6.057
Introduction to MATLAB

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Course Layout

Problem sets

- One per day, should take about 4 hours to complete
- Submit Word or PDF, include code and figures
- Some questions optional, but highly recommended!

Requirements for passing

- Attend 3/4 lectures (Friday is optional)
- Complete all problem sets (graded on a 3-level scale: -, √, +)...
- ... and achieve √ average

Prerequisites: You'll be fine!

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 Python
  - Commands are executed line-by-line

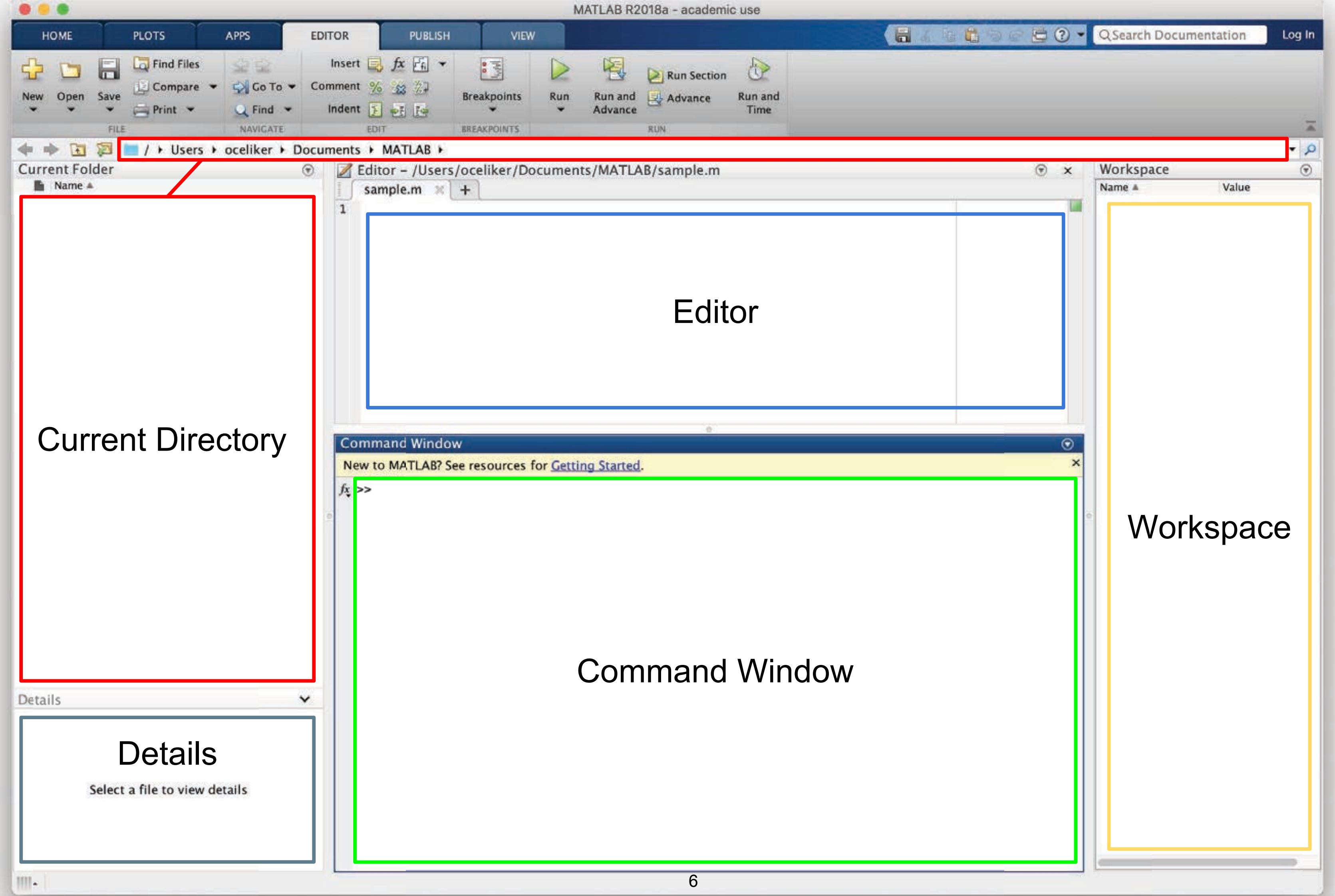
Outline

I. Getting Started
II. Scripts
III. Making Variables
IV. Manipulating Variables
V. Basic Plotting

Getting Started

- To get MATLAB Student Version for yourself

- You can also use MATLAB online
    - https://matlab.mathworks.com (requires Mathworks account with license)


MATLAB R2018a - academic use
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Current Folder
Name
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Details
Select a file to view details
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Editor
Command Window
New to MATLAB? See resources for Getting Started.
>>
Command Window
Workspace
Name
Value
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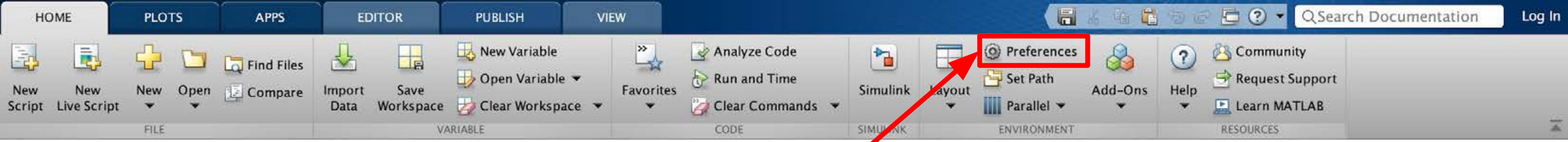
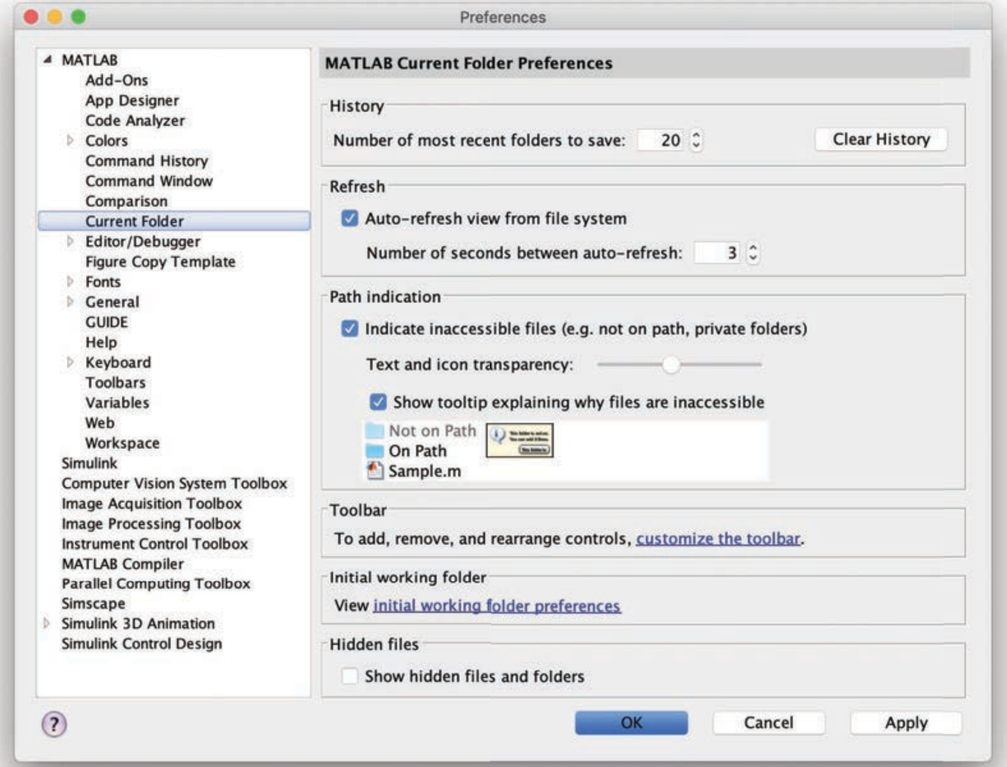
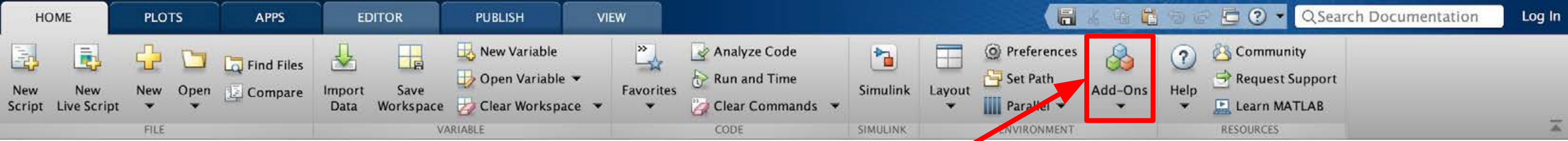


Customization

- In the top ribbon, navigate to:
  Home -> Environment -> Preferences

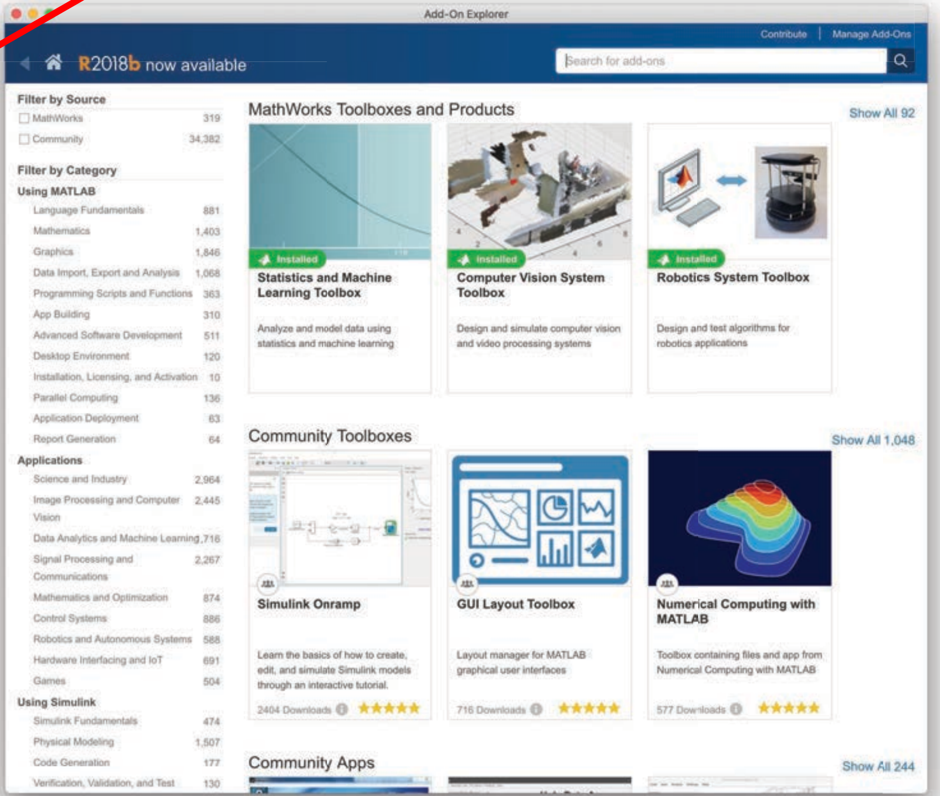
- Allows you to customize your MATLAB experience (colors, fonts, etc.)





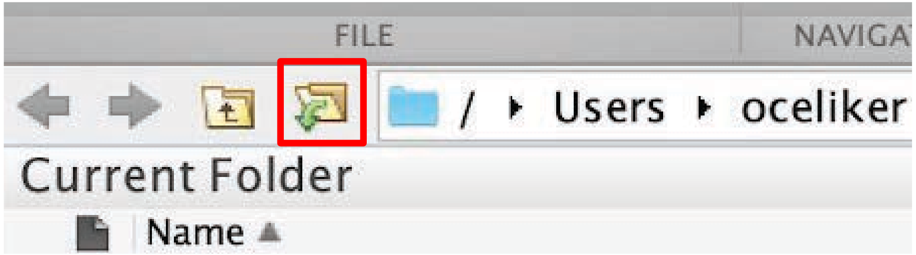
Installing Toolboxes

- In the top ribbon, navigate to: Home -> Environment -> Add-Ons
- Allows you to install toolboxes included with your license
- Recommended toolboxes:
  - Curve Fitting Toolbox
  - Computer Vision System Toolbox
  - Image Processing Toolbox
  - Optimization Toolbox
  - Signal Processing Toolbox
  - and anything related to your field!



Making Folders

- Use folders to keep your programs organized
- To make a new folder, click "Browse" next to the file path



- Click the Make New Folder button, and change the name of the folder. In the MATLAB folder (which should be open by default), make the following folder structure:

```
MATLAB
↳ IAP MATLAB
      ↳ Day1
```

Help/Docs

- `help`
  - The most important command 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 documentation
- To get a nicer version of help with examples and easy-to-read description:
  - `doc sin`
- To search for a function by specifying keywords:
  - `docsearch sin trigonometric`

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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 the command line:
    - `edit MyFileName.m`
    - or click the "New Script" button on the top left

Scripts: Some notes

- COMMENT!
  - Anything following a % sign is interpreted as a comment
  - The first contiguous comment becomes the script's help file
  - Comment thoroughly to avoid wasting time later!
  - Mark beginning of a code block by using %%
- Note that scripts are somewhat static, with no explicit input and output
- All variables created or modified in a script retain their values after script execution

Exercise: Scripts

- Make a script with the name **helloWorld.m**
- When run, the script should show the following text:

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

Hint: Use `disp(...)` to display strings. Strings are written between single quotes, e.g. `'This is a string'`

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Variable Types

- MATLAB is a "weakly typed" language
  - No need to initialize variables!
- MATLAB supports various types; the most popular ones are
  - 3.84
    - 64-bit double (default)
  - 'A'
    - 16-bit char
- Most variables you'll deal with are vectors, matrices, doubles or chars
- Other types are also supported: complex, symbolic, 16-bit and 8-bit integers (uint16 & uint8), etc.

Naming Variables

- To create a variable, simply assign a value to a name:

```
myNumberVariable = 3.14
myStringVariable = 'hello world!'
```

- Variable name rules
    - First character must be a LETTER
    - After that, any combination of numbers, letters and _
    - Names are CASE-SENSITIVE (e.g. `var1` is different than `Var1`)

Naming Variables (cont.)

Built-in variables (don't use these names for anything else!):

`i, j`: can be used to indicate complex numbers*

`pi`: has the value 3.1415...

`ans`: stores the result of the last unassigned value

`Inf, -Inf`: infinities

`NaN`: "Not a Number"

ops, use `ii, jj, kk`, etc. for loop counters.

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:
  - Matrix of numbers (either double or complex)
  - Cell array of objects (more advanced data structure)

MATLAB makes vectors easy!
That's its power!

Row vectors

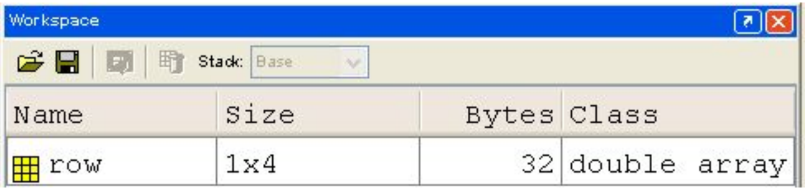
- Row vector: comma- or space-separated values between square brackets
  - `row = [ 1 2 3.2 4 6 5.4 ];`
  - `row = [ 1, 2, 4, 7, 4.3, 1.1 ];`
- Command window:

```
>> 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 square brackets
  - `col = [ 1; 2; 3.2; 4; 6; 5.4 ];`

- Command window:

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

column =

     4
     2
     7
     4
```

- Workspace:

Workspace

Stack: Base

Name	Size	Bytes	Class
column	4x1	32	double array

Size and length

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

```
>> size(row)

ans =

     1     4

>> length(row)

ans =

     4
```

```
>> size(column)

ans =

     4     1

>> length(column)

ans =

     4
```

Matrices

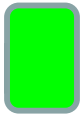
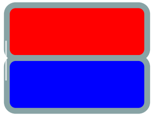
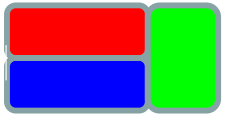
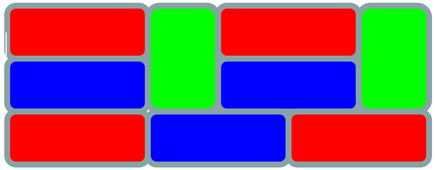
- Make matrices like vectors
  - Element by element
    - `a= [1 2;3 4];`

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

- 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 in the current directory
  - Default working directory is MATLAB unless you navigate to another folder
  - Make sure you are in the correct folder. Right now we should be in \MATLAB\IAP MATLAB\Day 1
- Use clear to save variables to a file
  - `clear a b`
  - Look at workspace: variables a and b are gone
- Use load to load variables into the workspace
  - `load myFile`
  - Look at workspace: a and b are back

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 II

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

  I started learning MATLAB on [date, time]

- Hint: Use the `disp` command again
- 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.

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Basic Scalar Operations

- Arithmetic operations (+, -, *, /)
  - `7/45`
  - `(1+1i)*(1+2i)`
  - `1/0`
  - `0/0`
- Exponentiation
  - `4^2`
  - `(3+4*1j)^2`
- Complicated expressions: use parentheses
  - `((2+3)*3)^0.1`

Built-in Functions

- MATLAB has an <u>enormous</u> library of built-in functions
- Call using parentheses, passing parameters to function
  - `sqrt(2)`
  - `log(2), log10(0.23)`
  - `cos(1.2), atan(-.8)`
  - `exp(2+4*1i)`
  - `round(1.4), floor(3.3), ceil(4.23)`
  - `angle(1i); abs(1+1i);`

Exercise: Scalars

`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 6.057, I will know X% of MATLAB
```

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

Transpose

- The transpose operator 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
  - Transposes and conjugates all complex numbers
- For vectors of real numbers .' and ' give same result
  - For transposing a vector, always use .' to be safe

Addition and Subtraction

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

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

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

Addition and Subtraction

- `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

Element-wise functions

- 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
```

Operators

- Multiplication can be done in a standard way or element-wise
- Standard multiplication (*) is matrix 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: for now, just multiply by inverse (more on this later)

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

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

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

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

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

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

Exercise: Vector Operations

Calculate how many seconds elapsed since 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, secPerMin, 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

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

Automatic Initialization

- Initialize a vector of **ones**, **zeros**, or **random** 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 (representing uninitialized variables)

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 is not 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:

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

Vector Indexing

- <u>MATLAB indexing starts with **1**, not **0**</u>
  - ➢ We will not respond to any emails where this is the problem.
- a(n) returns the n^{th} element

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

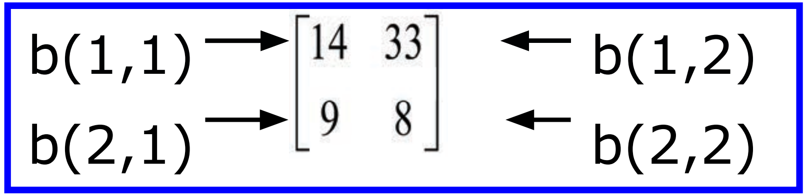
a(1) a(2) a(3) a(4)

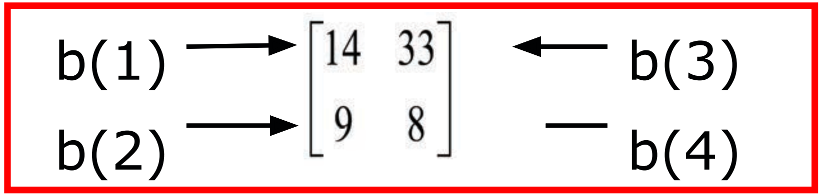
- The index argument can be a vector. In this case, each element is looked up individually, and returned as a vector of the same size as the index vector.


```
» x=[12 13 5 8];
```

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
```

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
  ```
  » vec = [5 3 1 9 7]
  ```

- To get the minimum value and its index (similar for `max`):
  ```
  » [minVal,minInd] = min(vec);
  ```

- To find the indices of specific values or ranges
  ```
  » ind = find(vec == 9); vec(ind) = 8;
  » ind = find(vec > 2 & vec < 6);
  ```
  - ➢ **find** expressions can be very complex, more on this later
  - ➢ When possible, **logical indexing** is faster than **find**!
  - ➢ E.g., `vec(vec == 9) = 8;`

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:
  Convert **halfTime** to days by using secPerDay. I will know half of MATLAB after X 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);`

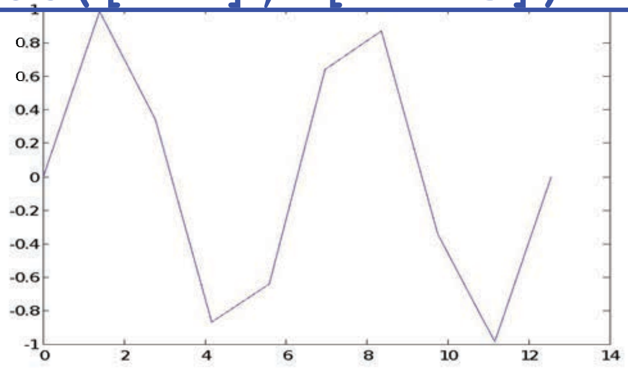
- Plot values against their index
  - » `plot(y);`
- Usually we want to plot y versus x
  - » `plot(x,y);`

MATLAB makes visualizing data fun and easy!

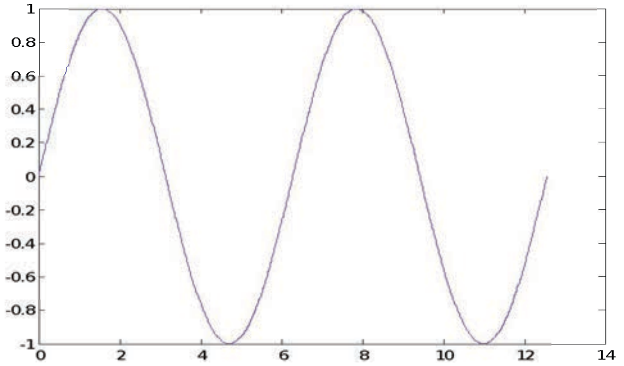
What does plot do?

- **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])`

10 x values:



1000 x values:



Exercise: Plotting

Plot the learning trajectory

- In helloWorld.m, open a new figure (use `figure`)
- Plot 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

End of Lecture 1

(1) Getting Started
(2) Scripts
(3) Making Variables
(4) Manipulating Variables
(5)

Hope that wasn't too much and you enjoyed it!!

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