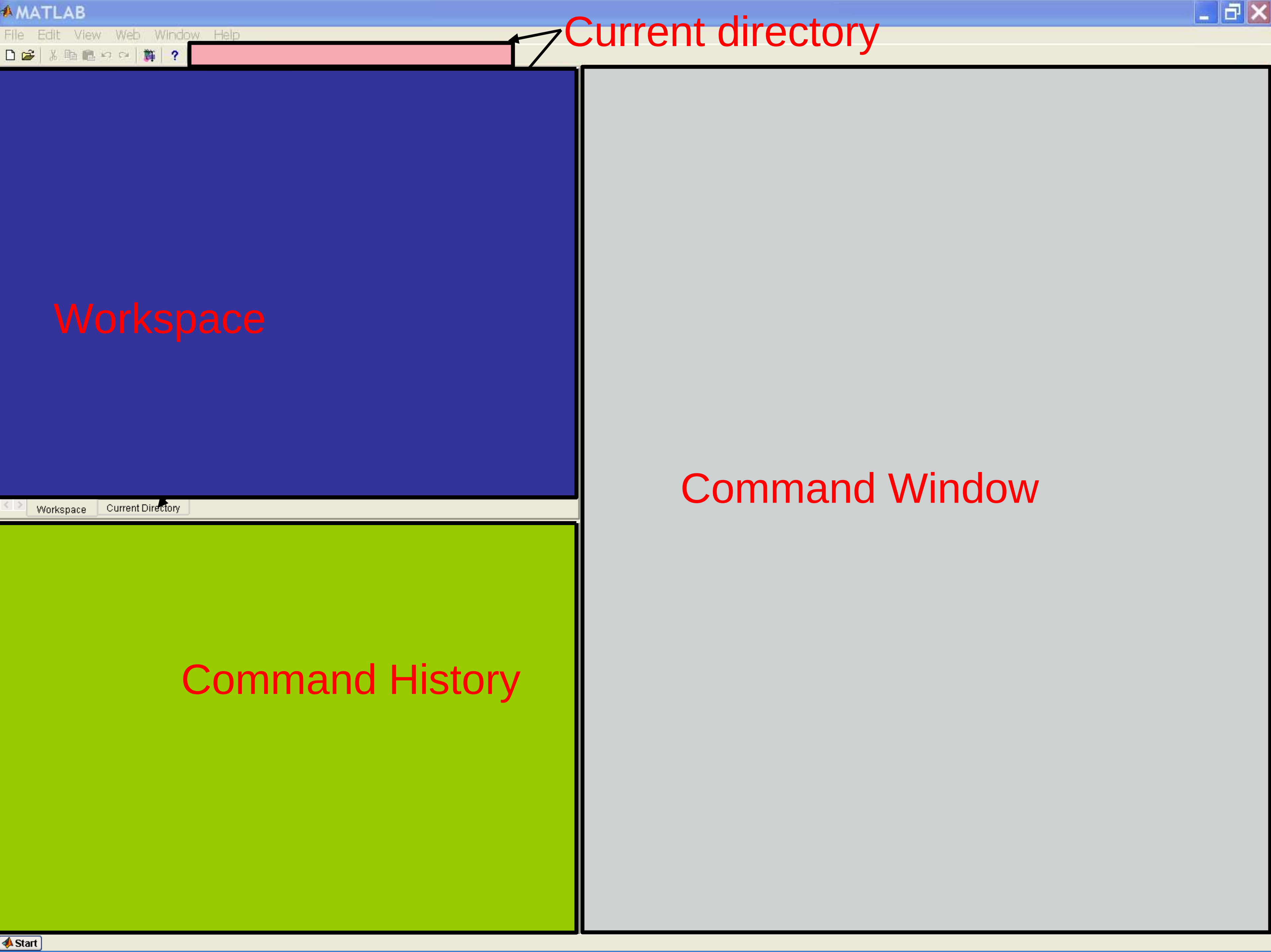
Introduction to MATLAB



Current directory

Workspace

Command Window

Command History

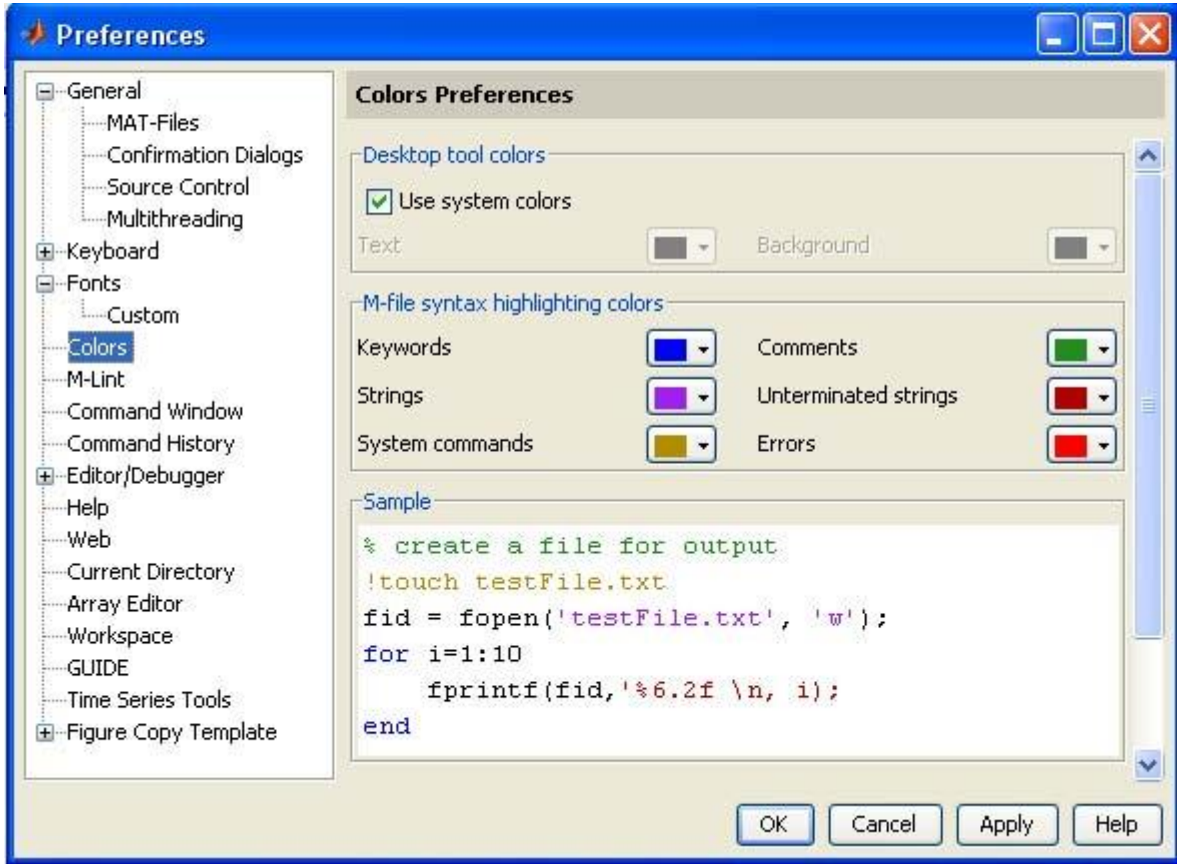
Making Folders

- Use folders to keep your programs organized
- To make a new folder, click the ‘Browse’ button next to ‘Current Directory’
- Click the ‘Make New Folder’ button, and change the name of the folder. **Do NOT use spaces** in folder names.
- Highlight the folder you just made and click ‘OK’
- The current directory is now the folder you just created
- To see programs outside the current directory, they should be in the Path. Use File-> Set Path to add folders to the path

Customization

- File ➪ Preferences

  Allows you personalize your MATLAB experience



Colors Preferences

Desktop tool colors

☑ Use system colors

Text ▨ Background ▨

M-file syntax highlighting colors

Keywords 🟦 Comments 🟩

Strings 🟪 Unterminated strings 🟥

System commands 🟨 Errors 🟥

Sample

```
% create a file for output
!touch testFile.txt
fid = fopen('testFile.txt', 'w');
for i=1:10
    fprintf(fid,'%6.2f \n, i);
end
```

MATLAB Basics

- MATLAB can be thought of as a super-powerful graphing calculator

- In addition it is a programming language
    - MATLAB is an interpreted language, like Java
    - Commands executed line by line

Help/Docs

- `help`
    - **The most** important function for learning MATLAB on your own
- To get info on how to use a function:
    - » `help sin`
        - Help lists related functions at the bottom and links to the doc
- To get a nicer version of help with examples and easy-to-read descriptions:
    - » `doc sin`
- To search for a function by specifying keywords:
    - » `doc` + Search tab

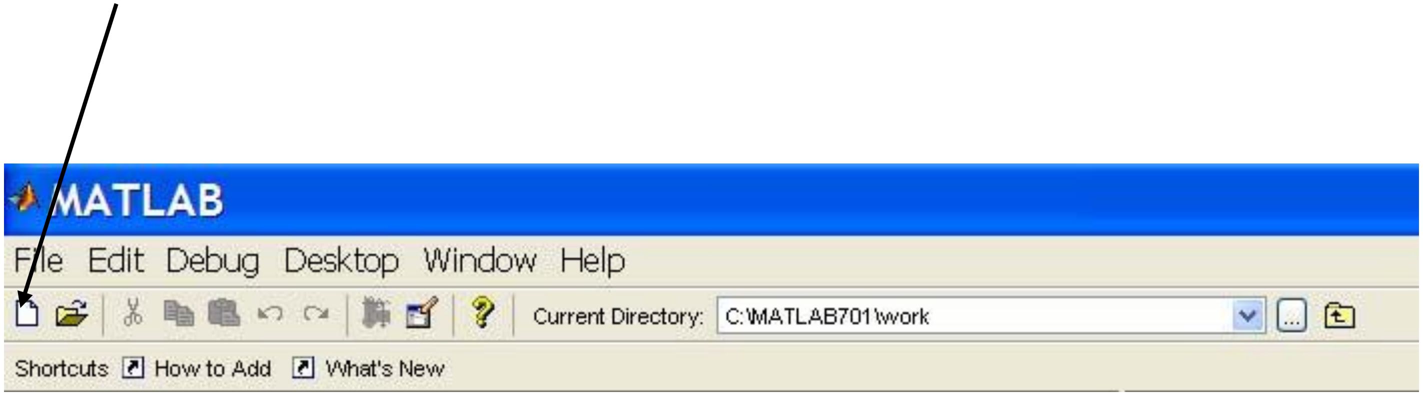
Scripts: Overview

- Scripts are
  - collection of commands executed in sequence
  - written in the MATLAB editor
  - saved as MATLAB files (.m extension)

- To create an MATLAB file from command-line

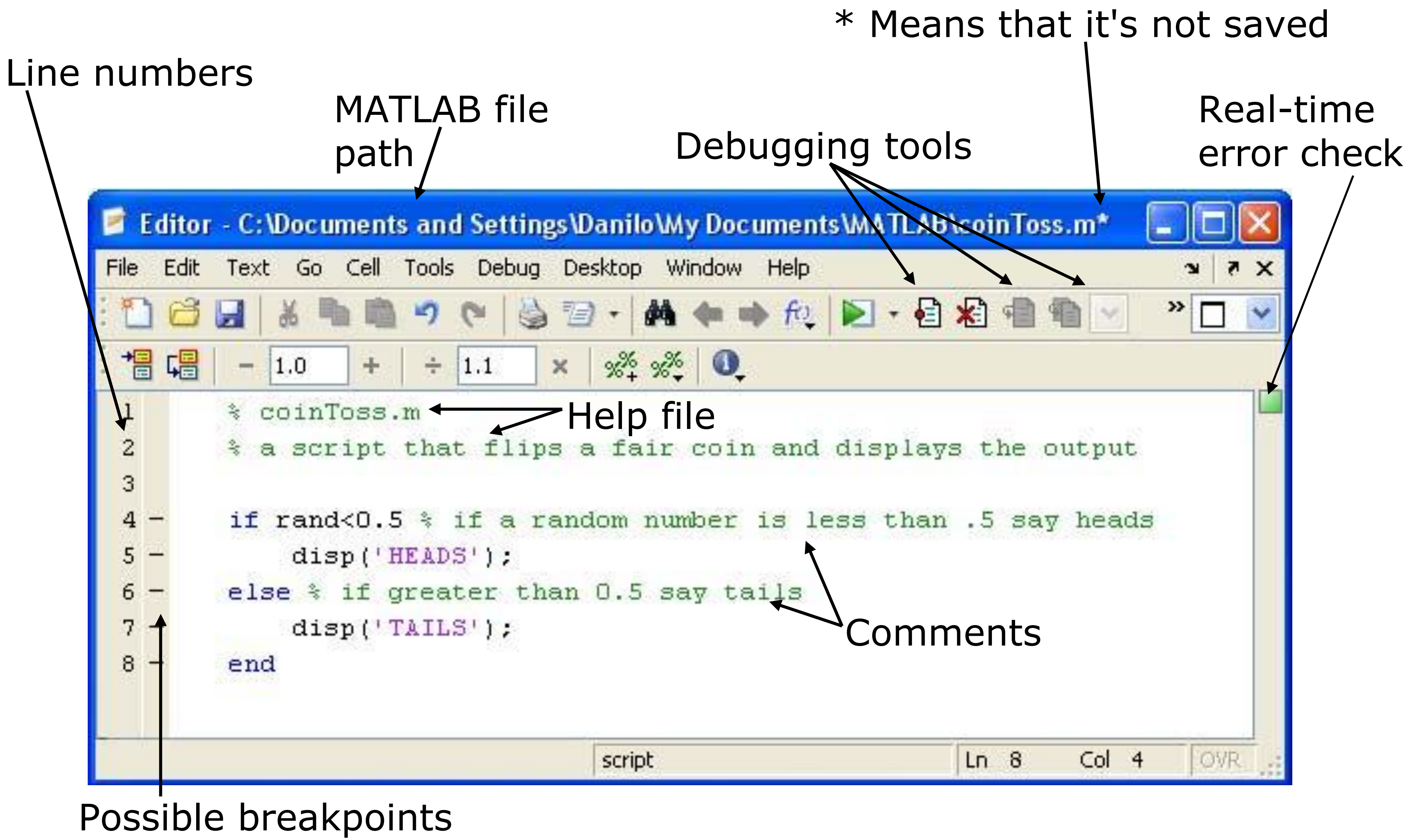
```
» edit helloWorld.m
```

- or click



Current Directory: C:\MATLAB701\work

Scripts: the Editor



Line numbers

MATLAB file path

Debugging tools

* Means that it's not saved

Real-time error check

Help file

Comments

Possible breakpoints

Editor - C:\Documents and Settings\Danilo\My Documents\MATLAB\coinToss.m*

```
% coinToss.m
% a script that flips a fair coin and displays the output

if rand<0.5 % if a random number is less than .5 say heads
    disp('HEADS');
else % if greater than 0.5 say tails
    disp('TAILS');
end
```

Scripts: Some Notes

- **COMMENT!**
    - Anything following a % is seen as a comment
    - The first contiguous comment becomes the script's help file
    - Comment thoroughly to avoid wasting time later

- Note that scripts are somewhat static, since there is no input and no explicit output

- All variables created and modified in a script exist in the workspace even after it has stopped running

Exercise: Scripts

Make a `helloWorld` script

- When run, the script should display the following text:

```
Hello World!
I am going to learn MATLAB!
```

- **Hint:** use `disp` to display strings. Strings are written between single quotes, like `'This is a string'`

Variable Types

- MATLAB is a weakly typed language
    - No need to initialize variables!
- MATLAB supports various types, the most often used are
    - » `3.84`
        - 64-bit double (default)
    - » `‘a’`
        - 16-bit char
- Most variables you’ll deal with will be vectors or matrices of doubles or chars
- Other types are also supported: complex, symbolic, 16-bit and 8 bit integers, etc. You will be exposed to all these types through the homework

Naming variables

- To create a variable, simply assign a value to a name:
  - `var1=3.14`
  - `myString=‘hello world’`

- Variable names
  - first character must be a LETTER
  - after that, any combination of letters, numbers and _
  - CASE SENSITIVE! (`var1` is different from `Var1`)

- Built-in variables. Don’t use these names!
  - `i` and `j` can be used to indicate complex numbers
  - `pi` has the value 3.1415926…
  - `ans` stores the last unassigned value (like on a calculator)
  - `Inf` and `-Inf` are positive and negative infinity
  - `NaN` represents ‘Not a Number’

Scalars

- A variable can be given a value explicitly

  ```
  » a = 10
  ```

  - 🕗 shows up in workspace!

- Or as a function of explicit values and existing variables

  ```
  » c = 1.3*45-2*a
  ```

- To suppress output, end the line with a semicolon

  ```
  » d = 13/3;
  ```

Arrays

- Like other programming languages, arrays are an important part of MATLAB
- Two types of arrays

(1) matrix of numbers (either double or complex)

(2) cell array of objects (more advanced data structure)

MATLAB makes vectors easy!
That's its power!

Row Vectors

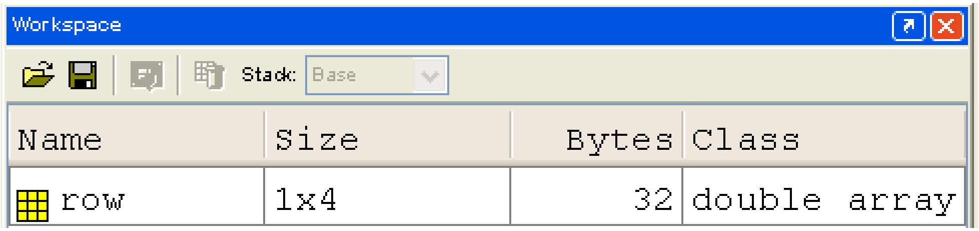
- Row vector: comma or space separated values between brackets

```
» row = [1 2 5.4 -6.6]
» row = [1, 2, 5.4, -6.6];
```

- Command window:

```
>> row=[1 2 5.4 -6.6]
```

- Workspace:



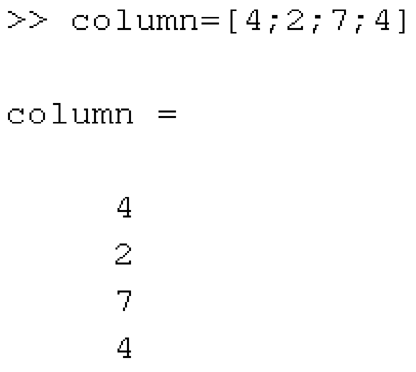
Name	Size	Bytes	Class
▦ row	1x4	32	double array

Column Vectors

- Column vector: semicolon separated values between brackets

```
» column = [4;2;7;4]
```

Command window:

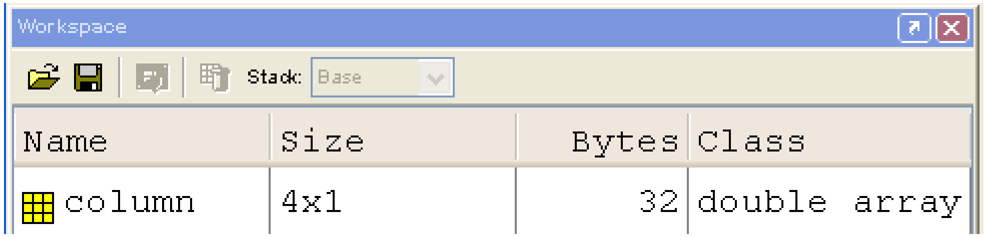


```
>> column=[4;2;7;4]

column =

     4
     2
     7
     4
```

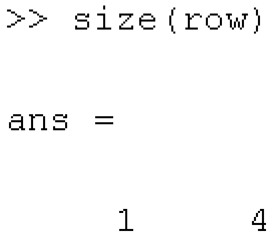
- Workspace:



Name	Size	Bytes	Class
▦ column	4x1	32	double array

size & length

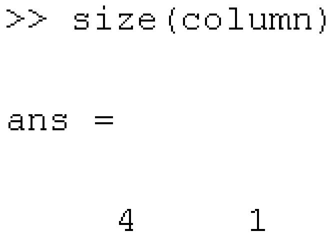
- You can tell the difference between a row and a column vector by:
  - Looking in the workspace
  - Displaying the variable in the command window
  - Using the size function



```
>> size(row)

ans =

     1     4
```

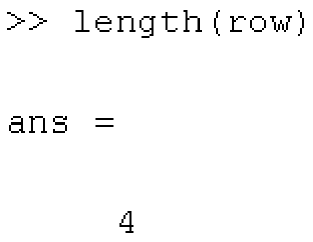


```
>> size(column)

ans =

     4     1
```

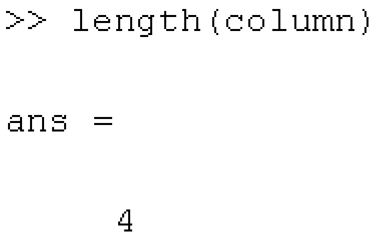
- To get a vector's length, use the length function



```
>> length(row)

ans =

     4
```



```
>> length(column)

ans =

     4
```

Matrices

- Make matrices like vectors

- Element by element

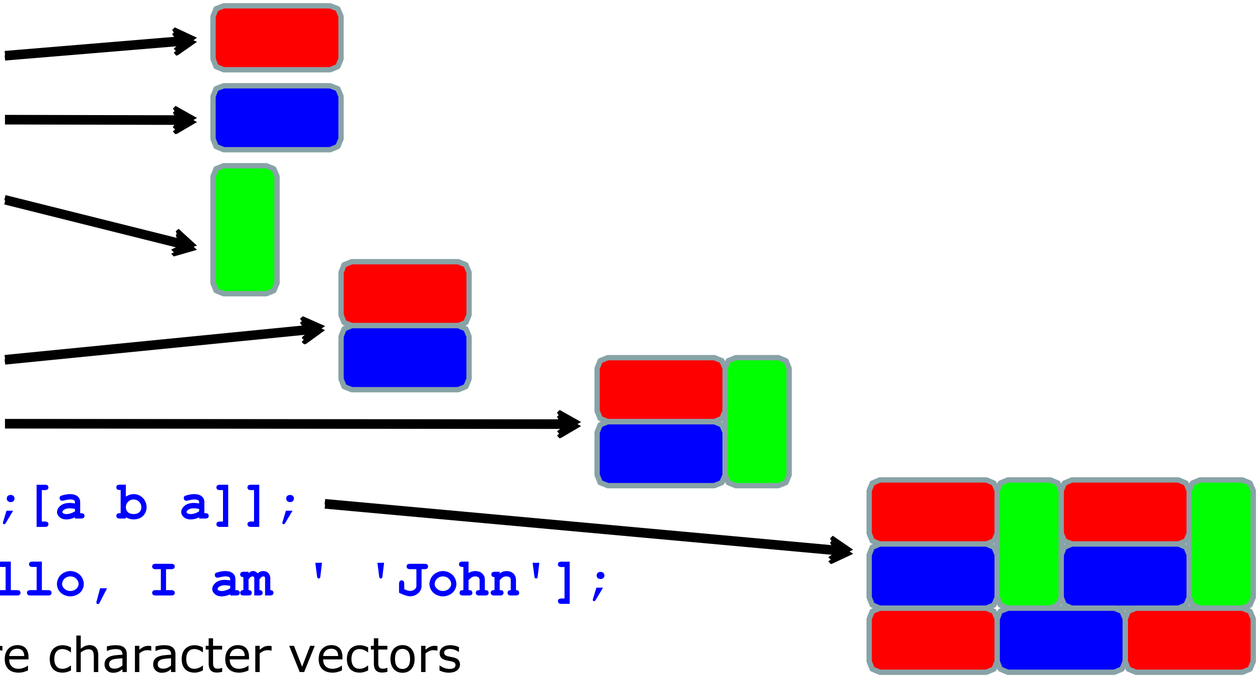
```
» a= [1 2;3 4];
```

$$a = \begin{bmatrix} 1 & 2 \\ 3 & 4 \end{bmatrix}$$

- By concatenating vectors or matrices (dimension matters)

```
» a = [1 2];
» b = [3 4];
» c = [5;6];

» d = [a;b];
» e = [d c];
» f = [[e e];[a b a]];
» str = ['Hello, I am ' 'John'];
```



  - Strings are character vectors

save/clear/load

- Use **save** to save variables to a file
  - » **`save myFile a b`**
    - saves variables a and b to the file myfile.mat
    - myfile.mat file is saved in the current directory
    - Default working directory is
  - » **`\MATLAB`**
    - Make sure you're in the desired folder when saving files. Right now, we should be in:
  - » **`MATLAB\IAPMATLAB\day1`**

- Use **clear** to remove variables from environment
  - » **`clear a b`**
    - look at workspace, the variables a and b are gone

- Use **load** to load variable bindings into the environment
  - » **`load myFile`**
    - look at workspace, the variables a and b are back

- Can do the same for entire environment
  - » **`save myenv; clear all; load myenv;`**

Exercise: Variables

Get and save the current date and time

- Create a variable `start` using the function `clock`
- What is the size of `start`? Is it a row or column?
- What does `start` contain? See `help clock`
- Convert the vector `start` to a string. Use the function `datestr` and name the new variable `startString`
- Save `start` and `startString` into a mat file named `startTime`

Exercise: Variables

Read in and display the current date and time

- In helloWorld.m, read in the variables you just saved using `load`
- Display the following text:

  I started learning MATLAB on *start date and time*

- Hint: use the `disp` command again, and remember that strings are just vectors of characters so you can join two strings by making a row vector with the two strings as sub-vectors.

Basic Scalar Operations

- Arithmetic operations (+,-,*,/)

```
» 7/45
» (1+i)*(2+i)
» 1 / 0
» 0 / 0
```

- Exponentiation (^)

```
» 4^2
» (3+4*j)^2
```

- Complicated expressions, use parentheses

```
» ((2+3)*3)^0.1
```

- Multiplication is NOT implicit given parentheses

```
» 3(1+0.7) gives an error
```

- To clear command window

```
» clc
```

Built-in Functions

- MATLAB has an **enormous** library of built-in functions

- Call using parentheses – passing parameter to function

```
» sqrt(2)
» log(2), log10(0.23)
» cos(1.2), atan(-.8)
» exp(2+4*i)
» round(1.4), floor(3.3), ceil(4.23)
» angle(i); abs(1+i);
```

Transpose

- The transpose operators turns a column vector into a row vector and vice versa

```
» a = [1 2 3 4+i]
» transpose(a)
» a'
» a.'
```

- The `.'` gives the Hermitian-transpose, i.e. transposes and conjugates all complex numbers

- For vectors of real numbers `.'` and `'` give same result

Addition and Subtraction

- Addition and subtraction are element-wise; sizes must match (unless one is a scalar):

$$\begin{array}{r l} & \begin{bmatrix} 12 & 3 & 32 & -11 \end{bmatrix} \\ + & \begin{bmatrix} 2 & 11 & -30 & 32 \end{bmatrix} \\ \hline = & \begin{bmatrix} 14 & 14 & 2 & 21 \end{bmatrix} \end{array}$$

$$\begin{bmatrix} 12 \\ 1 \\ -10 \\ 0 \end{bmatrix} - \begin{bmatrix} 3 \\ -1 \\ 13 \\ 33 \end{bmatrix} = \begin{bmatrix} 9 \\ 2 \\ -23 \\ -33 \end{bmatrix}$$

- The following would give an error

```
» c = row + column
```

- Use the transpose to make sizes compatible

```
» c = row′ + column
» c = row + column′
```

- Can sum up or multiply elements of vector

```
» s=sum(row);
» p=prod(row);
```

Element-Wise Functions

- All the functions that work on scalars also work on vectors

```
» t = [1 2 3];
» f = exp(t);
```

    - is the same as

```
» f = [exp(1) exp(2) exp(3)];
```

- If in doubt, check a function’s help file to see if it handles vectors element-wise

- Operators (*** / ^**) have two modes of operation
    - element-wise
    - standard

Operators: element-wise

- To do element-wise operations, use the dot: . (.*, ./, .^). BOTH dimensions must match (unless one is scalar)!

```
» a=[1 2 3];b=[4;2;1];
» a.*b, a./b, a.^b ➦  all errors
» a.*b', a./b’, a.^(b’) ➦  all valid
```

$$[1\quad 2\quad 3].*\begin{bmatrix}4\\2\\1\end{bmatrix}=\mathit{ERROR}$$

$$\begin{bmatrix}1\\2\\3\end{bmatrix}.*\begin{bmatrix}4\\2\\1\end{bmatrix}=\begin{bmatrix}4\\4\\3\end{bmatrix}$$

$$3\times1.*3\times1=3\times1$$

$$\begin{bmatrix}1&1&1\\2&2&2\\3&3&3\end{bmatrix}.*\begin{bmatrix}1&2&3\\1&2&3\\1&2&3\end{bmatrix}=\begin{bmatrix}1&2&3\\2&4&6\\3&6&9\end{bmatrix}$$

$$3\times3.*3\times3=3\times3$$

$$\begin{bmatrix}1&2\\3&4\end{bmatrix}.\hat{}\,2=\begin{bmatrix}1^2&2^2\\3^2&4^2\end{bmatrix}$$

Can be any dimension

Operators: standard

- Multiplication can be done in a standard way or element-wise
- Standard multiplication (*****) is either a dot-product or an outer-product
    - Remember from linear algebra: inner dimensions must MATCH!!
- Standard exponentiation (**^**) can only be done on square matrices or scalars
- Left and right division (**/ \**)   is same as multiplying by inverse
    - Our recommendation: just multiply by inverse (more on this later)

$$\begin{bmatrix}1 & 2 & 3\end{bmatrix} * \begin{bmatrix}4\\2\\1\end{bmatrix} = 11$$

$$1\times3 * 3\times1 = 1\times1$$

$$\begin{bmatrix}1 & 2\\3 & 4\end{bmatrix} \wedge 2 = \begin{bmatrix}1 & 2\\3 & 4\end{bmatrix} * \begin{bmatrix}1 & 2\\3 & 4\end{bmatrix}$$

Must be square to do powers

$$\begin{bmatrix}1 & 1 & 1\\2 & 2 & 2\\3 & 3 & 3\end{bmatrix} * \begin{bmatrix}1 & 2 & 3\\1 & 2 & 3\\1 & 2 & 3\end{bmatrix} = \begin{bmatrix}3 & 6 & 9\\6 & 12 & 18\\9 & 18 & 27\end{bmatrix}$$

$$3\times3 * 3\times3 = 3\times3$$

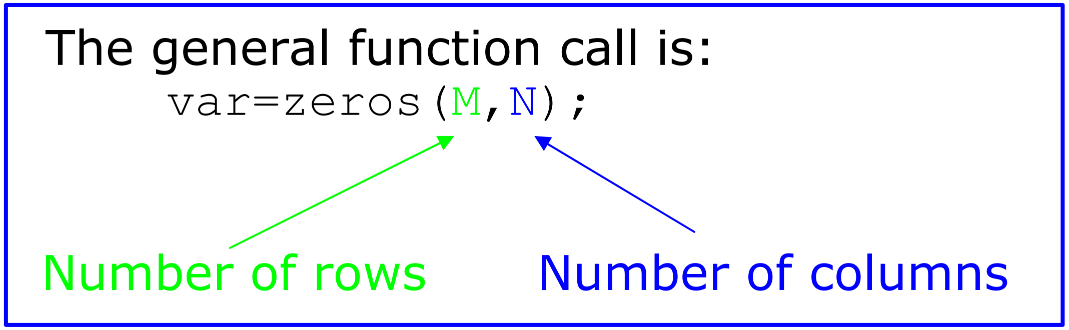
Exercise: Vector Operations

Calculate how many seconds elapsed since the start of class

- In helloWorld.m, make variables called `secPerMin`, `secPerHour`, `secPerDay`, `secPerMonth` (assume 30.5 days per month), and `secPerYear` (12 months in year), which have the number of seconds in each time period.
- Assemble a row vector called `secondConversion` that has elements in this order: `secPerYear`, `secPerMonth`, `secPerDay`, `secPerHour`, `secPerMinute`, `1`.
- Make a `currentTime` vector by using `clock`
- Compute `elapsedTime` by subtracting `currentTime` from `start`
- Compute `t` (the elapsed time in seconds) by taking the dot product of `secondConversion` and `elapsedTime` (transpose one of them to get the dimensions right)

Automatic Initialization

- Initialize a vector of **ones**, **zeros**, or **rand**om numbers
  - **`o=ones(1,10)`**
    - row vector with 10 elements, all 1
  - **`z=zeros(23,1)`**
    - column vector with 23 elements, all 0
  - **`r=rand(1,45)`**
    - row vector with 45 elements (uniform [0,1])
  - **`n=nan(1,69)`**
    - row vector of NaNs (useful for representing uninitialized variables)



The general function call is:

```
var=zeros(M,N);
```

Number of rows

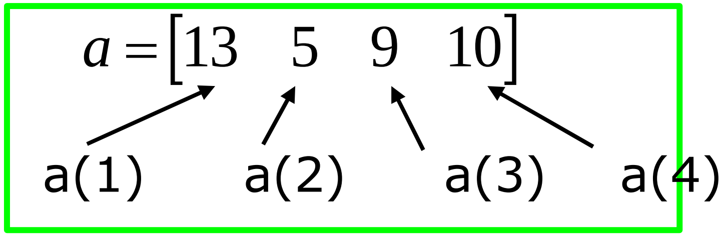
Number of columns

Automatic Initialization

- To initialize a linear vector of values use **linspace**
  - » `a=linspace(0,10,5)`
    - starts at 0, ends at 10 (inclusive), 5 values
- Can also use colon operator (**:**)
  - » `b=0:2:10`
    - starts at 0, increments by 2, and ends at or before 10
    - increment can be decimal or negative
  - » `c=1:5`
    - if increment isn’t specified, default is 1
- To initialize logarithmically spaced values use **logspace**
    - similar to **linspace**, but see **help**

Vector Indexing

- MATLAB indexing starts with **1**, not **0**
- a(n) returns the nth element



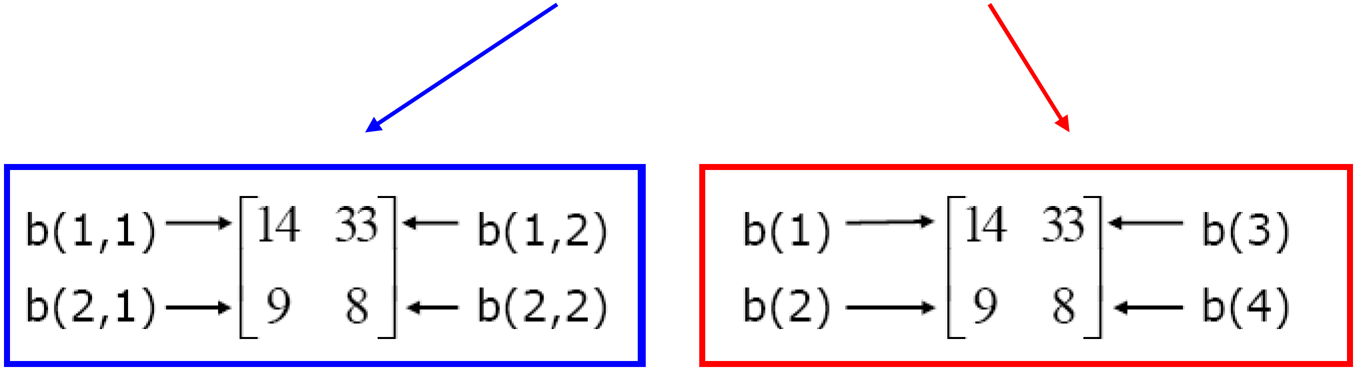
$$a = [13 \quad 5 \quad 9 \quad 10]$$

- The index argument can be a vector. In this case, each element is looked up individually, and returned as a vector of the same size as the index vector.

```
» x=[12 13 5 8];
» a=x(2:3);          →  a=[13 5];
» b=x(1:end-1);      →  b=[12 13 5];
```

Matrix Indexing

- Matrices can be indexed in two ways
  - using **subscripts** (row and column)
  - using linear **indices** (as if matrix is a vector)
- Matrix indexing: subscripts or linear indices



b(1,1) → $\begin{bmatrix} 14 & 33 \\ 9 & 8 \end{bmatrix}$ ← b(1,2)

b(2,1) → ← b(2,2)

b(1) → $\begin{bmatrix} 14 & 33 \\ 9 & 8 \end{bmatrix}$ ← b(3)

b(2) → ← b(4)

- Picking submatrices

```
» A = rand(5) % shorthand for 5x5 matrix
» A(1:3,1:2) % specify contiguous submatrix
» A([1 5 3], [1 4]) % specify rows and columns
```

Advanced Indexing 1

- To select rows or columns of a matrix, use the **:**

$$c = \begin{bmatrix} 12 & 5 \\ -2 & 13 \end{bmatrix}$$

```
» d=c(1,:);  →  d=[12 5];
» e=c(:,2);  →  e=[5;13];
» c(2,:)=[3 6];  %replaces second row of c
```

Advanced Indexing 2

- MATLAB contains functions to help you find desired values within a vector or matrix

```
» vec = [5 3 1 9 7]
```

- To get the minimum value and its index:

```
» [minVal,minInd] = min(vec);
```

  - **max** works the same way

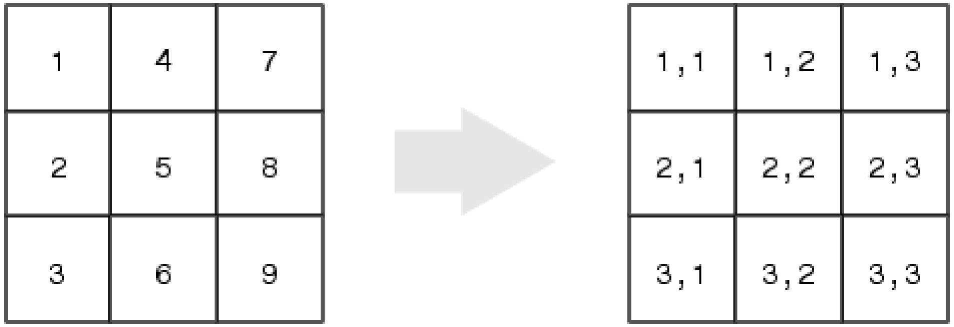
- To find any the indices of specific values or ranges

```
» ind = find(vec == 9);
» ind = find(vec > 2 & vec < 6);
```

  - **find** expressions can be very complex, more on this later

In Matrices

- To convert between subscripts and indices, use **ind2sub**, and **sub2ind**. Look up **help** to see how to use them.



1	4	7
2	5	8
3	6	9

1,1	1,2	1,3
2,1	2,2	2,3
3,1	3,2	3,3

Plotting

- Example

```
» x=linspace(0,4*pi,10);
» y=sin(x);
```

- Plot values against their index

```
» plot(y);
```

- Usually we want to plot y versus x

```
» plot(x,y);
```

MATLAB makes visualizing data fun and easy!

What does plot do?

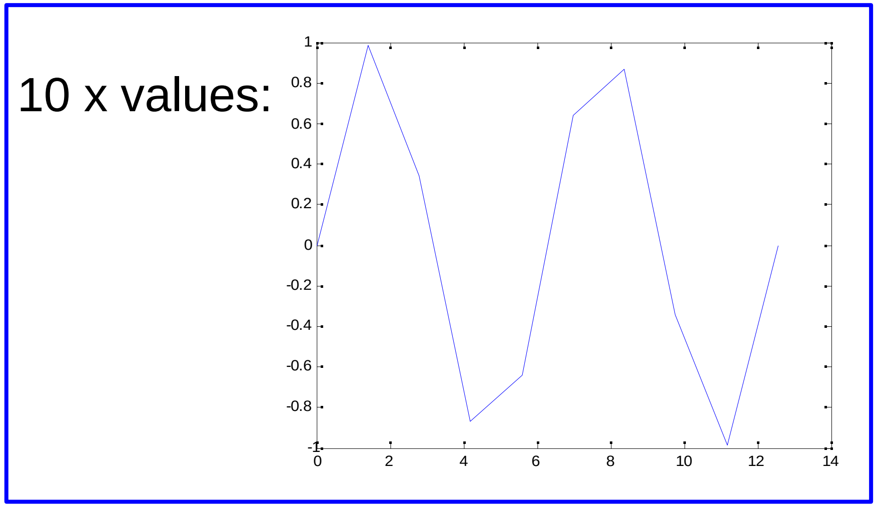
- **plot** generates dots at each (x,y) pair and then connects the dots with a line
- To make plot of a function look smoother, evaluate at more points

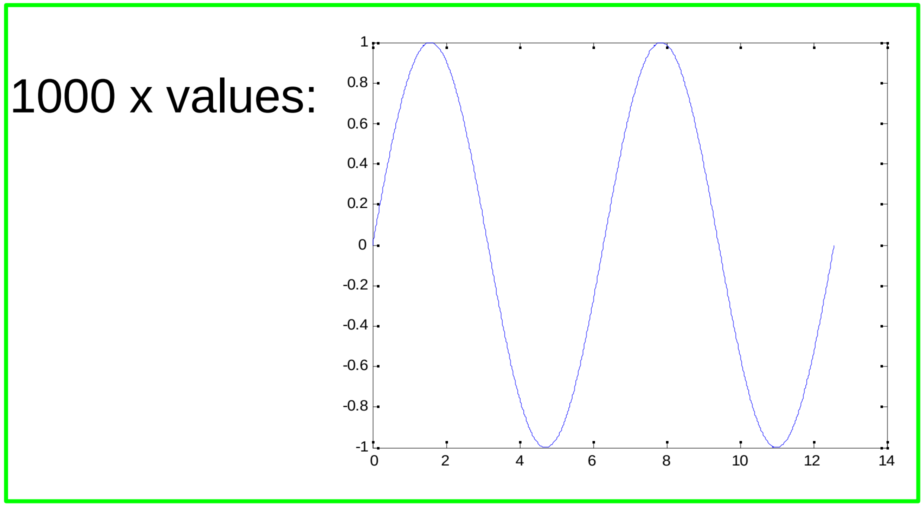
```
» x=linspace(0,4*pi,1000);
» plot(x,sin(x));
```

- x and y vectors must be same size or else you’ll get an error

```
» plot([1 2], [1 2 3])
```

  - error!!





Exercise: Plotting

Plot the learning trajectory

- In helloWorld.m, open a new figure (use `figure`)
- Plot the function y=sin(x) + cos(x) + 1 for x=0:2π