Introduction to Modeling and Simulation

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ME584

Agenda

- Dynamic Systems
- Modeling of Dynamic Systems
- Introduction to Matlab

- Active learning: Pair-share questions, Exercises in class

Dynamic Systems

Static V. Dynamic Systems

- Static
  - » **Output does not change with time**
  - » **Output at any time depends on input at that time only**
- Dynamic
  - » **Output is not instantaneously proportional to input or disturbance, may continue after input held constant**
  - » **Present output depends on past inputs**

Dynamic Systems in Engineering Disciplines

- Mechanical systems
- Electrical systems
- Fluid systems
- Thermal systems
- Mixed systems
  - » **Electro-Mechanical**
  - » **Fluid-Mechanical**
  - » **Thermo-Mechanical**
  - » **Electro-Thermal**

Name an example and describe its dynamic response

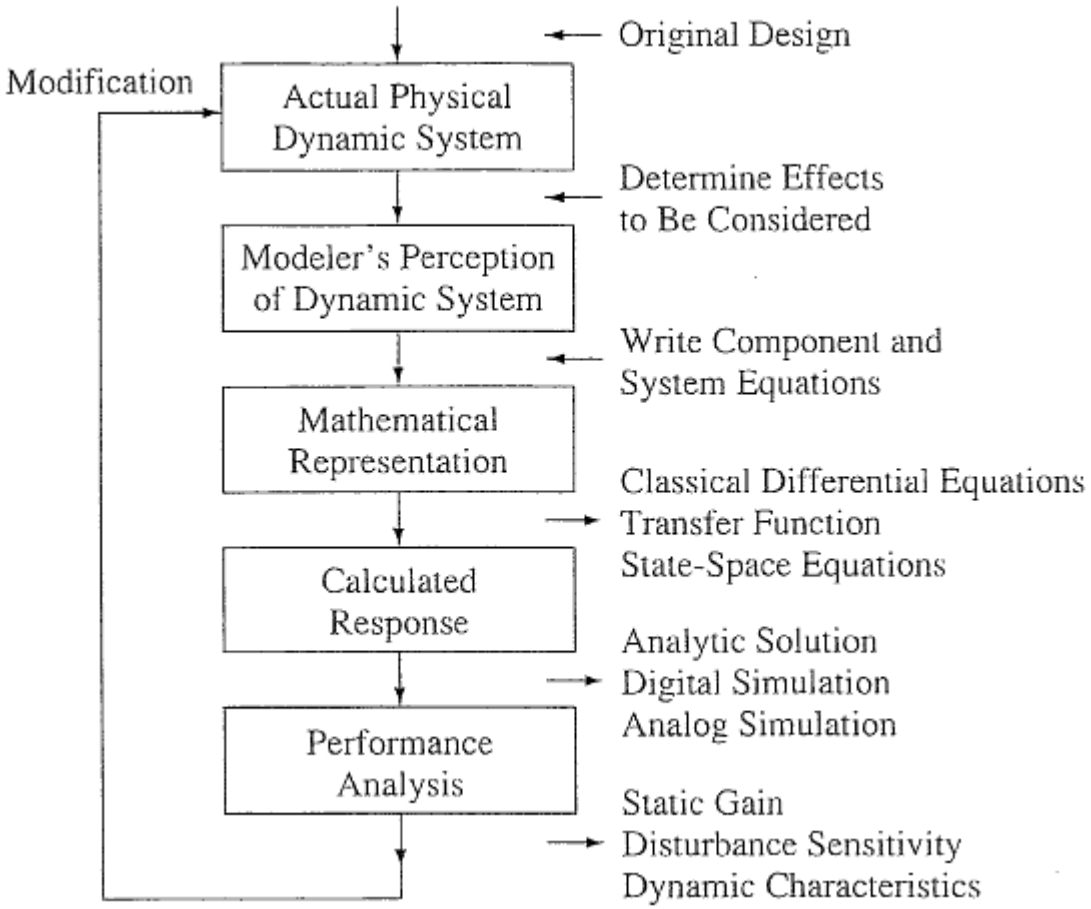
Modeling

- What is a model?
  - » **Physical models (e.g., scale model)**
  - » **Graphs or plots (e.g., time-dependent behavior)**
  - » **Mathematical models**
- Modeling
  - » **Identifying physical dynamic effects**
  - » **Writing differential equations using conservation and property laws**
  - » **Expressing in differential equations forms**

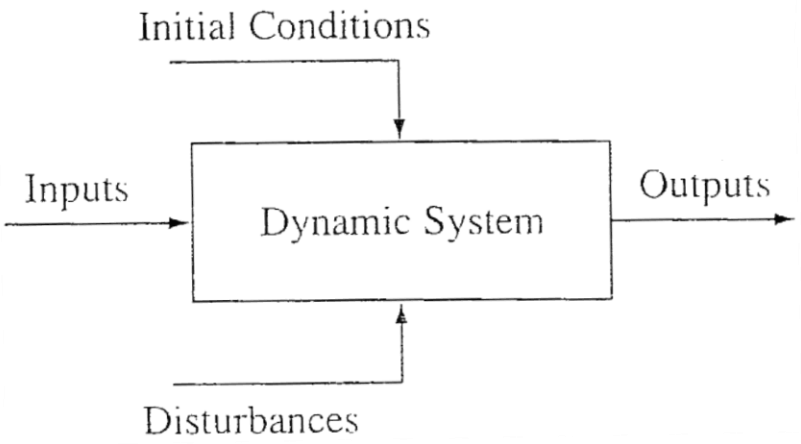
Modeling of Dynamic Systems

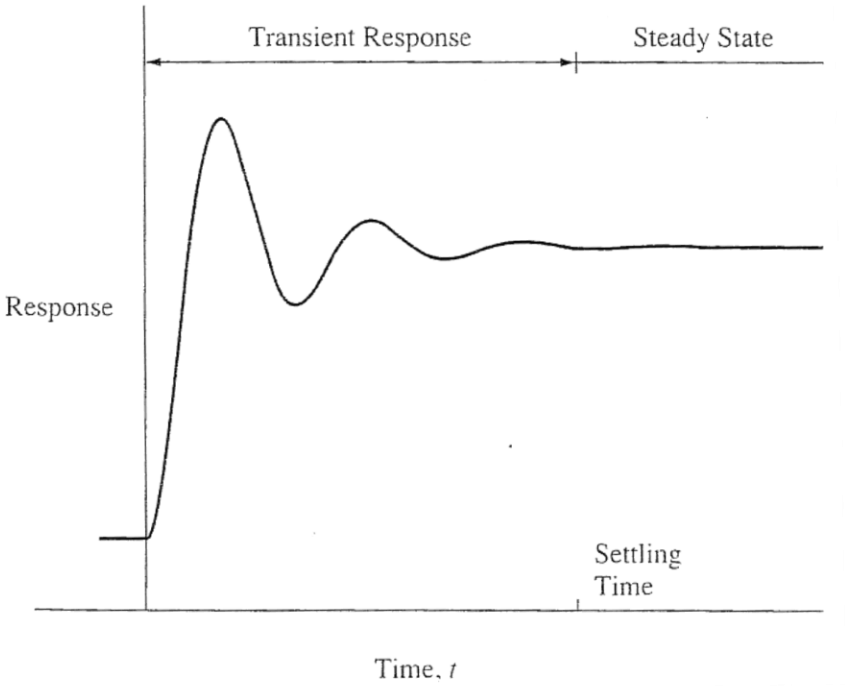
Modeling Steps

- Inaccuracies propagate in each step (e.g., linearization, ignoring higher dynamics)
- Iterative modifications needed to get required output
- Example: modeling steps for your favorite sport device



Representing Dynamic Systems

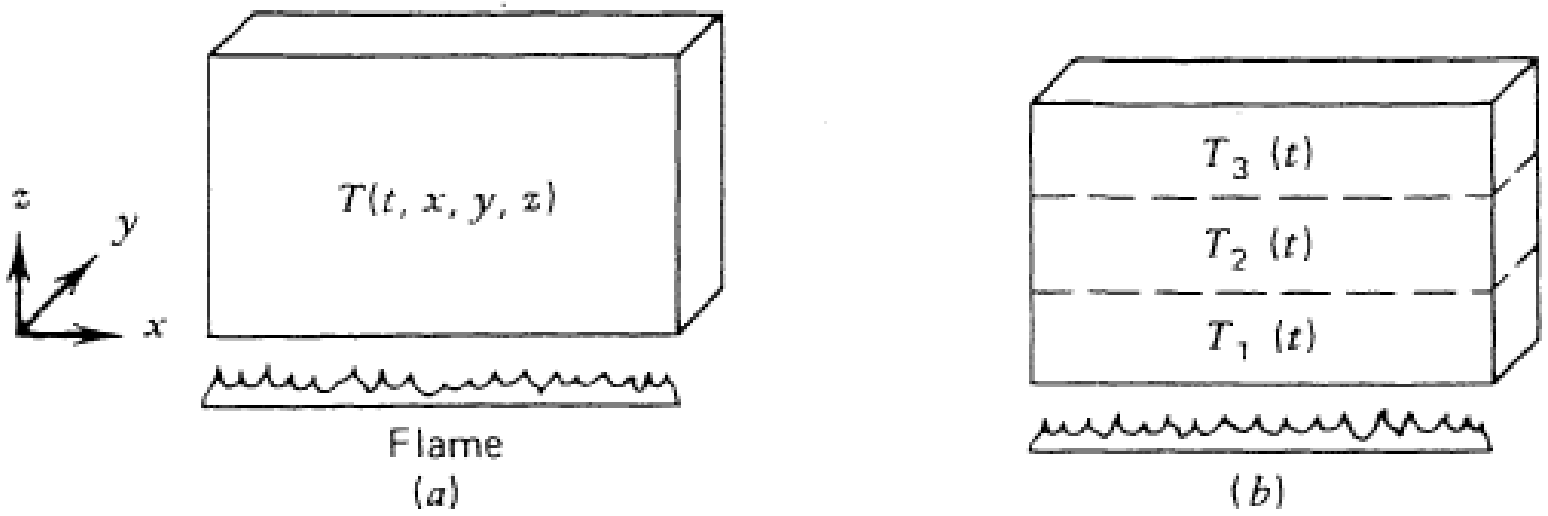




Mathematical Representation and Solution Methods

System Equations	Solution Methods
Classical differential equation $\ddot{x}+2\dot{x}+3x=f$	Analytical Solution
Transfer function $X(s)s^2+2sX(s)+3X(s)=F(s)$	Laplace Transform
State space $\begin{bmatrix}\dot{x}\\ \dot{z}\end{bmatrix}=\begin{bmatrix}0 & 1\\ -3 & -2\end{bmatrix}\begin{bmatrix}x\\ z\end{bmatrix}+\begin{bmatrix}0\\ 1\end{bmatrix}f$	Digital/Analog Simulation

Model Classification Tree

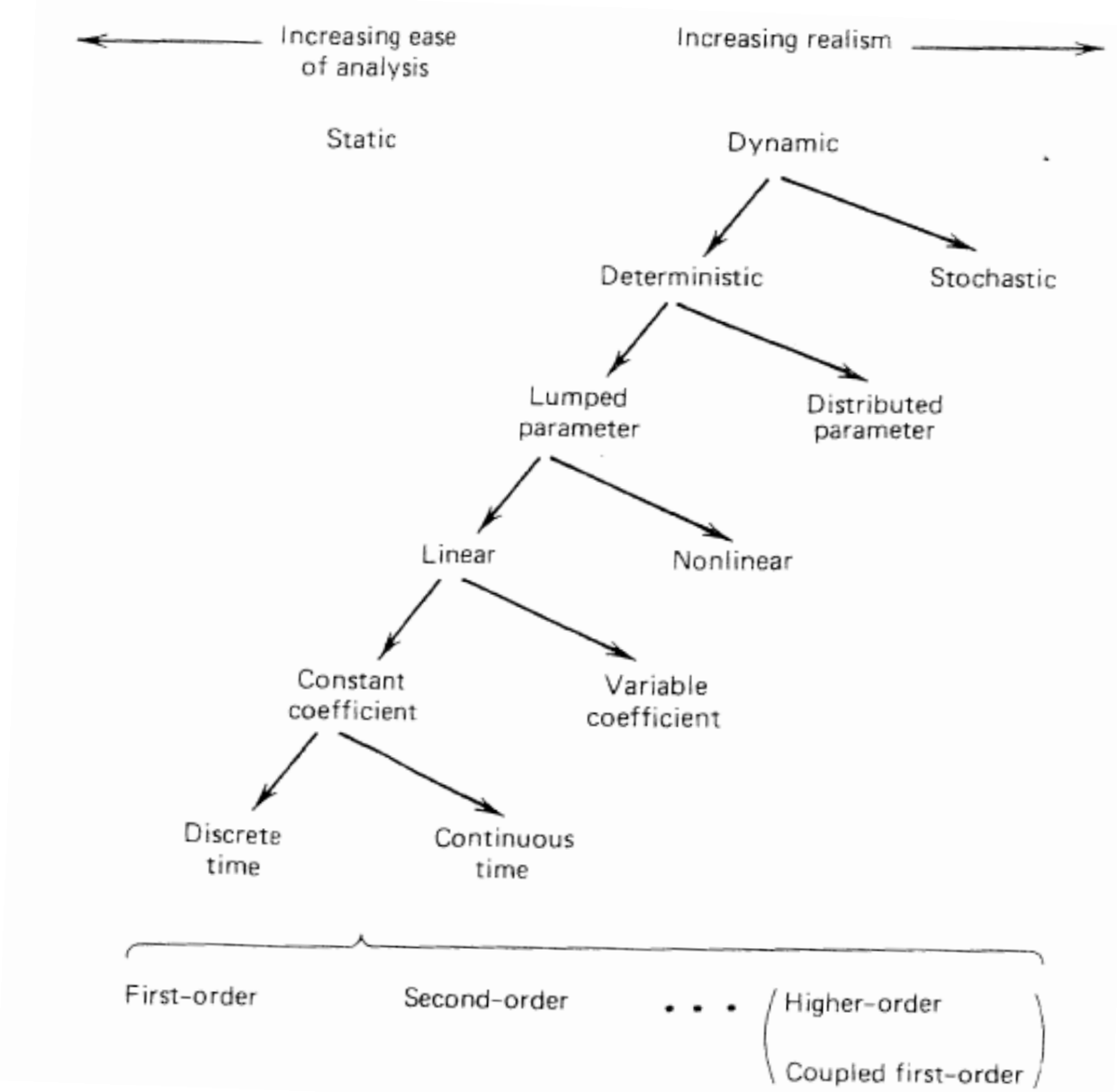


Temperature distribution in a plate. (*a*) Distributed-parameter representation. (*b*) Lumped-parameter representation using three elements.

$$f(T, \frac{\partial T}{\partial t}, \frac{\partial^2 T}{\partial x^2}, \frac{\partial^2 T}{\partial y^2}, \frac{\partial^2 T}{\partial z^2}) = 0$$

$$f(T, \frac{\partial T}{\partial t}) = 0$$

Model Classification Tree



Linear System

- Let u(t) be input and y(t) be output, the system is linear if
  - **Additivity: Response to u_1+u_2 is y_1+y_2**
  - **Homogeneity: Response to au_1 is ay_1**
- Example: Show that y(t) = 2x(t) + 3 is not linear
  - **If $x_1=2$ and $x_2=3$, then**
    - $y_1=2*2+3=7$, and $y_2=2*3+3=9$
  - **But for $x_3 = x_1 + x_2 = 5$, then**
    - $y_3=2*5+3=13$
    - And $y_3 \neq y_1 + y_2 = 16$
  - **System is not linear**

Pair-share exercise: Linear System Example

- Consider this system: $y(t) = t\,u(t)$
- Is this system is linear?
- Consider two *arbitrary* inputs u_1 and u_2
  - » $\mathbf{y_1 = tu_1}$
  - » $\mathbf{y_2 = tu_2}$
- Let $u_3 = au_1 + bu_2$, where a and b are *arbitrary* scalar constants
  - » $\mathbf{y_3 = tu_3 = t\,(au_1 + bu_2) = atu_1 + btu_2 = ay_1 + by_2}$
- System is linear

Introduction to Matlab

Outline

(1) Getting Started

(2) Scripts

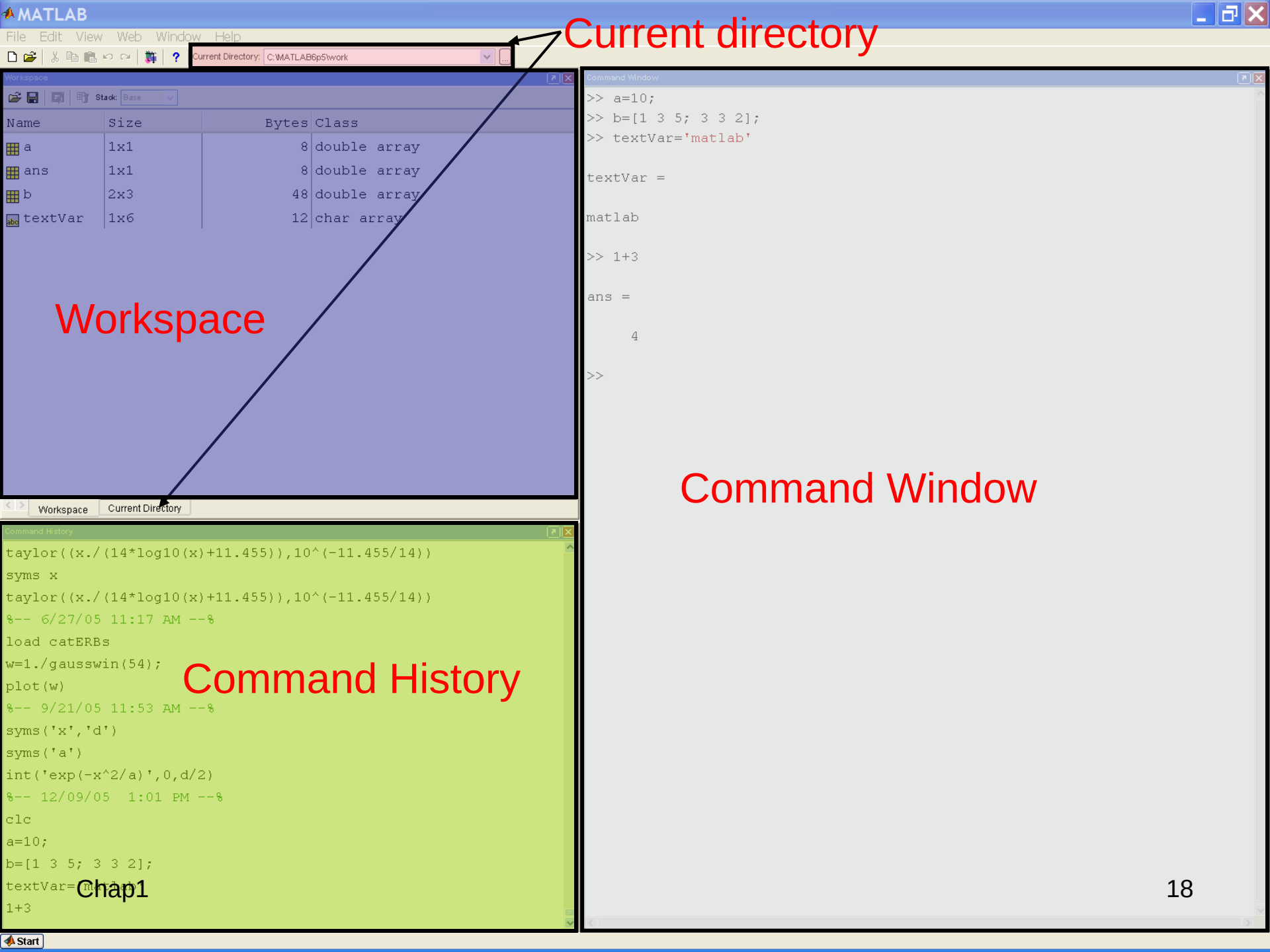
(3) Making Variables

(4) Manipulating Variables

(5) Basic Plotting

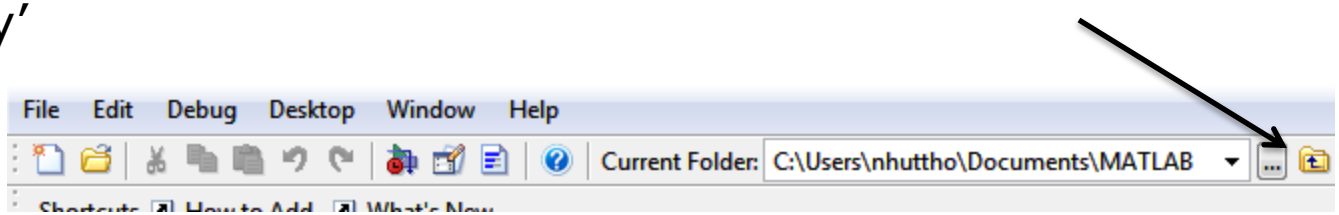
Getting Started

- Open up MATLAB for Windows
  - Through the START Menu
  - Or Click on Matlab icon


MATLAB
File Edit View Web Window Help
Current Directory: C:\MATLAB6p5\work
Current directory
Workspace
Name Size Bytes Class
a 1x1 8 double array
ans 1x1 8 double array
b 2x3 48 double array
textVar 1x6 12 char array
Workspace
Workspace
Current Directory
Command History
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];
1+3
Command History
Command Window
>> a=10;
>> b=[1 3 5; 3 3 2];
>> textVar='matlab'
textVar =
matlab
>> 1+3
ans =
4
>>
Command Window
Start

Making Folders

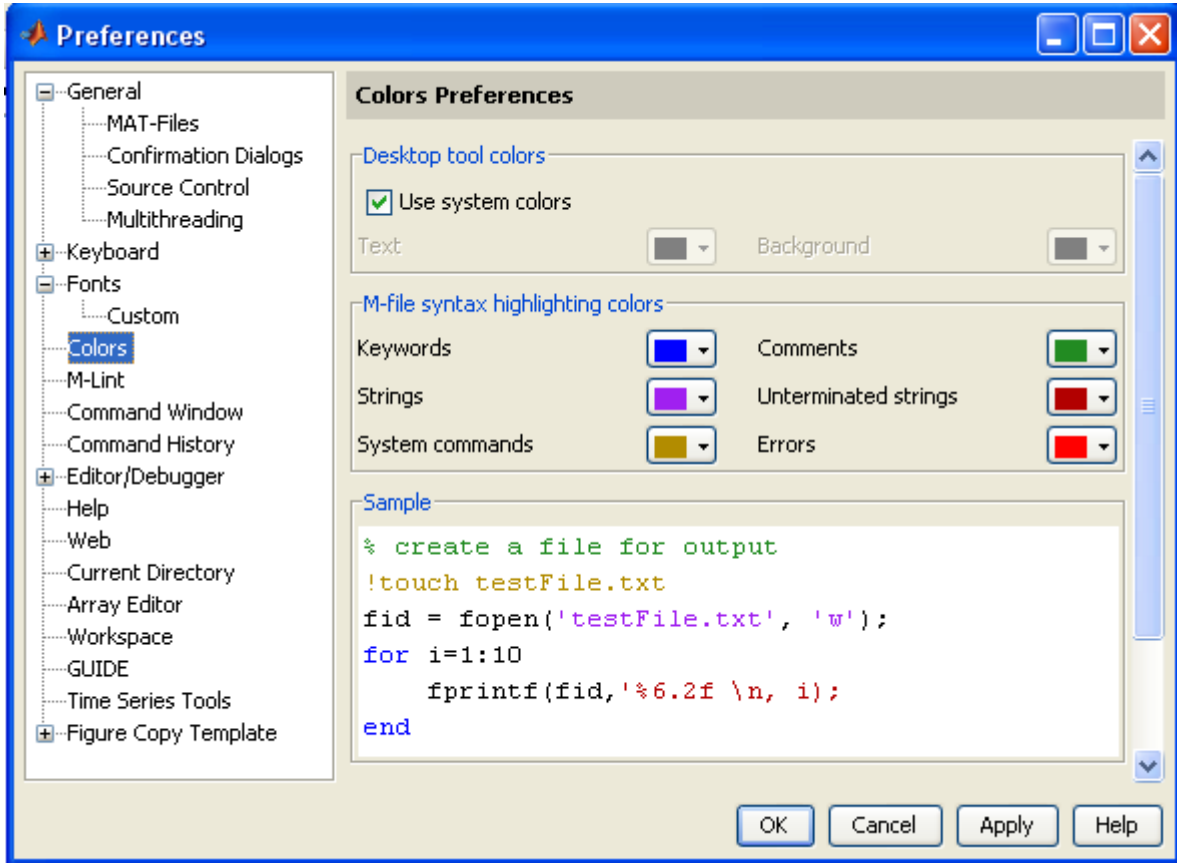
- Use folders to keep your programs organized
- To make a new folder, click the 'Browse' button next to 'Current Directory'



- Click the 'Make New Folder' button, and change the name of the folder. **Do NOT use spaces** in folder names. In the MATLAB folder, make a new folder: ME584\MatlabIntro
- 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

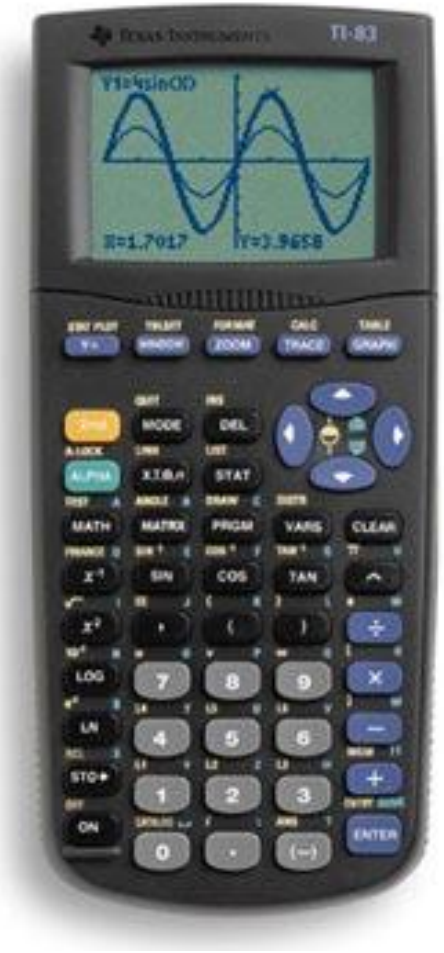
- File → Preferences
  - ➢ Allows you personalize your MATLAB experience



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

Outline

(1) Getting Started

(2) Scripts

(3) Making Variables

(4) Manipulating Variables

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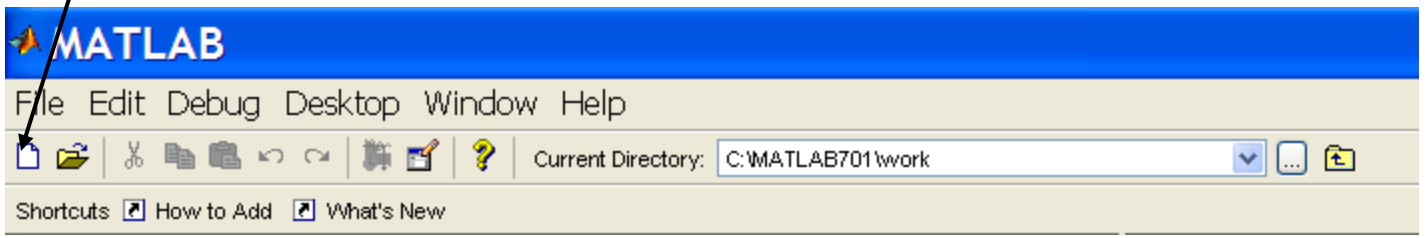
Scripts: Overview

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

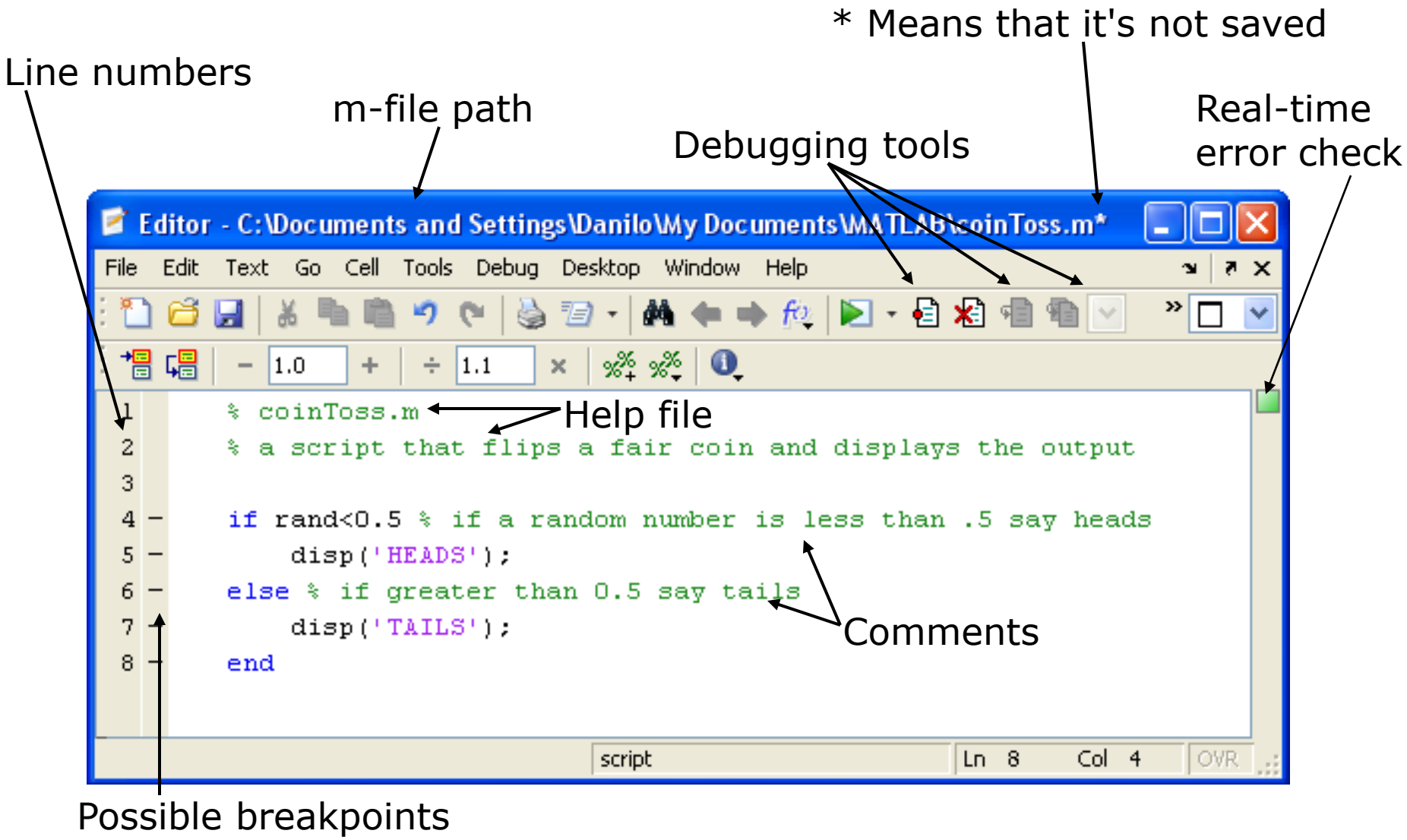
- To create an m-file from command-line

```
» edit helloWorld.m
```

- or click



Scripts: the Editor



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!');
```

Outline

(1) Getting Started
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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];
```

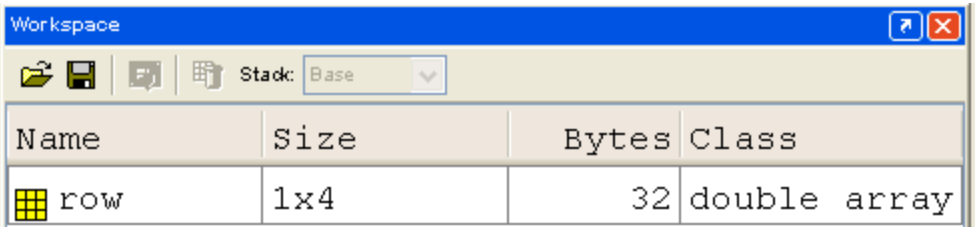
- Command window:

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

row =

    1.0000    2.0000    5.4000   -6.6000
```

- Workspace:



Column Vectors

- Column vector: semicolon separated values between brackets

```
» column = [4;2;7;4]
```

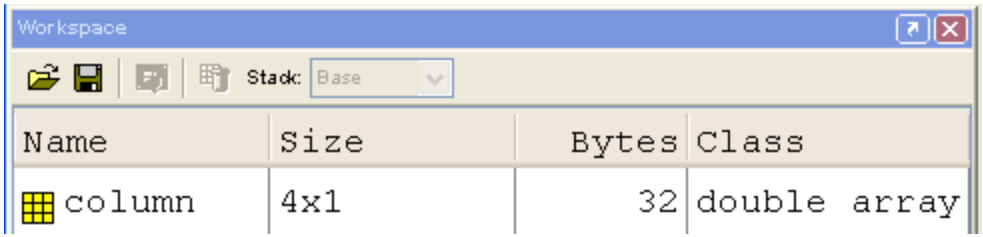
- Command window:

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

column =

     4
     2
     7
     4
```

- Workspace:



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

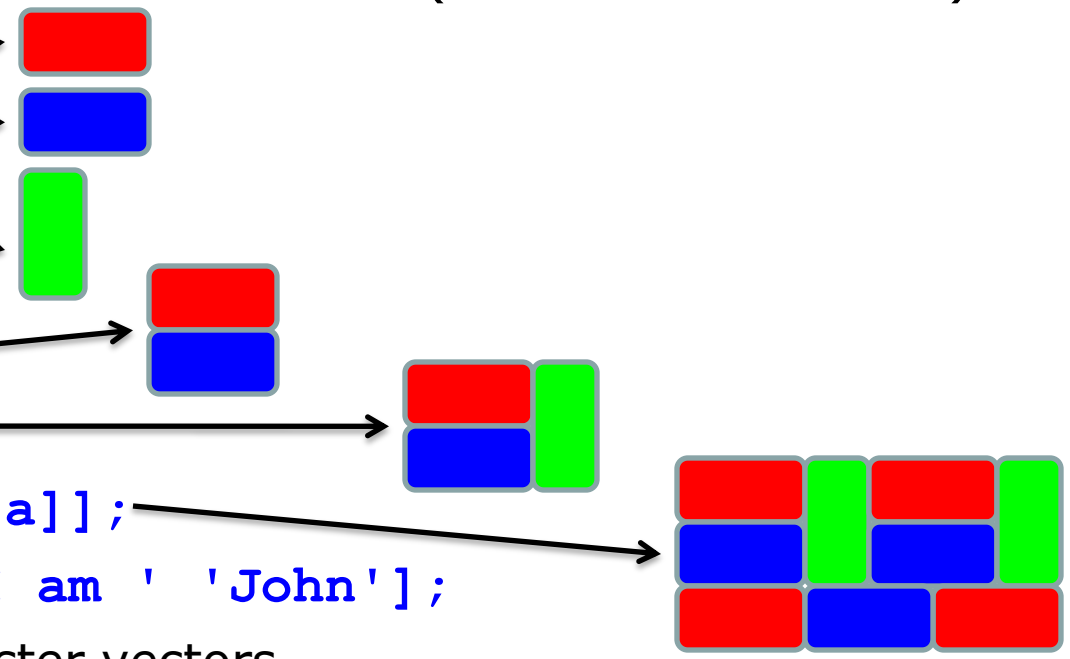
```
» a= [1 2;3 4];
```

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

- 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\ME584\MatlabIntro`

- 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

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?
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- 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
```

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.

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.

```
» load startTime
» disp(['I started learning Matlab on ' ...
  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`

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

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

$$3\times 1.*3\times 1 = 3\times 1$$

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

$$3\times 3.*3\times 3 = 3\times 3$$

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

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)

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

$$1\times 3 * 3\times 1 = 1\times 1$$

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

Must be square to do powers

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

$$3\times 3 * 3\times 3 = 3\times 3$$

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

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

- 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

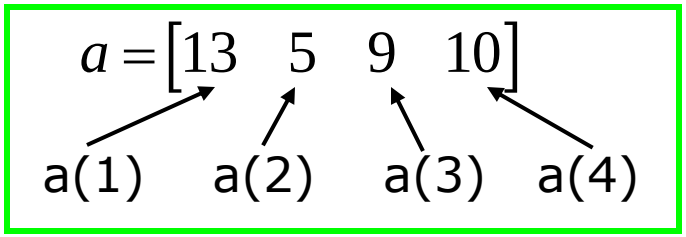
- In helloWorld.m, make a linear time vector **`tVec`** that has 10,000 samples between 0 and **`endOfClass`**
- Calculate the value of your knowledge (call it **`knowledgeVec`**) at each of these time points using the same equation as before:

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

```
» 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 n^{th} element

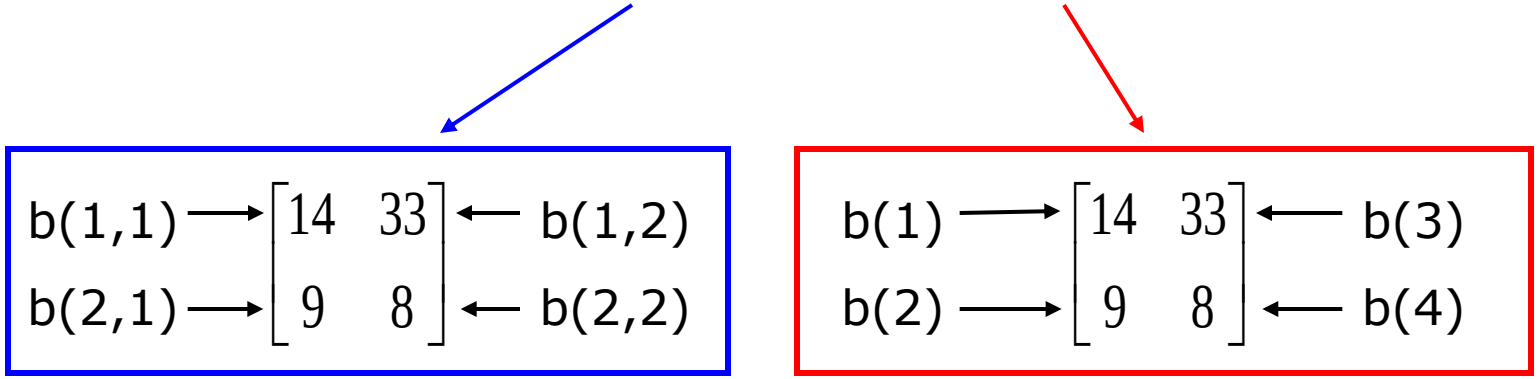


- The index argument can be a vector. In this case, each element is looked up individually, and returned as a vector of the same size as the index vector.

```
» 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



- 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 $|knowledgeVec - 0.5|$ 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?

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- 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

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

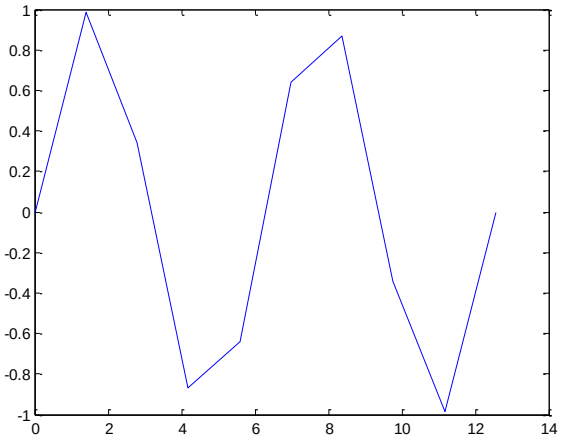
```
» plot(x,y);
```

MATLAB makes visualizing data fun and easy!

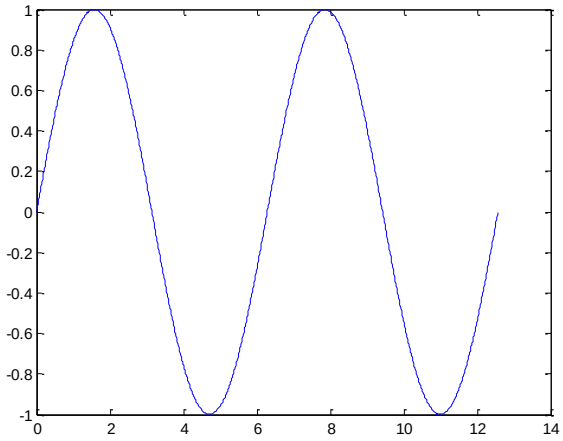
What does plot do?

- **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);
```

Matlab Tutorial

- Matlab tutorials
  - » http://www.engin.umich.edu/group/ctm/basic/basic.html
  - » http://www.engin.umich.edu/group/ctm/model/model.html
- Tutorials included in Matlab

Homework 1: chapter 1

- 1.1
- 1.3
- 1.7
- 1.10

References

- Woods, R. L., and Lawrence, K., Modeling and Simulation of Dynamic Systems, Prentice Hall, 1997.
- Palm, W. J., Modeling, Analysis, and Control of Dynamic Systems
- Matlab slides are from: Lecture 1: Variables, Scripts, and Operations, by Danilo Šćepanović, IAP 2010 Course, MIT