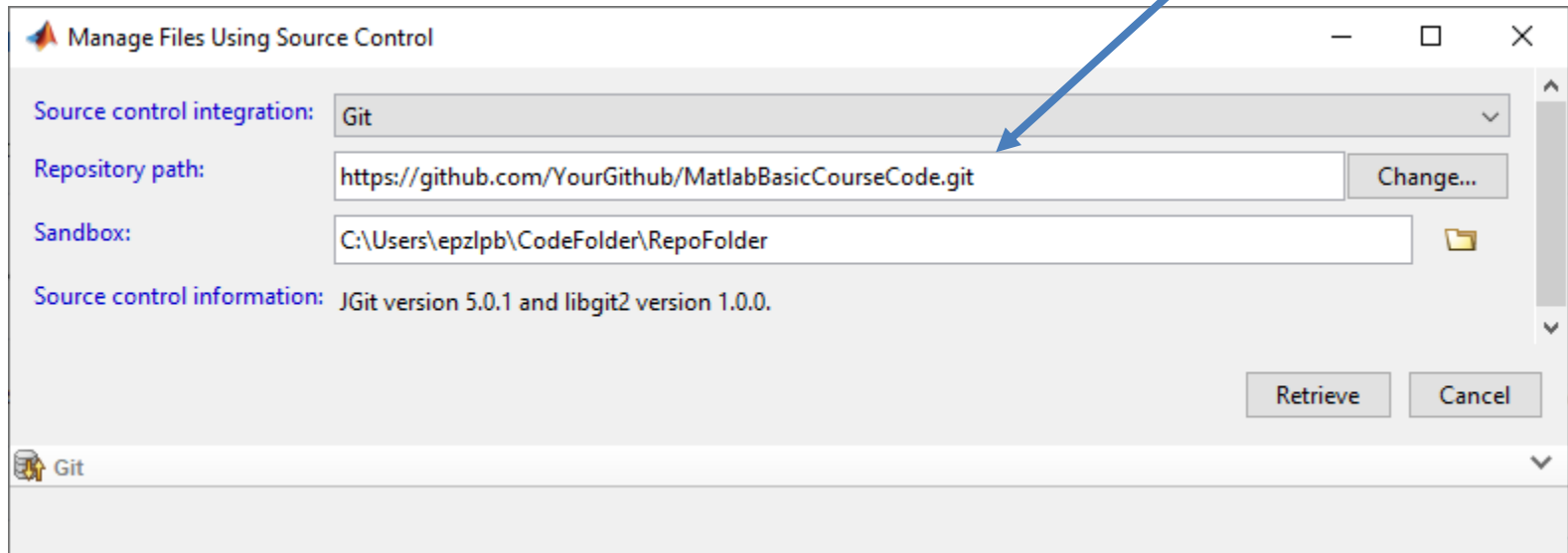
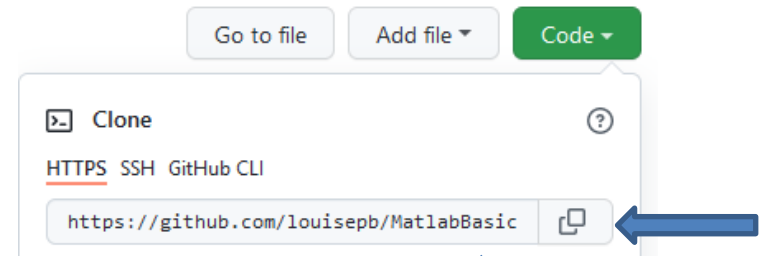
# Fork Course Code

- First create a fork of the code in your Github:
  - Go to louisepb/MatlabBasicCourseCode on GitHub
  - Select Fork (top right of page)
  - You should see a copy of the repo in your GitHub



# Clone Code to Local Drive

- Then create a clone of the code on your local drive
  - Select the Code button and copy the address
  - Right click in Current Folder Window
  - Select Source Control -> Manage Files...



- Run setupPath.m to add subfolders to path



# Variables

- All variables in MATLAB are stored as arrays
- Scalar is 1x1 array
- Vector is 1xn or nx1 array
- Matrix is mxn array
- ...and so on for multi-dimensional arrays

Variables are created using an assignment statement

```
>> a = 10      creates a scalar variable
```

All variables are displayed in the workspace window

`who` – gives list of variable names

`whos` – gives name, size, type and memory size

# Variable display format

- Use `format` command to change display format
- `format long` - fixed point format with 15 digits
- `format short` – fixed point format with 4 digits
- Note that `format` does not affect the way in which the variable is stored in memory
- Type `help datatypes` to see other available data types

# Variable Names

- Must start with a letter but may include `_` and numbers
- Case sensitive
- Certain reserved words cannot be used. Type `iskeyword` to see these
- Built in function names may be used but this will block access to the original functions. (Clear workspace to restore)
- Beware of overwriting `pi`, `i` and `j`

`i` and `j` are used as complex numbers by default

Type `i` or `j` at the command prompt

```
0 + 1.0000i
```

# Saving Workspace Data

## MATLAB format:

Variables in the workspace can be saved to a file using the Save Workspace button or by typing `save <filename>` at the command line

Using `save('filename', 'var1', 'var2', ...)` allows selected variables to be saved

Saves with `.mat` extension in format readable by MATLAB

Has advantage that it is operating system independent

## ascii format:

Use a `'-ascii'` parameter to save data in ascii format.

```
>> save('Data.dat','x','y', '-ascii')
```

Conventionally a `.dat` file extension is used

# Vectors

```
>> A = [1 2 3 4]
>> A = [1,2,3,4]
```

Both give 1x4 vector

A =

1 2 3 4

```
>> A = [1:4]
```

Colon operator gives regularly spaced elements

Specify increment using format [first:step:last]

```
>> B = [1:2:9]
```

gives B = 1 3 5 7 9

Increment can be decimal as well as integer

```
>> C = [1:0.2:2]
```

gives

C =

1.0000 1.2000 1.4000 1.6000 1.8000 2.0000

# More Vectors

Create a vector with a given number of equispaced points using `linspace( start, end, number of elements)`

```
>> vec = linspace( 1, 8, 5 )  
vec = 1.0000    2.7500    4.5000    6.2500    8.0000
```

`logspace` can be used to create logarithmically spaced points  
`y = logspace(a,b,n)` generates `n` points between decades  $10^a$  and  $10^b$

```
>> vec = logspace(1,2,5)  
vec =  
10.0000    17.7828    31.6228    56.2341   100.0000
```

# Character Vectors

Create character vectors using single quotes

```
charVec = 'Here are some characters'
```

Stored as 1x24 char array

**Type** `help strings` for more information, or `doc strings` for full documentation

# Column Vectors

Either semicolon operator

```
>> A = [1;2;3;4]
```

or transpose operator

```
>> A = [1:4]'
```

can be used to  
create a column  
vector:

```
A =  
1  
2  
3  
4
```



# Indexing Vectors

A = 

10	3	20	7	30	11	13
----	---	----	---	----	----	----

Subscript notation: A(3) gives 5

Subscript can be a vector: A([1 4 6]) gives 1 7 11

Colon notation to extract range: A(2:5) gives 3 5 7 9

Use 'end' either on its own or in range: A(4:end) gives 7 9 11 13

Replace element using index on left: A([1 3 5]) = [10 20 30]

# Exercise 2.1

1) >> A = [5:2:17]

A =

5   7   9   11   13   15   17

3) >> C = A([1 4 6])

C =

5   11   15

2) >> B = [3:-1:-3]'

B =

3

2

1

0

-1

-2

-3

4) >> B([3 5 7]) = C

B =

3

2

5

0

11

-2

15

# Arithmetic Operations

Addition	$a + b$
Subtraction	$a - b$
Multiplication	$a * b$ for matrix or scalar multiplication
	$a.*b$ for element by element multiplication
Division	$a / b$ for matrix or scalar division
	$a ./ b$ for element by element division
Left division	$a \setminus b$ for matrix or scalar left division
	$a . \setminus b$ for element by element left division
Exponentiation	$a ^ b$ for matrix or scalar exponentiation
	$a . ^ b$ for element by element exponentiation

# Order of Precedence

Arithmetic operations will be carried out in the order:

- Evaluate parentheses working from inside to outside
- Exponential operations (^)
- Multiplication (\*) and division (/) from left to right
- Addition (+) and subtraction (-) from left to right

# Addition and Subtraction Operations

Scalar addition and subtraction performs the operation on each member of the vector or array:

```
>> A = [1:4]
```

```
A =
```

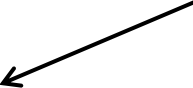
```
    1    2    3    4
```

```
>> A = A + 10
```

```
A =
```

```
   11   12   13   14
```

Note – this is achieved  
without using a loop



Array addition and subtraction is performed element  
by element

```
>> B = [5:8]
```

```
B =
```

```
    5    6    7    8
```

```
>> A = A + B
```

```
A =
```

```
   16   18   20   22
```

# Multiplication Based Operations

Multiplication ( and /,\,^ ) operate element by element on scalars in the same way as the addition operator.

```
>> A = [1:4]
```

```
A =
```

```
    1    2    3    4
```

```
>> A = A * 10
```

```
A =
```

```
   10   20   30   40
```

# Multiplication Based Operations

To multiply vectors or arrays element by element the 'dot' operators must be used. Note that vectors must be the same size.

```
>>A = [1:4]
A =
     1     2     3     4
```

```
>> B = [2:5]
B =
     2     3     4     5
```

```
>> D = A.*B
D =
     2     6    12    20
```

Note that just using the \* operator here will result in an error

# Multiplication Based Operators

Using multiplication based operators without a dot operator will result in standard matrix operations

```
>> A = [1:4]
```

```
A =
```

```
    1    2    3    4
```

```
>> B = [1:4]'
```

```
B =
```

```
    1
```

```
    2
```

```
    3
```

```
    4
```

So that

```
>> A*B
```

```
ans =  
    30
```

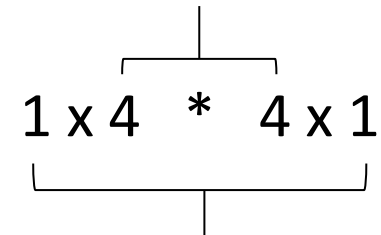
but

```
>> B*A
```

```
ans =
```

```
    1    2    3    4  
    2    4    6    8  
    3    6    9   12  
    4    8   12   16
```

Inner dimensions must match



Outer dimensions give final size



# Vectors as Function Input

Vectors can be used as input arguments to functions – both built-in and user defined

```
>> A = [0:pi/6:pi]
```

```
A =
```

```
0 0.5236 1.0472 1.5708 2.0944 2.6180 3.1416
```

```
>> B = sin(A)
```

```
B =
```

```
0 0.5000 0.8660 1.0000 .8660 0.5000 0.0000
```

# Exercise 2.2

1) `>> 1/(2+3^4) + 5/(6*7) + 7/8`

`ans =`

1.0061

2) `>> A = linspace( 0, 2*pi, 9 )`

`A =`

0 0.7854 1.5708 2.3562 3.1416 3.9270 ... 4.7124 5.4978 6.2832

`>> SinAng = sin(A)`

`SinAng =`

0 0.7071 1.0000 0.7071 0.0000 -0.7071 ... -1.0000 -0.7071 -0.0000

3) `>> SinAng = SinAng + 1`

`SinAng =`

1.0000 1.7071 2.0000 1.7071 1.0000 0.2929 0 0.2929 1.0000

# Exercise 2.2

```
4) >> B = [1:9]
```

```
B =
```

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

```
>> SinAng.*B
```

```
ans =
```

```
1.0000  3.4142  6.0000  6.8284  5.0000  1.7574  0  2.3431  9.0000
```

# Left Division

$a \backslash b = a^{-1}b$  for matrix operations

$a.\backslash b = b/a$  when performed element by element on arrays or when one of the operands is a scalar

```
>> A = [1:4]
```

```
A =
```

```
    1    2    3    4
```

```
>> A.\2
```

```
ans =
```

```
    2.0000    1.0000    0.6667    0.5000
```

# Using Left Division to Solve Simultaneous Equations

The pair of simultaneous equations

$$3x_1 + 2x_2 = 12$$

$$x_1 + 4x_2 = 14$$

can be written as  $Ax = B$

where  $A = \begin{bmatrix} 3 & 2 \\ 1 & 4 \end{bmatrix}$ ,  $B = \begin{bmatrix} 12 \\ 14 \end{bmatrix}$ , and  $x = \begin{bmatrix} x_1 \\ x_2 \end{bmatrix}$

Solving using linear algebra gives  $x = A^{-1}B$

In MATLAB set up the arrays

```
>> A = [3 2; 1 4]
```

```
A =
```

```
    3    2
    1    4
```

```
>> B = [12; 14]
```

```
B =
```

```
    12
    14
```

and solve using the left  
division operator

```
>> x = A \ B
```

```
x =
```

```
    2
    3
```

# Matrices

Use the semicolon operator to separate the rows of a matrix

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

```
A =
```

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

The colon operator can be used as for vectors.  
The same result is given by

```
>> A = [1:5;5:9]
```

## Exercise 2.3

```
>> A = [1 2 3; 2 3 -1; 4 -1 2]
```

```
A =
```

```
1    2    3
2    3   -1
4   -1    2
```

```
>> B = [13;4;13]
```

```
B =
```

```
13
 4
13
```

```
>> X = A\B
```

```
X =
```

```
2.0000
1.0000
3.0000
```

# Character Matrices

Arrays of characters must have the same number of elements in each row.

O	N	E		
S	E	V	E	N
F	I	V	E	

```
>> charArray = [ 'ONE'; 'SEVEN'; 'FIVE' ]
```

Error using vertcat

Dimensions of matrices being concatenated are not consistent.



# Character Matrices

Use `char` function to create arrays with padded strings

```
>> charArray = char('one', 'seven', 'five')
```

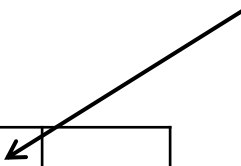
```
charArray =
```

```
one
```

```
seven
```

```
five
```

Creates 3x5 char array with spaces padding shorter strings



O	N	E		
S	E	V	E	N
F	I	V	E	

# String Scalars

Used to store a group of characters as a `string` type

```
>> str = "one"  
str =  
    "one"
```

```
>> strArray = ["one"; "seven"; "five"]  
strArray =  
    3x1 string array  
    "one"  
    "seven"  
    "five"
```

Addition operator can be used to concatenate strings:

```
>> str = "one" + " seven" + " five"  
str =  
    "one seven five"
```

# Indexing String Scalars

To access the string:

```
>> strArray(2)
      ans = "seven"
```

To access the char vector:

```
>> strArray{2}
      ans = 'seven'
>> strArray{2}(3)
      ans = 'v'
```

# Matrix Indexing

A =

1	2	3	4	5
5	6	7	8	9
9	10	11	12	13

row      column

↘      ↙

Subscript notation:  $A(3,2) = 10$

Colon notation to extract range in both rows and columns:  $A(2:3, 3:4) =$

7	8
11	12

Colon notation to extract whole row or column:  $A(2, :) =$

5	6	7	8	9
---	---	---	---	---

Or several rows or columns:  $A(:, [1 \ 3 \ 5]) =$

1	3	5
5	7	9
9	11	13

# Linear Indexing (1)

A =	1	2	3	4	5
	1	4	7	10	13
	5	6	8	11	14
	9	10	11	12	13
	3	6	9	12	15

Linear index is obtained by counting down each column in turn

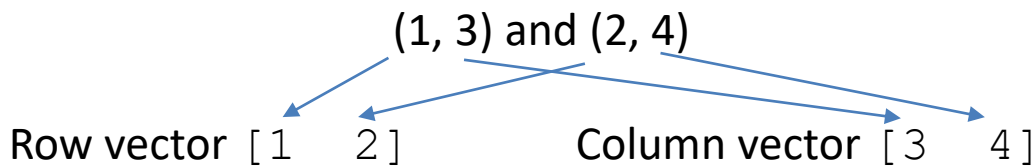
Linear index:  $A(5) = 6$

# Linear Indexing (2)

A =	1	1	2	4	3	7	4	10	5	13
	5	2	6	5	7	8	8	11	9	14
	9	3	10	6	11	9	12	12	13	15

Find indices for elements (1, 3) and (2, 4)

Use `sub2ind( size, row vector, column vector )` to convert from subscript to linear index



```
>> Index = sub2ind( size(A), [1 2], [3 4] )
Index =
     7     11
```

Then extract actual elements using the linear index vector: `A(Index) =` 3 8

# Combining Matrices

Larger arrays can be built up from smaller ones:

```
>> A = [1:5;5:9]
```

A =

1	2	3	4	5
5	6	7	8	9

```
>> B = [1:2:9;2:2:10]
```

B =

1	3	5	7	9
2	4	6	8	10

```
>> D = [A;B]
```

D =

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

Note that the dimensions of arrays being joined must be consistent.

```
>> E = [A B]
```

E =

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

# Matrix Functions

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

`length(X)` returns the largest dimension of an array: `length(A) = 5`

`size(X)` returns a vector containing the length of each dimension of the array:

```
>> dims = size(A)
      dims =
          2      5
```

The rows and columns can also be returned as separate variables:

```
>> [row, column] = size(A)
row =
     2
column =
     5
```



# Useful automatically generated matrices

Identity matrix: `eye(X)`

Only one parameter as the  
identity matrix is square

```
>> eye(2)
```

```
ans =
```

```
1    0
0    1
```

p... for matrices of more than  
two dimensions

All ones: `ones(m, n, p...)`

All zeros: `zeros(m, n, p...)`

```
>> ones(2, 3)
```

```
ans =
```

```
1    1    1
1    1    1
```

```
>> zeros(3, 2)
```

```
ans =
```

```
0    0
0    0
0    0
```

# Matrix Memory Management

Extra elements may be added to an array simply by allocating an element at a given position

```
A = 1 2  
     3 4
```

Adding an element at (5,5) grows the array:

```
>> A(5,5) = 10
```

```
A =
```

```
1 2 0 0 0  
3 4 0 0 0  
0 0 0 0 0  
0 0 0 0 0  
0 0 0 0 10
```



A new block of memory will be allocated each time extra elements are added to the array – this is slow!

If the final size of the array is known create an array of the final size (typically using the zeros() function) and then assign elements as required

# Sparse Arrays

For arrays with large numbers of zero elements the `sparse(N)` function can be used to squeeze out zero values.

A =

1	2	0	0	0
3	4	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	10

`sparse(A)` reduces the size of A from 200 to 84 bytes

# Exercise 2.4

1) >> A = [9 12 13 0;10 3 1 5;2 5 10 3]

A =

9	12	13	0
10	3	1	5
2	5	10	3

>> B = [1 4 2 11;9 8 16 7;12 5 0 3]

B =

1	4	2	11
9	8	16	7
12	5	0	3

2) >> C = A(3,3)

C =

10

>> D = A(:,3)

D =

13
1
10

>> E = [B(1,:);B(3,:)]

E =

1	4	2	11
12	5	0	3

>> F = [A;B]

F =

9	12	13	0
10	3	1	5
2	5	10	3
1	4	2	11
9	8	16	7
12	5	0	3

>> G = [A(:,1) B(:,4)]

G =

9	11
10	7
2	3

# Exercise 2.4

3)            >> E(2,2) = 20

E =

1	4	2	11
12	20	0	3

>> A(1,:) = 0

A =

0	0	0	0
10	3	1	5
2	5	10	3

>> F(:,3) = 1:6

F =

9	12	1	0
10	3	2	5
2	5	3	3
1	4	4	11
9	8	5	7
12	5	6	3

>> A(:,1) = B(:,2)

A =

4	0	0	0
8	3	1	5
5	5	10	3

# Scripts

Script files are created by selecting New Script or typing 'edit' at the command prompt.

MATLAB script files are saved with a '.m' extension (by default to the current folder)

Scripts are run by typing the script name at the command prompt

Comment lines start with %

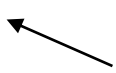
The first comment line in a script is the H1 line which is used as a help for the script.

A semicolon at the end of the line will suppress output to the monitor

# Simple User Input

Use `input(str)` command to fetch user input

```
>> value = input( 'Enter a value: ');  
Enter a value: 10
```



User input

A second parameter 's' indicates the input is a character or string.

```
>> str = input('Input yes or no ', 's')  
Input yes or no yes  
  
str =  
    yes
```

# Output

Use the `disp(str)` function for simple output

To display a variable use `disp (A)`

Or to output a string:

```
% Create a string  
str = 'Output from disp function';  
% Pass the string as a parameter to the disp function  
disp( str );
```

```
>> Output from disp function
```



# Output

Simple strings can be assembled to give output data.

Use the `num2str` function to convert numerical data into a string

```
>> Vel = 20;  
>> strTitle = ['Starting speed = ' num2str(Vel) ' m/s'];  
>> disp(strTitle);
```

```
Starting speed = 20 m/s
```

Or using string scalars:

```
>> strTitle = "Starting speed " + num2str(Vel) + " m/s"
```

# Freefall Script

Write a script called FreeFallExample.m which calculates the distance travelled by a freely falling object at ten time increments from release to time,  $t$ , using the equation

$$d = 0.5gt^2$$

The time will be user input.  
Output the distances calculated.

# Freefall Script

# Exercise 4.1

Write a script called FreeFall.m which calculates the distance travelled by a freely falling object at each time increment between two given times using the equation

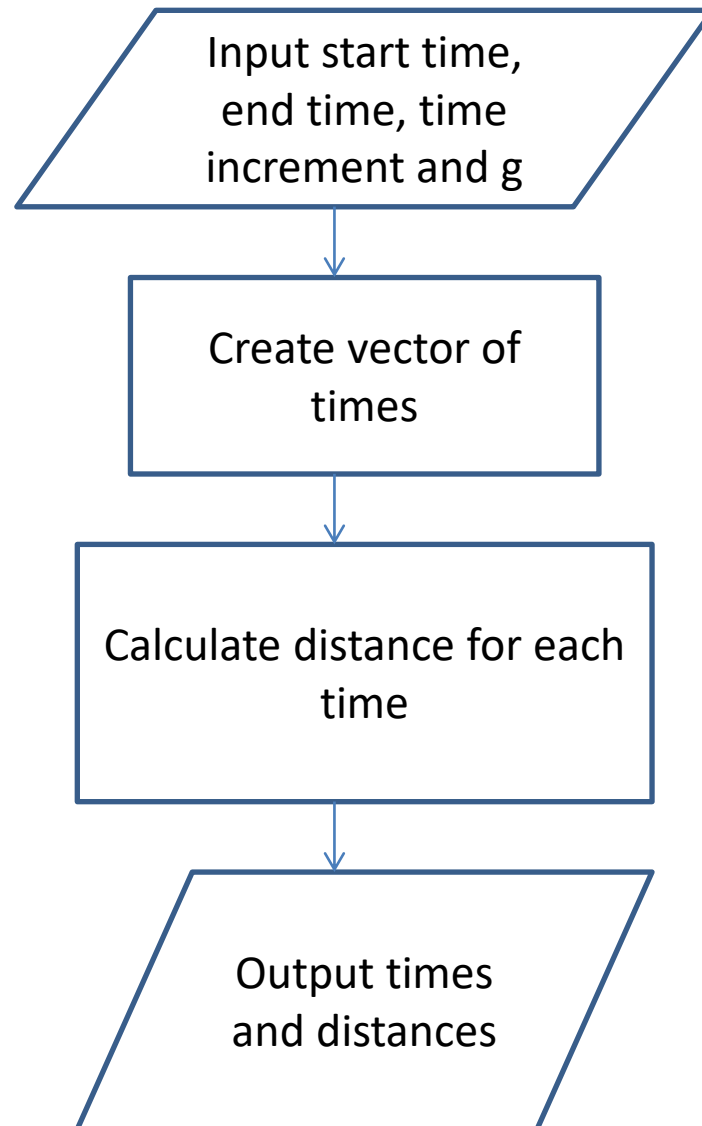
$$d = 0.5gt^2$$

The **start** and **end times** and **time increment** will be **user input**.  
Output the distances calculated.

(For more of a challenge present the output as two columns showing times and distances)

# Exercise 4.1

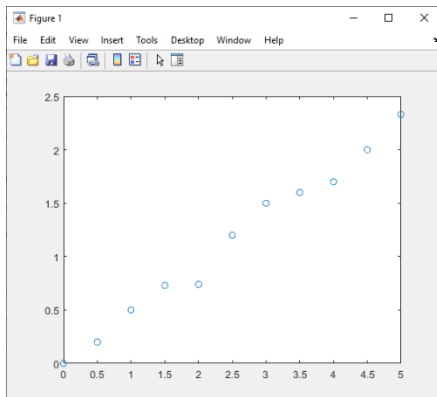
# Exercise 4.1



# Simple x-y plots

`plot(x,y)` plots vector `x` against vector `y`

```
>> t = 0:0.5:5  
>> distance = [0, 0.2, 0.5, 0.73, 0.74, 1.2, ...  
1.5, 1.6, 1.7, 2.0, 2.33]  
>> plot(t, distance, 'o')
```



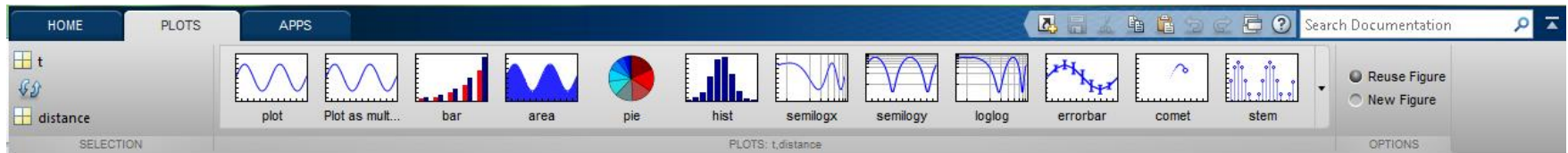
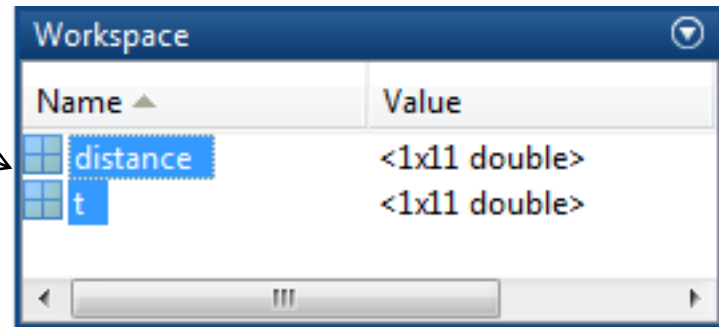
Third parameter used to  
specify line style, marker type  
and colour

`plot` command automatically fits axes to the data.

To control axis scaling use: `axis( [xmin, xmax, ymin, ymax])`

# Plot from Workspace

Select variables to plot



Select plot type from ribbon

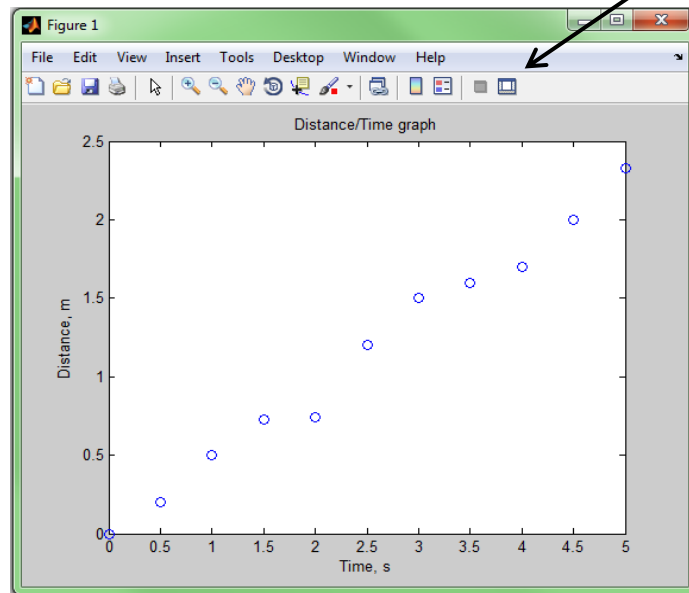


# Annotating Figures

From the script:

```
>> xlabel( 'Time, s')  
>> ylabel('Distance, m')  
>> title('Distance/Time  
graph')
```

Note – plot command must be  
executed first



Or using Plot Tools:

- Use Show Plot Tools and Dock Figure icon
- Or type 'plottools' at the command prompt
- Or using the live editor

Script for similar plots can be created using File->Generate code

# Plotting Multiple Data Sets

Various methods of plotting multiple data sets on one figure:

`hold on` - any plot commands will plot on same figure until `hold off` is executed

Send multiple sets of data in one plot command

```
>> plot( t, distance, 's', t, distance2, 'o' )
```

Collect multiple sets of data into one matrix

```
>> distances = [distance;distance2]
```

```
>> plot( t, distances, 'o' )
```

## Creating multiple figures:

Select the current figure to be plotted to using the `figure(n)` command.

Any subsequent plots will be performed on this figure

# Subplots

Several plots in the same window

Use `subplot(m,n,p)` command.

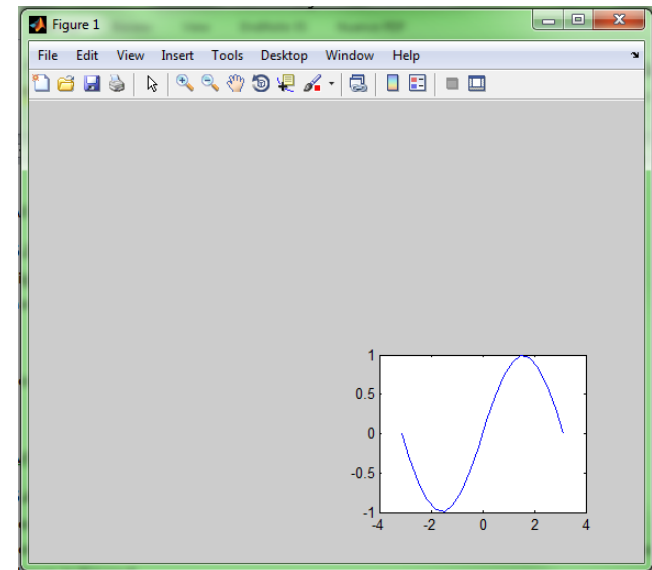
Window is split into grid of `m` rows by `n` columns.

`p` selects the window for plotting.

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

```
% Call plot commands before calling  
subplot again for next location
```

p = 1	p = 2
p = 3	p = 4



# Saving Figures

Save figures using `saveas` function:

```
saveas(gcf, 'filename', 'format')
```

 returns the handle to the current figure

```
>> saveas(gcf, 'Figure', 'png')
```

Saves to Figure.png

File->Save    Saves a Matlab .fig file

File->Save As...    Saves to standard image formats

# Exercise 5.2

Suggested initial values:

Start velocity = 60 m/s

Launch angle =  $\pi/3$

Plot horizontal distance on x-axis and vertical distance on y-axis

Format the title (to include the velocity and angle) using a vector of strings

Remember to convert the angle back into degrees to display in the title

Use `num2str` to create strings from variables to include in the string, eg '30 degrees'

# Debugging

3 types of errors: syntax, runtime and logical

Syntax errors:

At the command line an error message is displayed

In the edit window: orange bar – warning

red bar - error

Runtime errors:

Occur as code executes, eg out of bounds index

Within a script an error message is given including the line number

Note that in MATLAB divide by 0 does not generate an error – a value of Inf is assigned and the program continues to run

Logical errors:

Hardest to find. Program runs but gives incorrect results

In MATLAB can use Code Cells or the built-in debugger

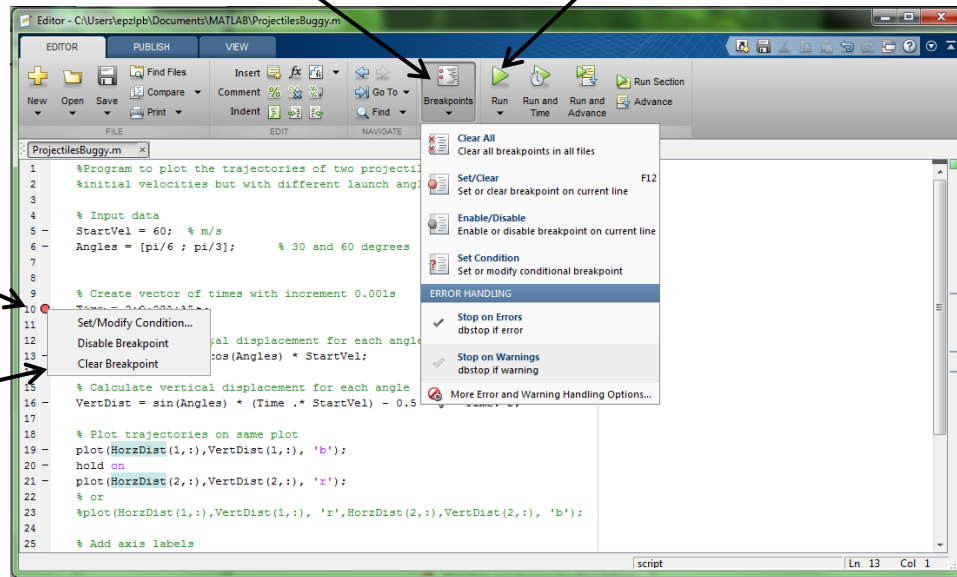
# Using the Built-in Debugger

Set/clear breakpoint (F12)

Save and run (F5)

Breakpoint

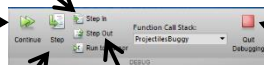
Right click on  
breakpoint to  
display options



When running debug the menu is displayed:

Step into (F11)

Continue (F5)



Exit debug mode (Shift + F5)

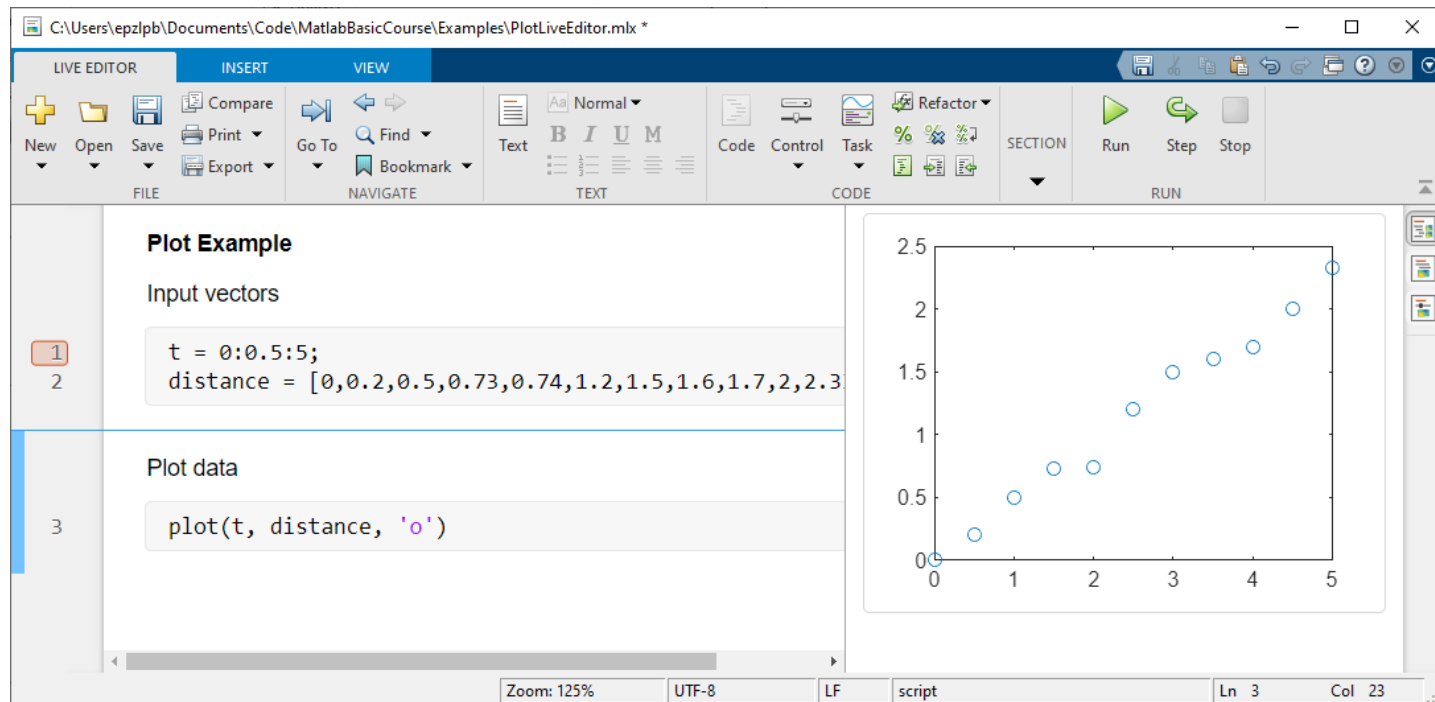
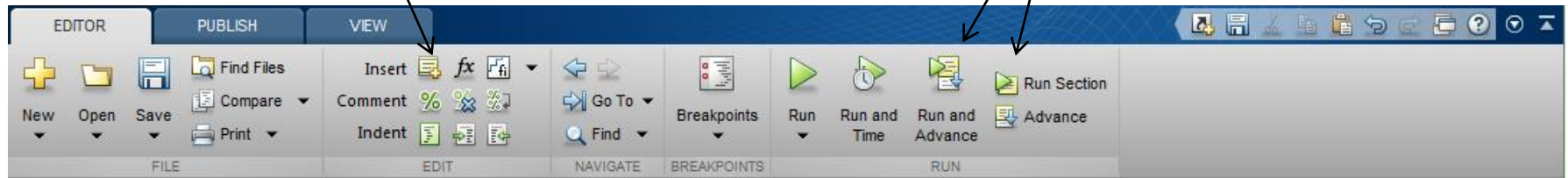
Step (F10)

Step out (Shift + F11)

# Code Sections and Live Editor

Insert section break

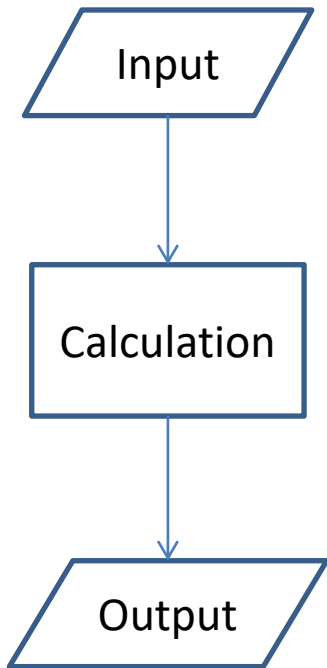
Run section options



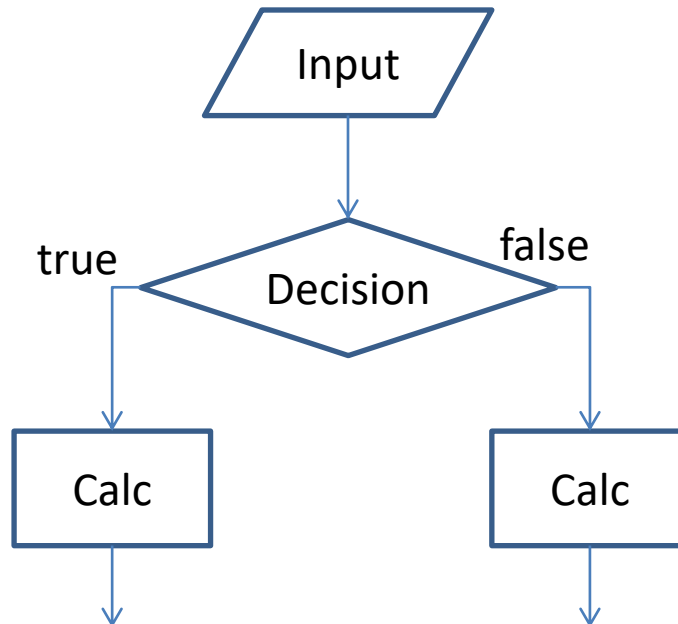


# Program Structure

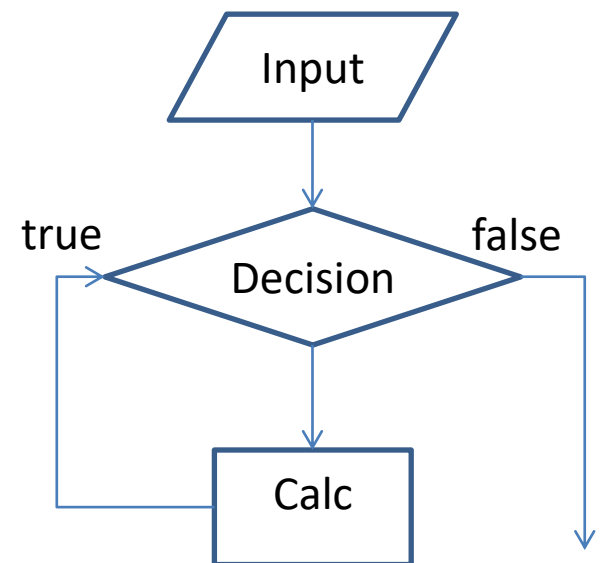
Sequential



Selection



Repetition



# Relational and Logical Operators

Logical data type: `a = true` or `a = false` – occupies 1 byte  
convert to logical using `b = logical(x)`

Relational	<code>a &lt; b</code>	less than
	<code>a &lt;= b</code>	less than or equal to
	<code>a &gt; b</code>	greater than
	<code>a &gt;= b</code>	greater than or equal to
	<code>a == b</code>	equal to
	<code>a ~= b</code>	not equal to

Logical	<code>a &amp; b</code>	and
	<code>a   b</code>	or
	<code>~ a</code>	not
	<code>xor( a,b )</code>	exclusive or

# Comparing Matrices

Comparisons on matrices will compare corresponding elements and create a matrix of the results using the logical data type

```
>> a = 1:5
```

```
a =  
    1    2    3    4    5
```

```
>> b = [3 1 2 4 0]
```

```
b =  
    3    1    2    4    0
```

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

```
c =  
    0    1    1    0    1
```

# Logical Indexing

Relational and logical operators are performed element-wise on vectors or matrices resulting in a logical matrix:

```
A = 1 2 3 4 5  
     3 4 5 6 7
```

Note that for compound tests each test is written out in full:

$A > 2$  and  $A < 6$

```
>> B = A > 2 & A < 6
```

Can't use  $2 < A < 6$  type format

```
B = 0 0 1 1 1  
     1 1 1 0 0
```

Logical matrix B can be used as a mask to perform operations on selected elements of a matrix

```
>> A(B) = sqrt(A(B))
```

```
A = 1.0000 2.0000 1.7321 2.0000 2.2361  
     1.7321 2.0000 2.2361 6.0000 7.0000
```

# Logical Indexing(2)

```
A = 1 2 3 4 5  
     3 4 5 6 7
```

```
B = 0 0 1 1 1  
     1 1 1 0 0
```

Extract the elements which satisfy the test: `>> C = A(B)`

```
C =  
     3  
     4  
     3  
     5  
     4  
     5
```

To find the indices of the elements which satisfy the test use the `find()` function

```
>> D = find(A>2 & A<6)
```

```
D =
```

```
2  
4  
5  
6  
7  
9
```

# find()

Index = find(x,1) – returns the linear index of the first nonzero element, or first element which satisfies a specified condition

```
>> B = [0 0 0 3 4 5 6]
```

```
B =
```

```
    0    0    0    3    4    5    6
```

```
>> find( B,1 )
```

```
ans =
```

```
    4
```

```
>> find( B>4, 1)
```

```
ans =
```

```
    6
```

# Floating Point Comparisons

## Comparison of floats or doubles

Small differences resulting from floating point arithmetic may cause errors when checking for equality.

```
>> a = 0.5-0.4-0.1  
a =  
    -2.775557561562891e-17
```

Use a tolerance check:

```
>> abs(a) < tolerance
```

```
A  
    0.9999999999
```

```
if ( A == 1)    % will be false
```

```
Tol = 1e-6;  
abs( A - 1.0 ) < Tol    % will return true
```

# Exercise 8.1

1) >> A = [9 12 18 0;10 3 1 7;2 5 14 22]

A =

9	12	18	0
10	3	1	7
2	5	14	22

>> B = A >=7 & A < 15

B =

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

2) >> A(B) = A(B).^2

A =

81	144	18	0
100	3	1	49
2	5	196	22

3) >> find(A>100)

ans =

4

9

4) >> B = A(A>100)

B =

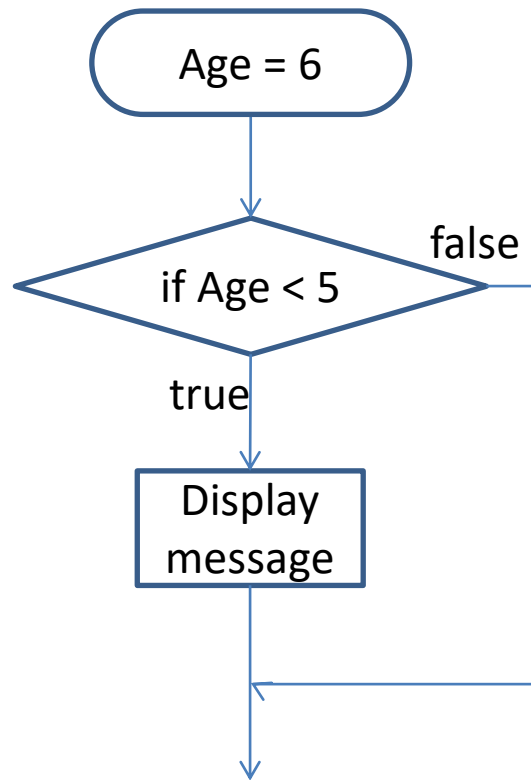
144

196



# Conditional Statements

Selection

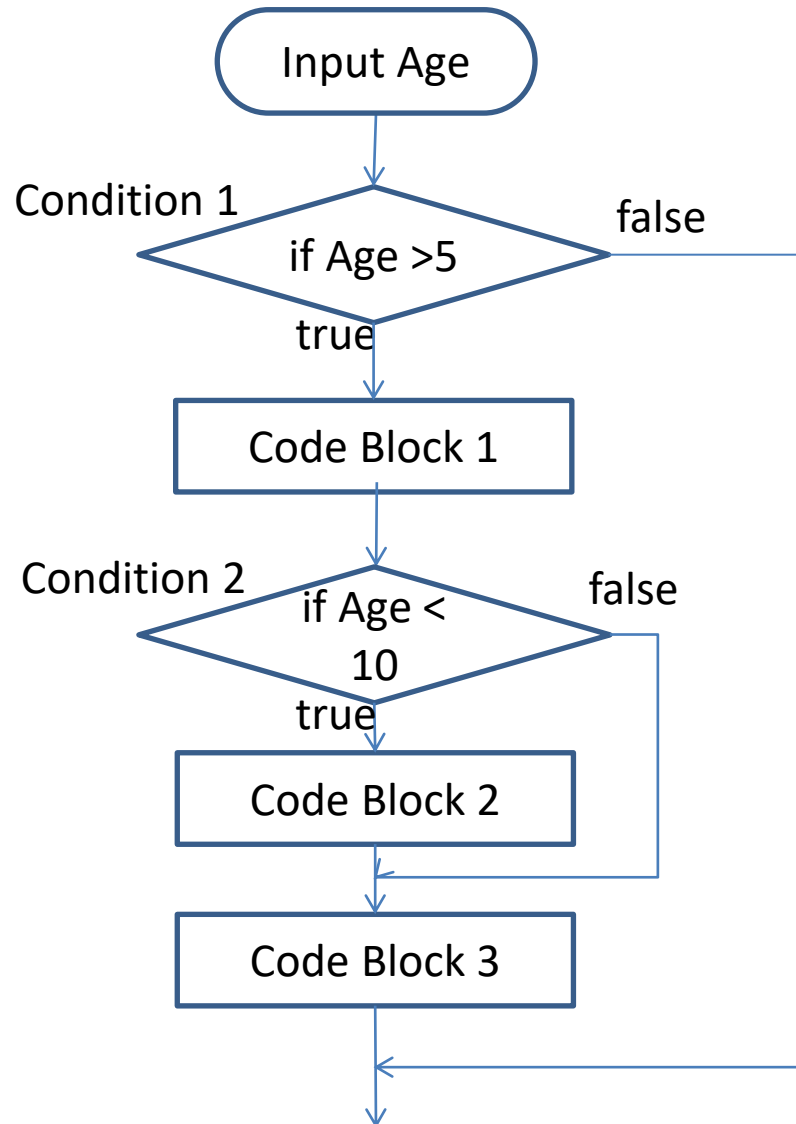


```
if condition  
    Code block  
end
```

```
Age = 6;  
if Age < 5  
    disp('a is less than 5');  
end
```

Note that if the condition is applied to an array it will only be true if *all* elements of the array satisfy the condition

# Nested if statements



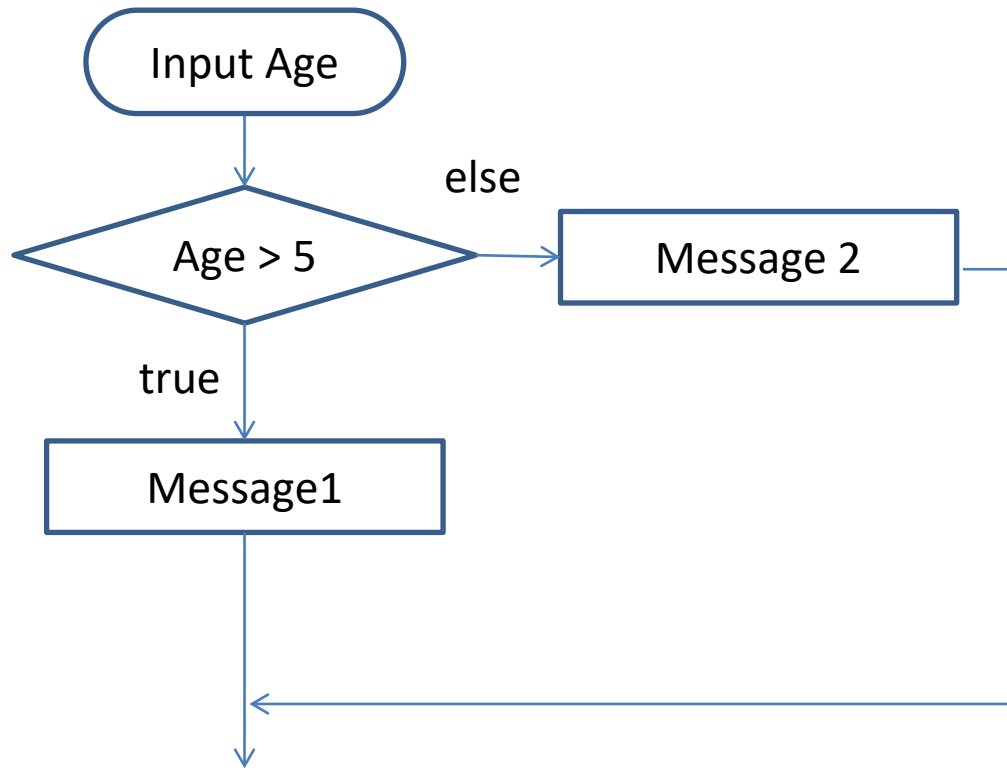
if statements can be nested:

```
if condition1
    Code block 1
    if condition 2
        Code block 2
    end    % End of condition 2
    Code block 3
end      % End of condition 1
```

Remember the 'end' statement  
at the end of each code block

Indentation is not necessary  
but is good style and makes  
code more readable

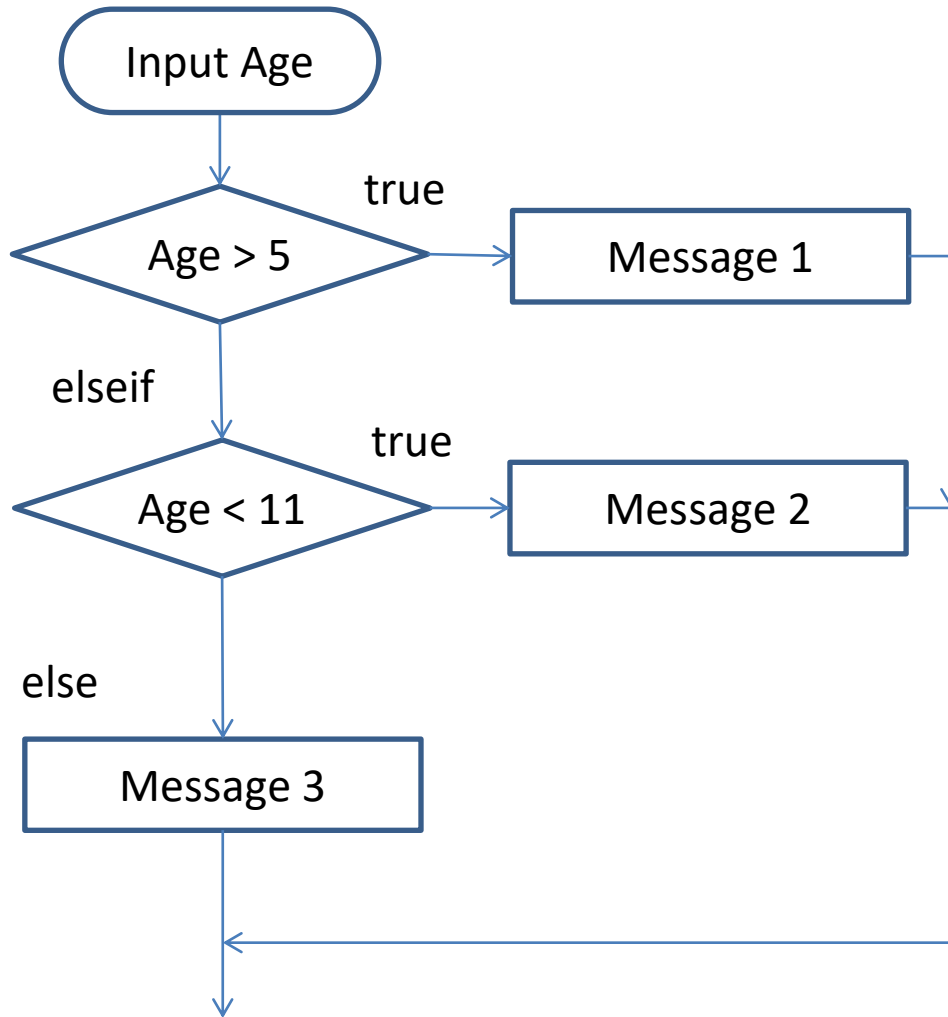
# if/else Statements



```
if condition 1
    Code block 1
else
    Code block 2
end
```

```
if age < 5
    disp('Age is less than 5');
else
    disp('Age is 5 or over');
end
```

# if/elseif/else Statements



```
if condition 1
    Code block 1
elseif condition 2
    Code block 2
else
    Code block 3
end
```

# if/elseif/else Statements

```
if age < 5
    disp('Age is less than 5');
elseif age < 11
    disp('Age is between 5 and 10');
else
    disp('Age is 11 or over');
end
```

Don't overspecify conditions:

elseif age < 11 & age >=5 - second condition is redundant

elseif age < 11 & age >5 - would give incorrect result for age = 5

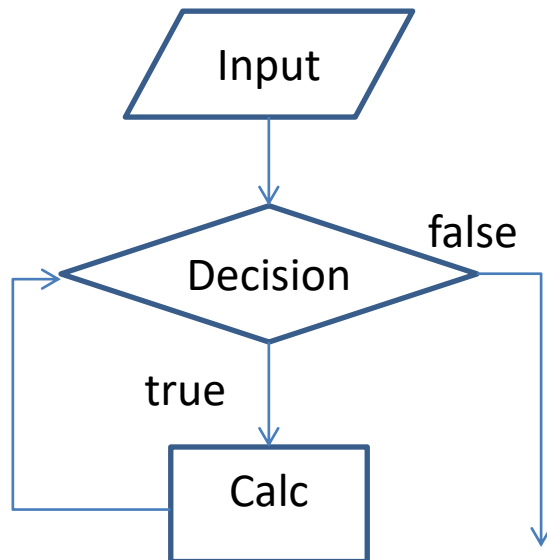
# Switch Statement

```
switch variable
    case value1
        Code block 1
    case value2
        Code block 2
    ...
    case value n
        Code block n
    otherwise
        Code executed if
        expression none of
        values specified
end
```

```
%Menu and switch/case statement example
Colour = menu('Select Colour', 'Red',
'Blue', 'Green');
switch Colour
    case 1
        disp('You chose red');
    case 2
        disp('You chose blue');
    case 3
        disp('You chose green');
    otherwise
        disp('You didn''t make a
selection');
end
```

# Repetition Operators

Repetition



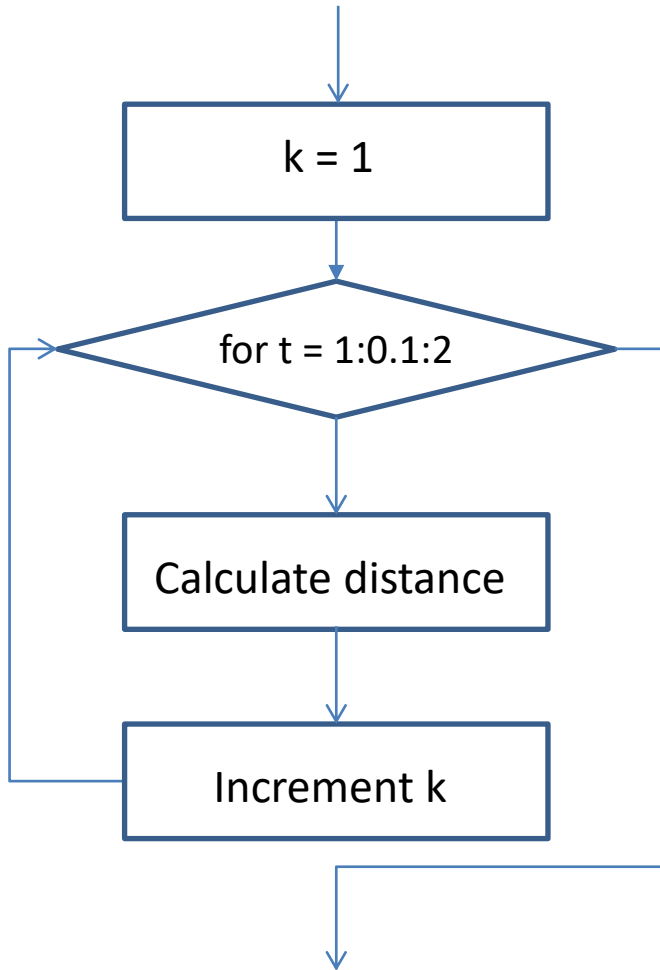
For loop:

Use to iterate through a given set of values (given by an index matrix)

While loop:

Loop until a specified condition is satisfied

# for Loops



```
for index = [matrix]  
    Code block
```

```
end
```

Note that step doesn't  
have to be integer

```
k = 1;  
for t = 1:0.1:2  
    % Calculate distance in freefall  
    d(k) = 0.5 * 9.81 * t^2;  
    k = k+1;  
end
```

This will grow the array d by  
one element on each iteration



# for Loops

```
k = 1;
for t = 1:0.1:2
    % Calculate distance in freefall
    d(k) = 0.5 * 9.81 * t^2;
    k = k+1;
end
```

Note that vectorised form is much more efficient:


```
t = [1:0.1:2];
d = 0.5 * 9.81 * t.^2;
```

```
for index = [matrix]
    Code block
end
```

← If 2D matrix the index will contain a column of the matrix for each iteration of the loop – ie a column vector

# tic/toc

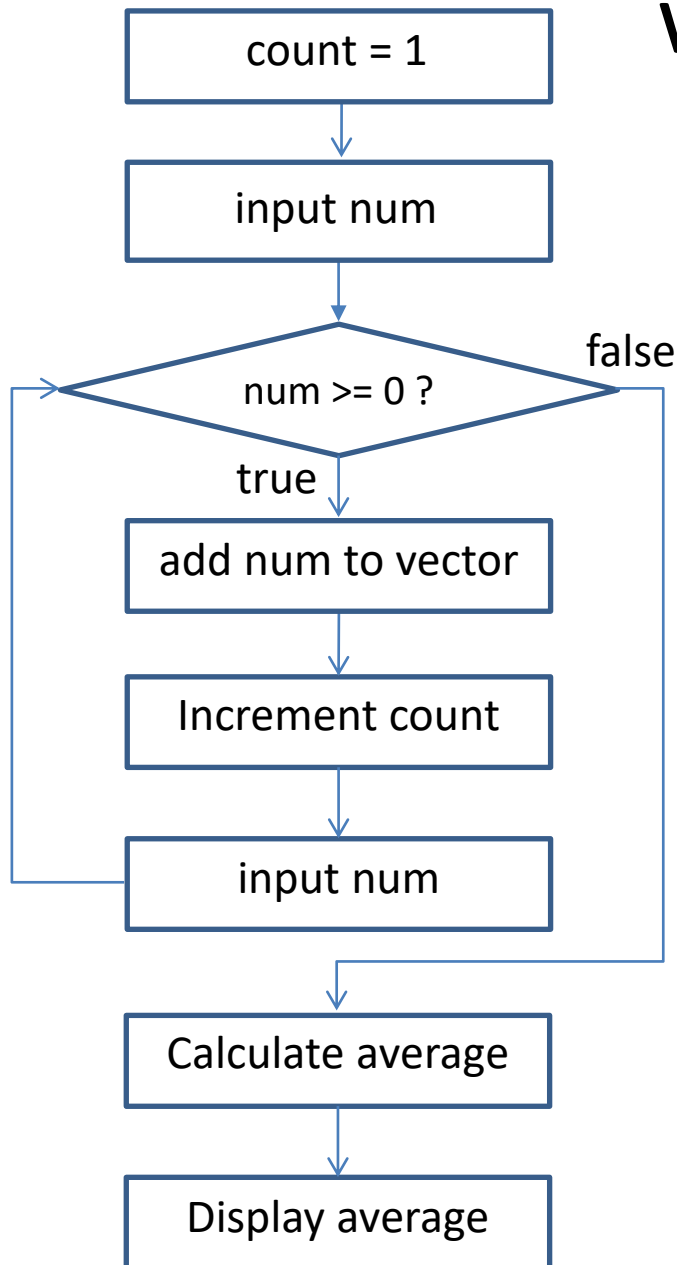
```
tic  
Some code  
.  
.  
.  
toc
```



Times the code executed between  
the tic and toc commands

```
Elapsed time is 0.000039 seconds.
```

# while Loops



Use while loop to input values

and calculate an average *while condition==true*

*Code block*

```
count = 1;
num = input('Input first number: ');

% negative number terminates loop
while num >= 0
    numbers(count) = num;
    count = count + 1;
    num = input('Input next number: ');
end
average = mean(numbers);
disp(['Average is ', num2str(average)]);
```

# Exercise 9.2

Change the Projectiles script to loop until a valid input has been entered.

What sort of loop will be used?

While loop – continuing until condition is satisfied

Probably need to set angle to an invalid value to start so that the loop is executed at least once

# Functions

Must have function  
declaration

Must be the same  
as the filename –  
funcName.m

Dummy input  
arguments

function [argout1, argout2..] = funcName( argin1, argin2, ..)

% H1 comment line

% Other comments

Code Block

(return)

(end)

Dummy output  
arguments

Optional

# Calling Functions

Called from a script or the command window by using the function name

```
distance = DistBetweenPoints( x1, y1, x2, y2 );
```

Use square brackets on the left for functions which return more than one value

```
[row, column] = find(4 )
```

The function .m file cannot be run on its own.

Note – parameters are passed by value. A copy of the arguments is passed to the function

# Functions and Arrays

Arrays can be passed as parameters to and from functions

Ensure that any multiplication based operations within the function use the dot operator

# Subfunctions

Can have several functions in one file:

- First function is primary function and has same name as filename
- Subfunctions follow in the same file and are only visible to other functions in that file (equivalent to private functions in C++)
- Help still provided by H1 line but accessed using >  
>> `help myFunction>mySubFunc`



# Anonymous Functions

Anonymous functions are local functions only available until the workspace is cleared

```
Fnhandle = @ (input arguments) functioncode;
```



Shows function handle being created

```
logfunc = @(x) log(x) + x
```

Can be saved in .mat file using load and save commands

```
>> logfunc(2.3)
```

```
ans =
```

```
3.1329
```

# Function Functions

Function functions take another function as input:

```
fplot( @sin, [-pi,pi] ); plot sin in range -pi to pi
```



Obtains function handle

```
fplot( logfunc, [1,100] )
```



Already function handle, doesn't need @

# Persistent variables

Local variables are cleared when exit from functions

Persistent variables remain between function calls

```
persistent count
% Check if count has been initialised
and set to 0 if not
if isempty( count )
    count = 0;
end
count = count + 1;
```

declare variable, initialized to empty matrix

Persistent variable name must not be the same as any other in the workspace

Clear persistent variables from memory

using `clear functions`

# Exercise 10.2

```
>> poly1 = @(x) 3*x.^2 + 4*x +5;
```

```
>> plot([-10:10],poly1(-10:10) )
```

```
>> fplot(poly1, [0,20])
```

```
>> poly1(1:10)
```

```
ans =
```

12	25	44	69	100	137	180	229	284	345
----	----	----	----	-----	-----	-----	-----	-----	-----

# Tables

- Useful for heterogenous, column oriented or tabular data
- Variables can have different data types
- All columns must have the same number of rows
- Not restricted to column vectors (eg could have matrix but number of rows condition still applies)

Create table from workspace data using the `table` function:

```
TableName = table(var1, var2, var3,... );
```

or by using `readtable` to load a data set:

```
TableName = readtable('data.dat');
```

# Indexing into Tables

Address column data using dot notation:

```
PatientData.Gender % Accesses the whole column
```

Then normal indexing for the data type:

```
PatientData.Gender(10) % Accesses data in column
```

Access particular rows and columns using subscript notation:

```
PatientData(1:3, :);
```

```
ans =
```

Gender	Age	Height	Weight
_____	_____	_____	_____
'Male'	38	71	176
'Male'	43	69	163
'Female'	38	64	131

# Add, Remove and SaveTable Data

Extra data can be added by using a new column name and assigning it a data item with the correct number of rows:

```
PatientData.ID = (1:100)';
```

Delete column using []

```
PatientData.ID = []
```

Table data can be written to a file using the `writetable` function:

```
writetable( PatientData, 'PatientData.txt' );
```

# Table Metadata

Table metadata is contained in table.Properties:

```
PatientData.Properties
```

```
ans =  
  
    Description: ''  
VariableDescriptions: {}  
    VariableUnits: {}  
DimensionNames: {'Row'  'Variable'}  
    UserData: []  
    RowNames: {}  
VariableNames: {'Gender'  'Age'  'Height'  'Weight'}
```

Edit the metadata using dot notation for the relevant property:

```
PatientData.Properties.VariableUnits{'Height'} = 'inches'  
PatientData.Properties.VariableUnits  
ans =  
    ''    ''    'inches'    ''
```



# Plotting Data from Tables

Use dot notation to plot data for a whole column:

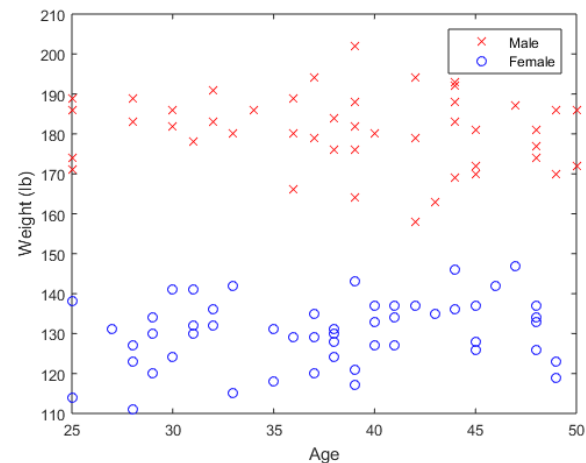
```
plot(PatientData.Age, PatientData.Weight, 'xr')
```

Logical indexing can be used to select data to plot. To plot data for just the males in the data set:

```
ind = strcmp( PatientData.Gender, 'Male');  
plot(PatientData.Age(ind), PatientData.Weight(ind), 'xr')
```

Invert the selection to plot the data for females:

```
plot(PatientData.Age(~ind), PatientData.Weight(~ind), 'ob')
```



# Importing Data

## Import Wizard

Use the Import Data button  
or right click on filename and select Import Data...

Data can be imported as row or column vectors where headers are present  
Otherwise imported as matrix

Use Import Selection-> Generate Script or Generate Function to create  
code to reproduce import of the selected data

Also launch using

```
>> uiimport('SimonVega.jpg')
```



# Cleaning Data

Bad or missing data will be imported as NaN

This can be removed using logical indexing

```
badData = isnan(Age);  
CleanAge = Age(~badData);
```

Gives logical vector with  
value of 1 where data is  
NaN



Use ~ (not) so that good  
data has value of 1 in  
logical vector

# Toolboxes

## Signal Processing

- <https://uk.mathworks.com/products/signal.html>

## Image Processing

- <https://uk.mathworks.com/products/image.html>

## Optimisation

- <https://uk.mathworks.com/products/optimization.html>

## Symbolic Maths

- <https://uk.mathworks.com/products/symbolic.html>

## Data Acquisition

- <https://uk.mathworks.com/products/daq.html>

## Control System

- <https://uk.mathworks.com/help/control/index.html>

## Curve Fitting

- <https://uk.mathworks.com/products/curvefitting.html>

## Statistics and Machine Learning

- <https://uk.mathworks.com/products/statistics.html>

# More to Explore

Version Control using GIT – keep track of changes to your code

- [https://uk.mathworks.com/help/matlab/matlab\\_prog/set-up-git-source-control.html](https://uk.mathworks.com/help/matlab/matlab_prog/set-up-git-source-control.html)

App Designer – for generating user interfaces

- [https://uk.mathworks.com/help/matlab/gui-development.html?category=gui-development&tid=CRUX\\_topnav](https://uk.mathworks.com/help/matlab/gui-development.html?category=gui-development&tid=CRUX_topnav)

Profiler – use to find bottlenecks in programs and speed up code

- [https://uk.mathworks.com/help/matlab/matlab\\_prog/profiling-for-improving-performance.html](https://uk.mathworks.com/help/matlab/matlab_prog/profiling-for-improving-performance.html)

Testing Frameworks – use to set up automated tests for your code

- <https://uk.mathworks.com/help/matlab/matlab-unit-test-framework.html>