6.094
Introduction to Programming in MATLAB

Lecture 1: Variables, Scripts, and Operations

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IAP 2010

Outline

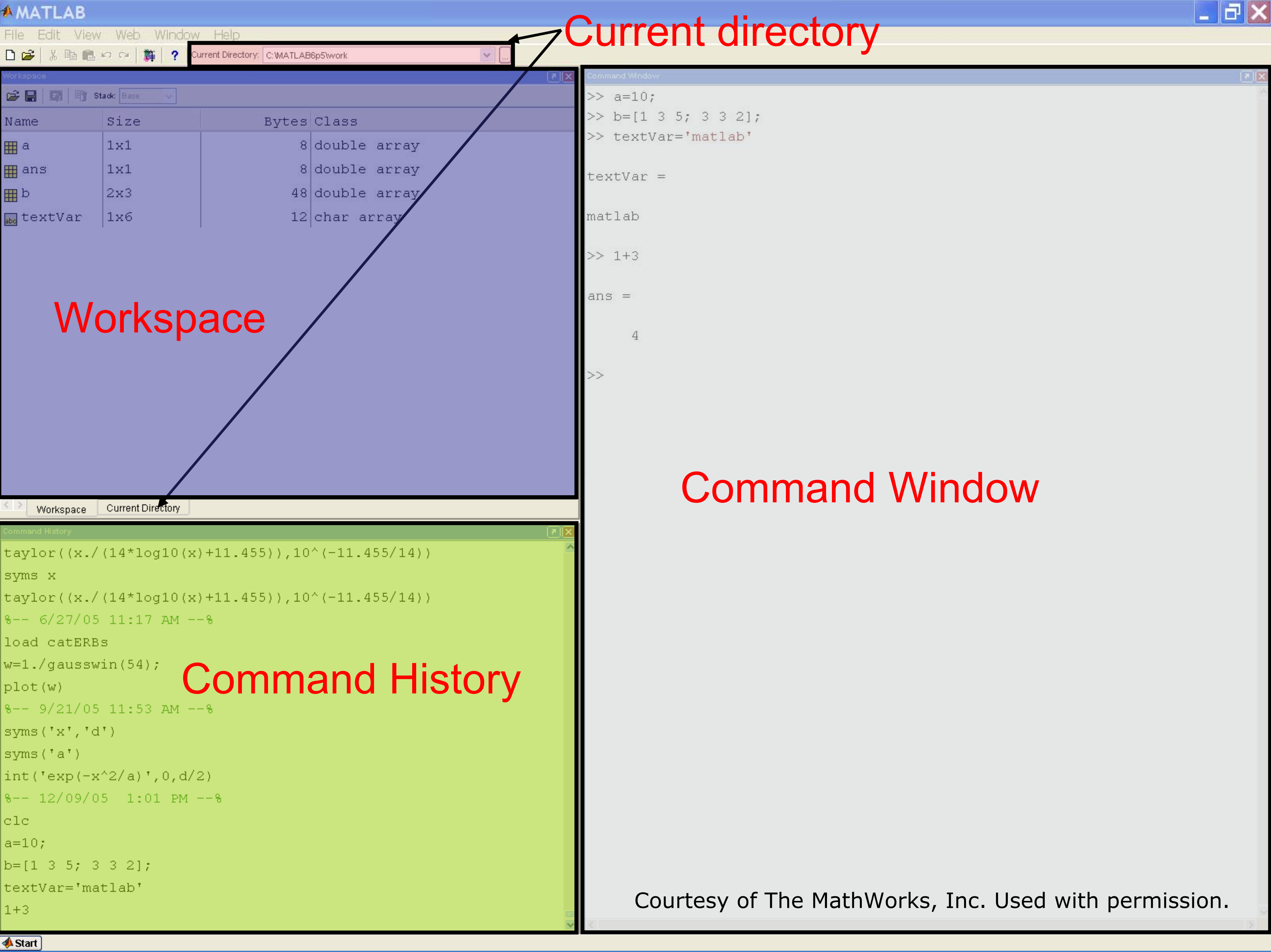
(1) Getting Started

(2) Scripts

(3) Making Variables

(4) Manipulating Variables

(5) Basic Plotting



Current Directory: C:\MATLAB6p5\work

Name	Size	Bytes	Class
a	1x1	8	double array
ans	1x1	8	double array
b	2x3	48	double array
textVar	1x6	12	char array

```
>> a=10;
>> b=[1 3 5; 3 3 2];
>> textVar='matlab'

textVar =

matlab

>> 1+3

ans =

     4

>>
```

```
taylor((x./(14*log10(x)+11.455)),10^(-11.455/14))
syms x
taylor((x./(14*log10(x)+11.455)),10^(-11.455/14))
%-- 6/27/05 11:17 AM --%
load catERBs
w=1./gausswin(54);
plot(w)
%-- 9/21/05 11:53 AM --%
syms('x','d')
syms('a')
int('exp(-x^2/a)',0,d/2)
%-- 12/09/05  1:01 PM --%
clc
a=10;
b=[1 3 5; 3 3 2];
textVar='matlab'
1+3
```

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MATLAB Basics

- MATLAB can be thought of as a super-powerful graphing calculator
    - Remember the TI-83 from calculus?
    - With many more buttons (built-in functions)

- 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

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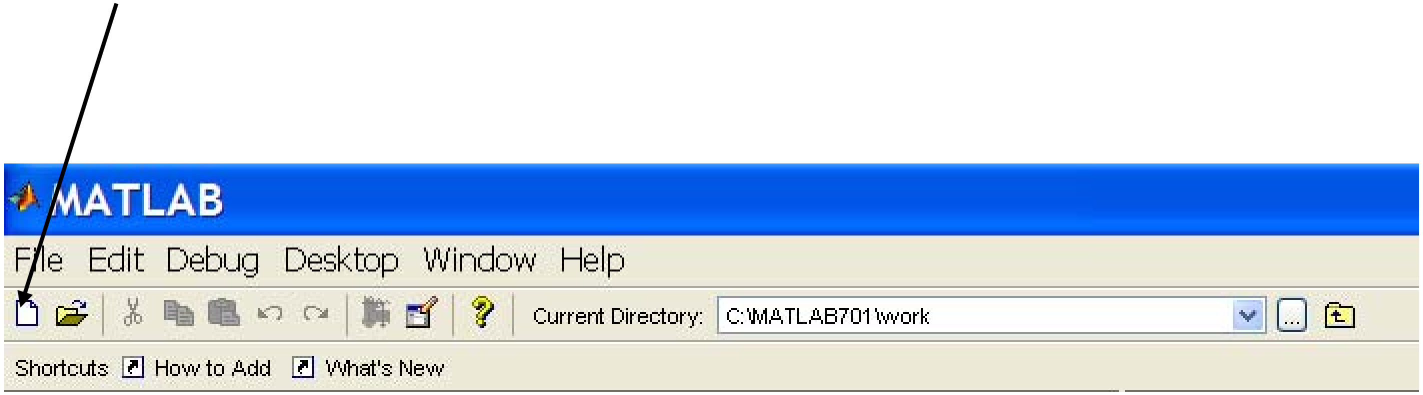
Scripts: Overview

- 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

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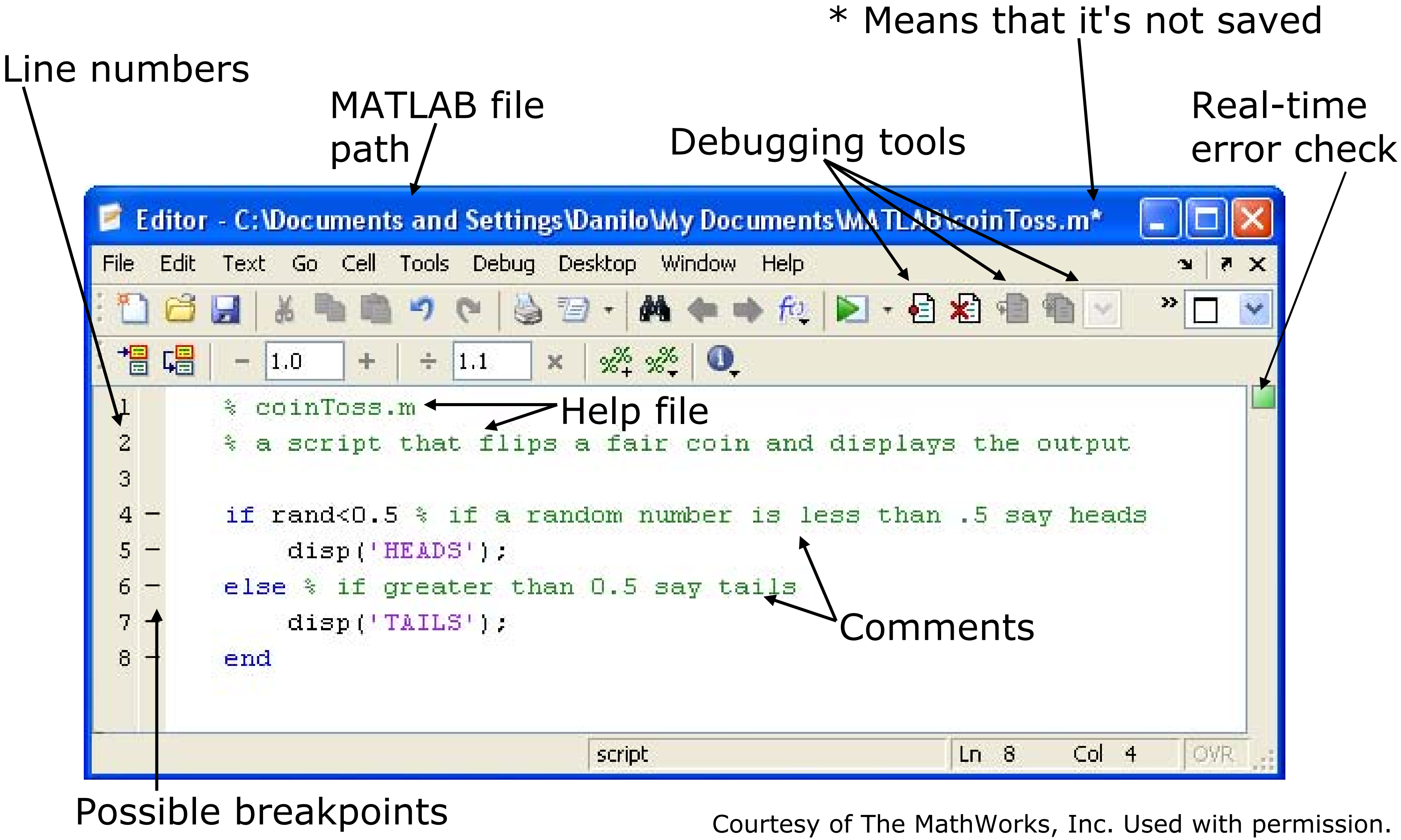
Scripts: the Editor


Editor - C:\Documents and Settings\Danilo\My Documents\MATLAB\coinToss.m*
File Edit Text Go Cell Tools Debug Desktop Window Help
1.0
1.1
script
Ln 8 Col 4
OVR

```
% 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
```

Line numbers

MATLAB file path

Debugging tools

* Means that it's not saved

Real-time error check

Help file

Comments

Possible breakpoints

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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'`

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'`

- Open the editor and save a script as helloWorld.m. This is an easy script, containing two lines of code:

```
» % helloWorld.m
» % my first hello world program in MATLAB

» disp('Hello World!');
» disp('I am going to learn MATLAB!');
```

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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

  ```
  » cooldude = 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)

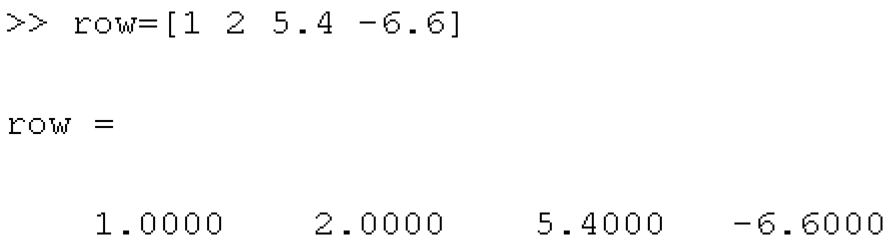
MATLAB makes vectors easy!
That's its power!

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:

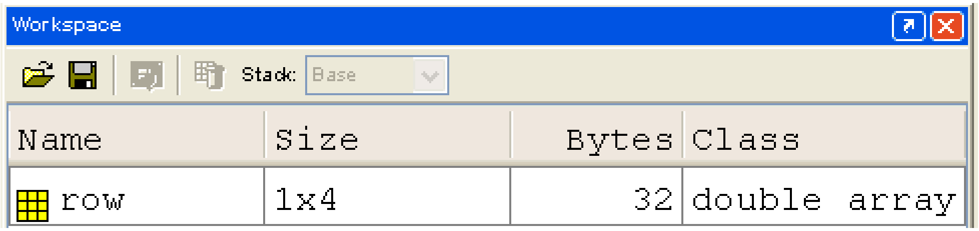


```
>> row=[1 2 5.4 -6.6]

row =

    1.0000    2.0000    5.4000   -6.6000
```

- Workspace:



Name	Size	Bytes	Class
▦ row	1x4	32	double array

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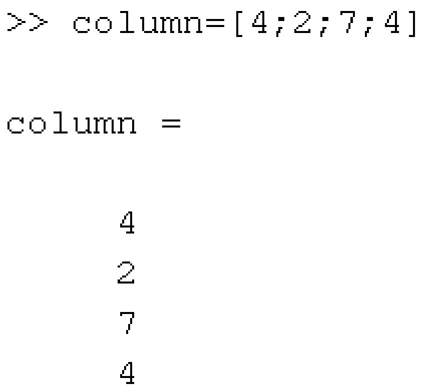
Column Vectors

- Column vector: semicolon separated values between brackets

```
» column = [4;2;7;4]
```

- Command window:

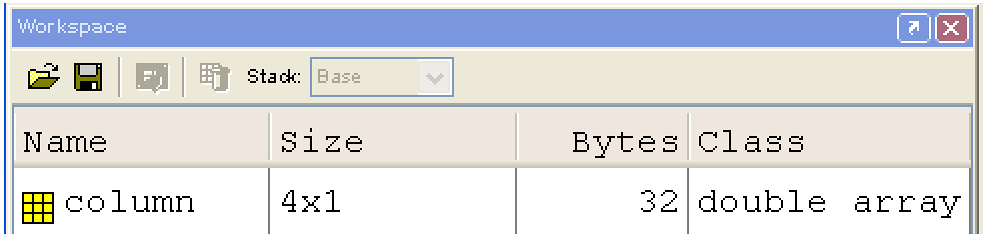


```
>> column=[4;2;7;4]

column =

     4
     2
     7
     4
```

- Workspace:

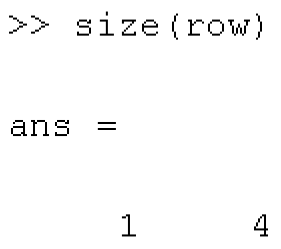


Name	Size	Bytes	Class
column	4x1	32	double array

Courtesy of The MathWorks, Inc. Used with permission.

size & length

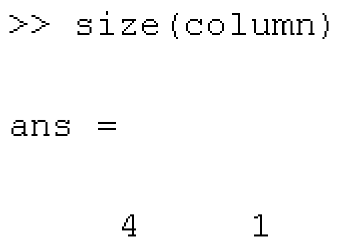
- You can tell the difference between a row and a column vector by:
  - Looking in the workspace
  - Displaying the variable in the command window
  - Using the size function



```
>> size(row)

ans =

     1     4
```

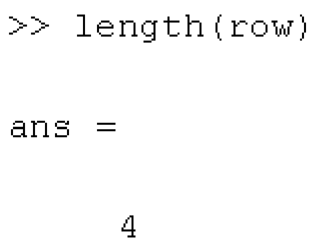


```
>> size(column)

ans =

     4     1
```

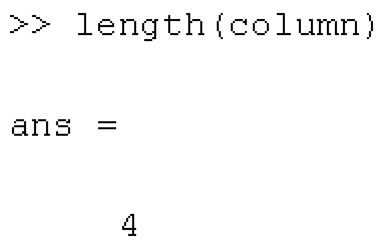
- To get a vector's length, use the length function



```
>> length(row)

ans =

     4
```



```
>> length(column)

ans =

     4
```

Matrices

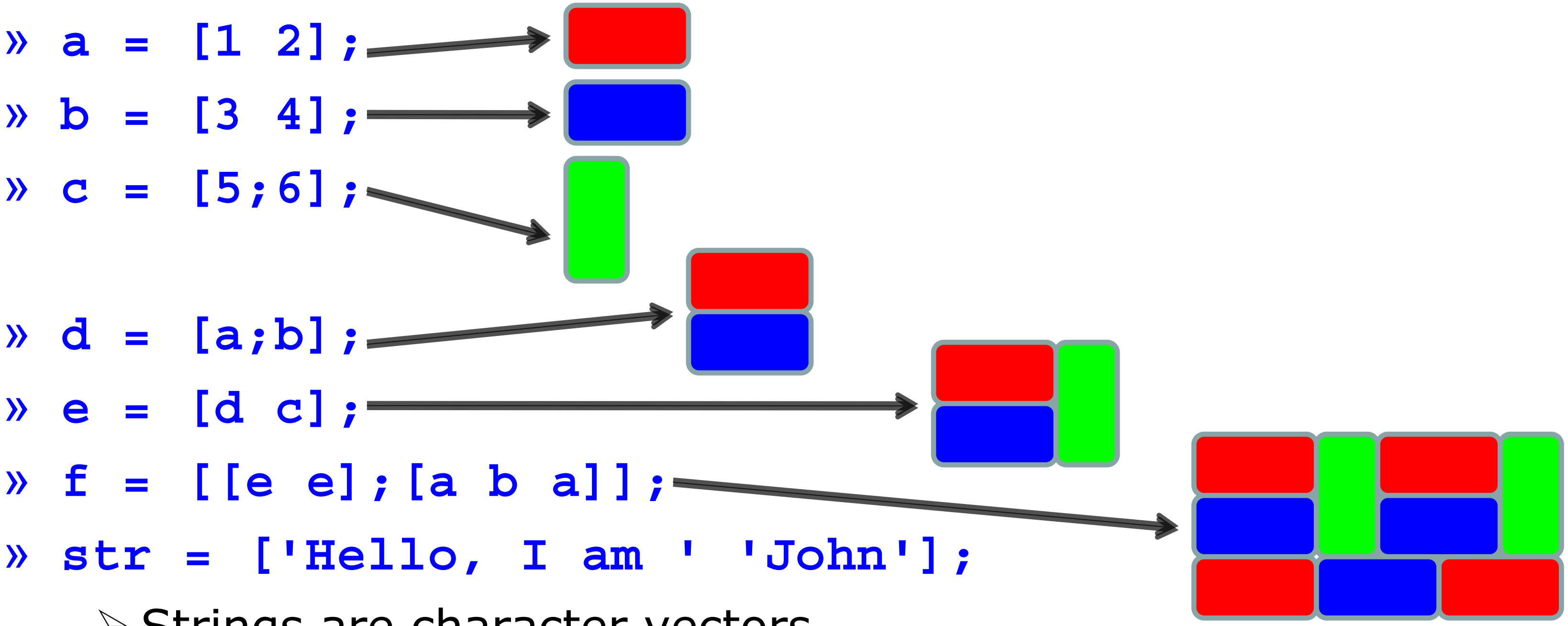
- Make matrices like vectors

- 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

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

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`

```
» help clock
» start=clock;
» size(start)
» help datestr
» startString=datestr(start);
» save startTime start startString
```

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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);
```

Exercise: Scalars

You will learn MATLAB at an exponential rate! Add the following to your helloWorld script:

- Your learning time constant is 1.5 days. Calculate the number of **seconds** in 1.5 days and name this variable `tau`
- This class lasts 5 days. Calculate the number of seconds in 5 days and name this variable `endOfClass`
- This equation describes your knowledge as a function of time t:

$$k = 1 - e^{-t/\tau}$$

- How well will you know MATLAB at `endOfClass`? Name this variable `knowledgeAtEnd`. (use `exp`)
- Using the value of `knowledgeAtEnd`, display the phrase:

At the end of 6.094, I will know X% of MATLAB

- Hint: to convert a number to a string, use `num2str`

Exercise: Scalars

```
» secPerDay=60*60*24;
» tau=1.5*secPerDay;
» endOfClass=5*secPerDay
» knowledgeAtEnd=1-exp(-endOfClass/tau);
» disp(['At the end of 6.094, I will know ' ...
  num2str(knowledgeAtEnd*100) '% of MATLAB'])
```

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):

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

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

- 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 elementwise

- 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
```

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

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

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

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

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

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

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)

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

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

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

$$\textit{Must be square to do powers}$$

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

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

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)

Exercise: Vector Operations

```
» secPerMin=60;
» secPerHour=60*secPerMin;
» secPerDay=24*secPerHour;
» secPerMonth=30.5*secPerDay;
» secPerYear=12*secPerMonth;
» secondConversion=[secPerYear secPerMonth ...
  secPerDay secPerHour secPerMin 1];
» currentTime=clock;
» elapsedTime=currentTime-start;
» t=secondConversion*elapsedTime';
```

Exercise: Vector Operations

Display the current state of your knowledge

- Calculate `currentKnowledge` using the same relationship as before, and the `t` we just calculated:

$$k = 1 - e^{-t/\tau}$$

- Display the following text:

At this time, I know X% of MATLAB

Exercise: Vector Operations

Display the current state of your knowledge

- Calculate `currentKnowledge` using the same relationship as before, and the `t` we just calculated:

$$k = 1 - e^{-t/\tau}$$

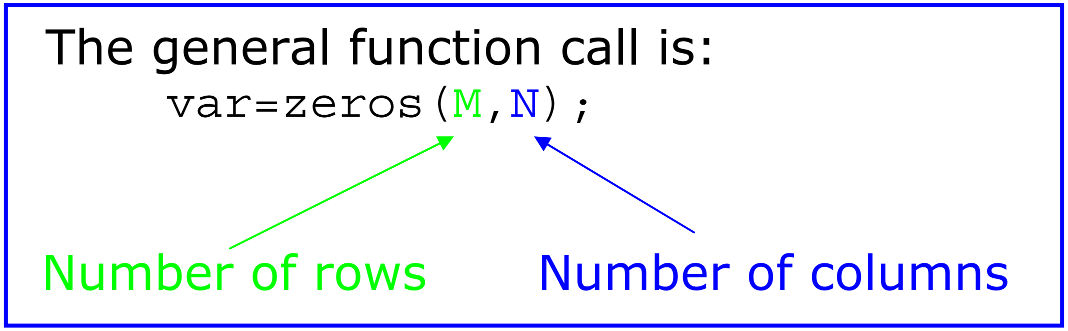
- Display the following text:

At this time, I know X% of MATLAB

```
» currentKnowledge=1-exp(-t/tau);
» disp(['At this time, I know ' ...
  num2str(currentKnowledge*100) '% of MATLAB']);
```

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**

Exercise: Vector Functions

Calculate your learning trajectory

- In helloWorld.m, make a linear time vector `tVec` that has 10,000 samples between 0 and `endOfClass`
- Calculate the value of your knowledge (call it `knowledgeVec`) at each of these time points using the same equation as before:

$$k = 1 - e^{-t/\tau}$$

Exercise: Vector Functions

Calculate your learning trajectory

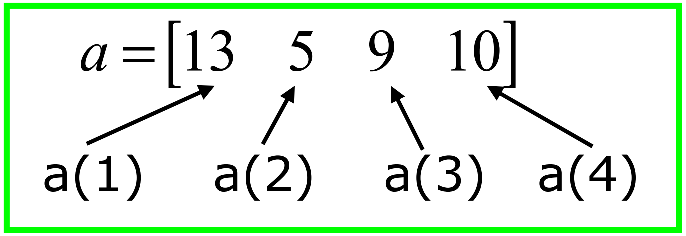
- In helloWorld.m, make a linear time vector `tVec` that has 10,000 samples between 0 and `endOfClass`
- Calculate the value of your knowledge (call it `knowledgeVec`) at each of these time points using the same equation as before:

$$k = 1 - e^{-t/\tau}$$

```
» tVec = linspace(0,endOfClass,10000);
» knowledgeVec=1-exp(-tVec/tau);
```

Vector Indexing

- MATLAB indexing starts with **1**, not **0**
  - We will not respond to any emails where this is the problem.
- a(n) returns the nth element



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

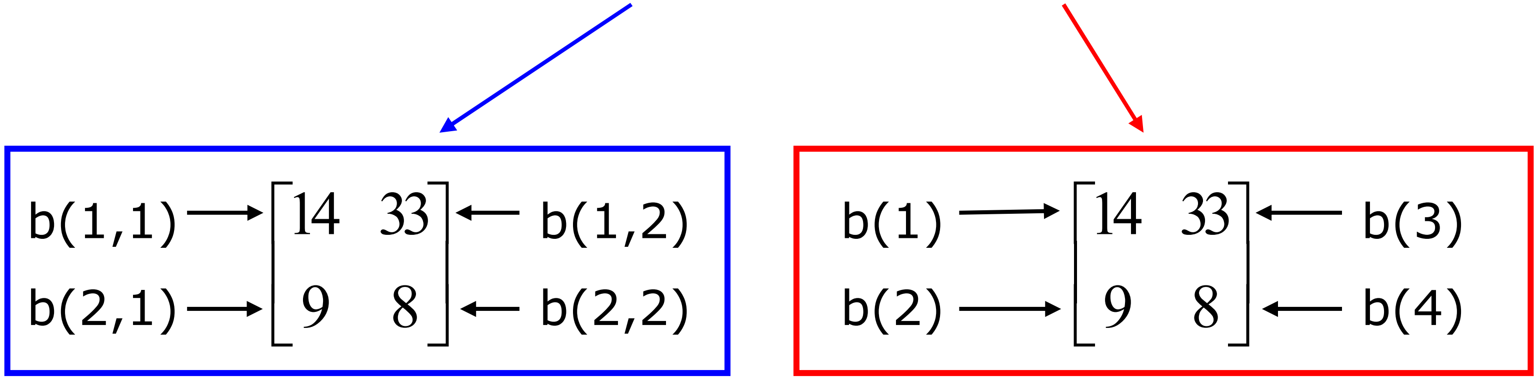
a(1) a(2) a(3) a(4)

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

Exercise: Indexing

When will you know 50% of MATLAB?

- First, find the index where `knowledgeVec` is closest to 0.5. Mathematically, what you want is the index where the value of $\left|knowledgeVec - 0.5\right|$ is at a minimum (use `abs` and `min`).
- Next, use that index to look up the corresponding time in `tVec` and name this time `halfTime`.
- Finally, display the string: I will know half of MATLAB after X days Convert `halfTime` to days by using `secPerDay`

Exercise: Indexing

When will you know 50% of MATLAB?

- First, find the index where `knowledgeVec` is closest to 0.5. Mathematically, what you want is the index where the value of $\left|knowledgeVec - 0.5\right|$ is at a minimum (use `abs` and `min`).
- Next, use that index to look up the corresponding time in `tVec` and name this time `halfTime`.
- Finally, display the string: I will know half of MATLAB after X days Convert `halfTime` to days by using `secPerDay`

```
» [val,ind]=min(abs(knowledgeVec-0.5));
» halfTime=tVec(ind);
» disp(['I will know half of MATLAB after ' ...
  num2str(halfTime/secPerDay) ' days']);
```

Outline

(1) Getting Started

(2) Scripts

(3) Making Variables

(4) Manipulating Variables

(5) Basic Plotting

Did everyone sign in?

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

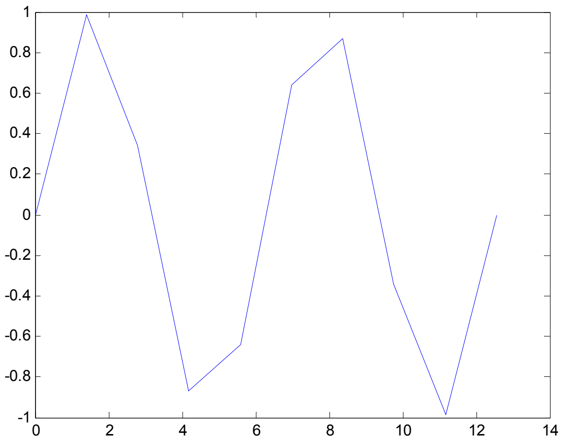
```
» x=linspace(0,4*pi,1000);
» plot(x,sin(x));
```

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

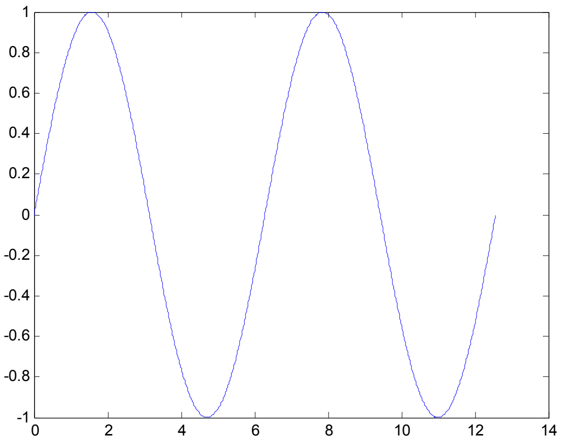
```
» plot([1 2], [1 2 3])
```

  - ➢ error!!

10 x values:



1000 x values:



Exercise: Plotting

Plot the learning trajectory

- In helloWorld.m, open a new figure (use `figure`)
- Plot the knowledge trajectory using `tVec` and `knowledgeVec`. When plotting, convert `tVec` to days by using `secPerDay`
- Zoom in on the plot to verify that `halfTime` was calculated correctly

Exercise: Plotting

Plot the learning trajectory

- In helloWorld.m, open a new figure (use `figure`)
- Plot the knowledge trajectory using `tVec` and `knowledgeVec`. When plotting, convert `tVec` to days by using `secPerDay`
- Zoom in on the plot to verify that `halfTime` was calculated correctly

```
» figure
» plot(tVec/secPerDay, knowledgeVec);
```

End of Lecture 1

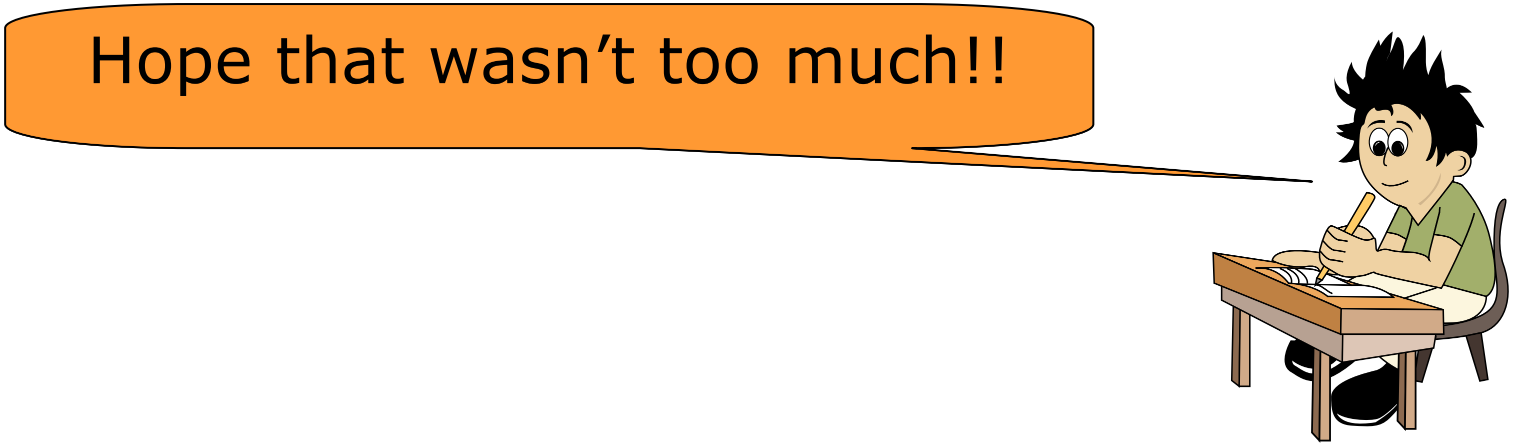
(1) Getting Started

(2) Scripts

(3) Making Variables

(4) Manipulating Variables

(5) Basic Plotting



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