PENGOLAHAN SINYAL DIGITAL

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MATLAB

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WHY MATLAB?

- Matrix Labratory
- Created in late 1970’s
- Intended for used in courses in matrix theory, linear algebra and numerical analysis
- Currently has grown into an interactive system and high level programming language for general scientific and technical computation

WHY MATLAB? COMMON USES FOR MATLAB IN RESEARCH

- Data Acquisition
- Multi-platform, Multi Format data importing
- Analysis Tools (Existing, Custom)
- Statistics
- Graphing
- Modeling

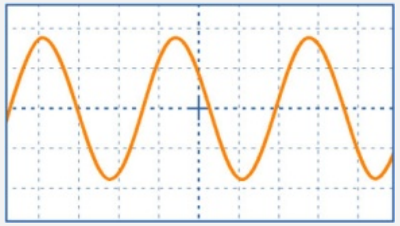
WHY MATLAB? DATA ACQUISITION

- A framework for bringing live, measured data into MATLAB using PC-compatible, plug-in data acquisition hardware

WHY MATLAB? MULTI-PLATFORM, MULTI FORMAT DATA IMPORTING

- Data can be loaded into Matlab from almost any format and platform
- Binary data files (eg. REX, PLEXON etc.)
- Ascii Text (eg. Eyelink I, II)
- Analog/Digital Data files

PC
UNIX



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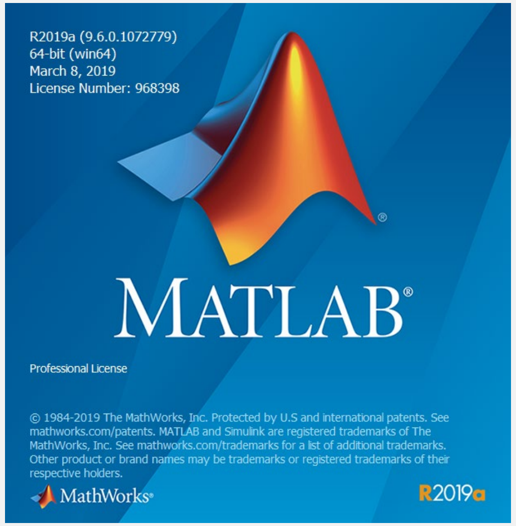
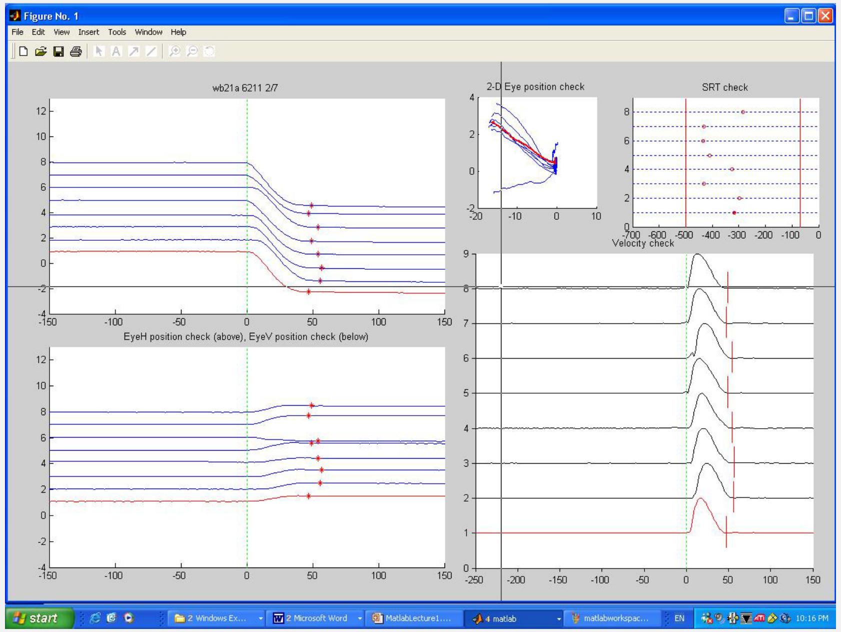


WHY MATLAB? ANALYSIS TOOLS

- A Considerable library of analysis tools exist for data analysis
- Provides a framework for the design, creation, and implementation of any custom analysis tool imaginable

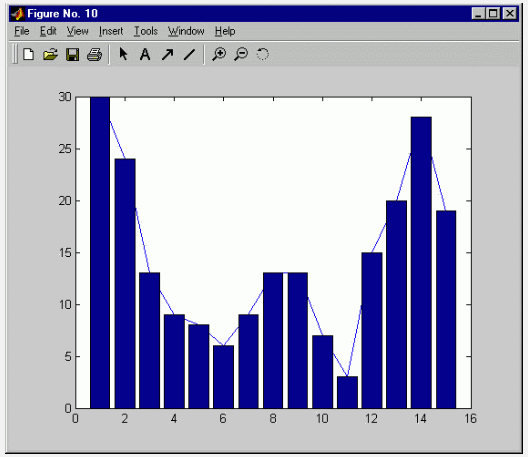


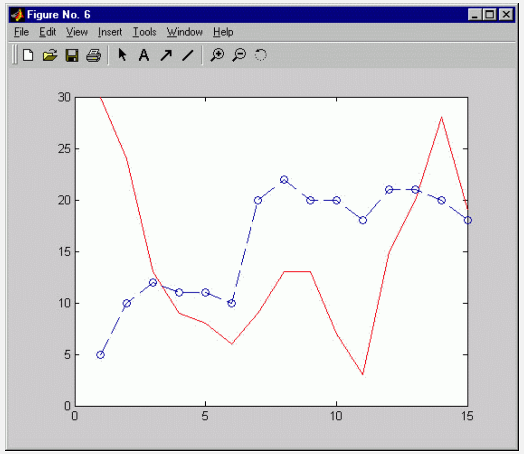
WHY MATLAB? STATISTICAL ANALYSIS

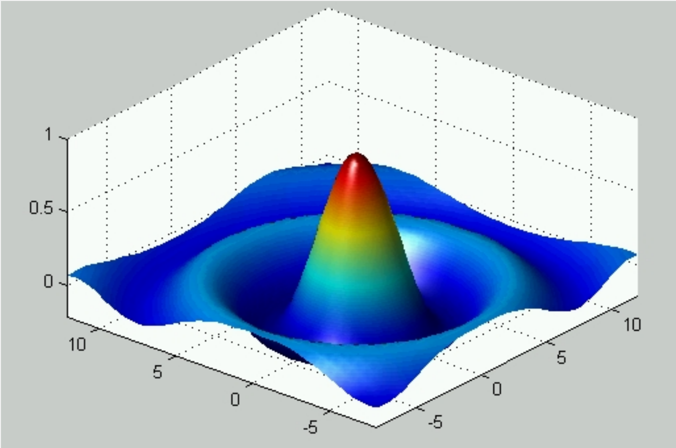
- A considerable variety of statistical tests available including:
  - T-TEST
  - Mann-Whitney Test
  - Rank Sum Test
  - ANOVAs
  - Linear Regressions
  - Curve Fitting

WHY MATLAB? GRAPHING

- A Comprehensive array of plotting options available from 2 to 4 dimensions
- Full control of formatting, axes, and other visual representational elements

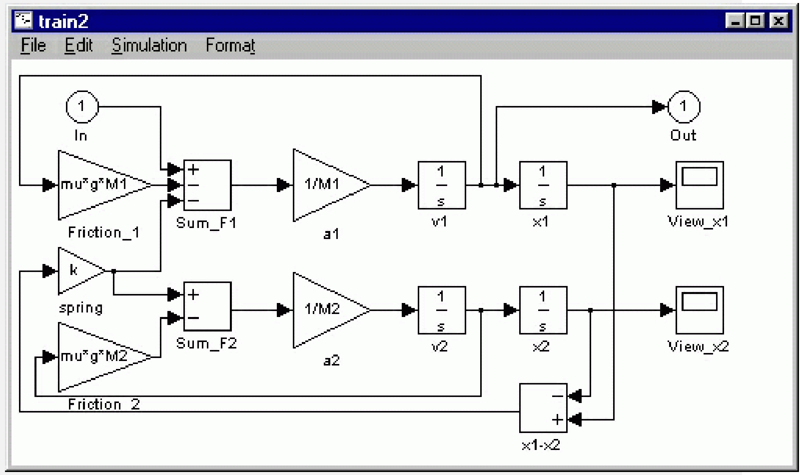


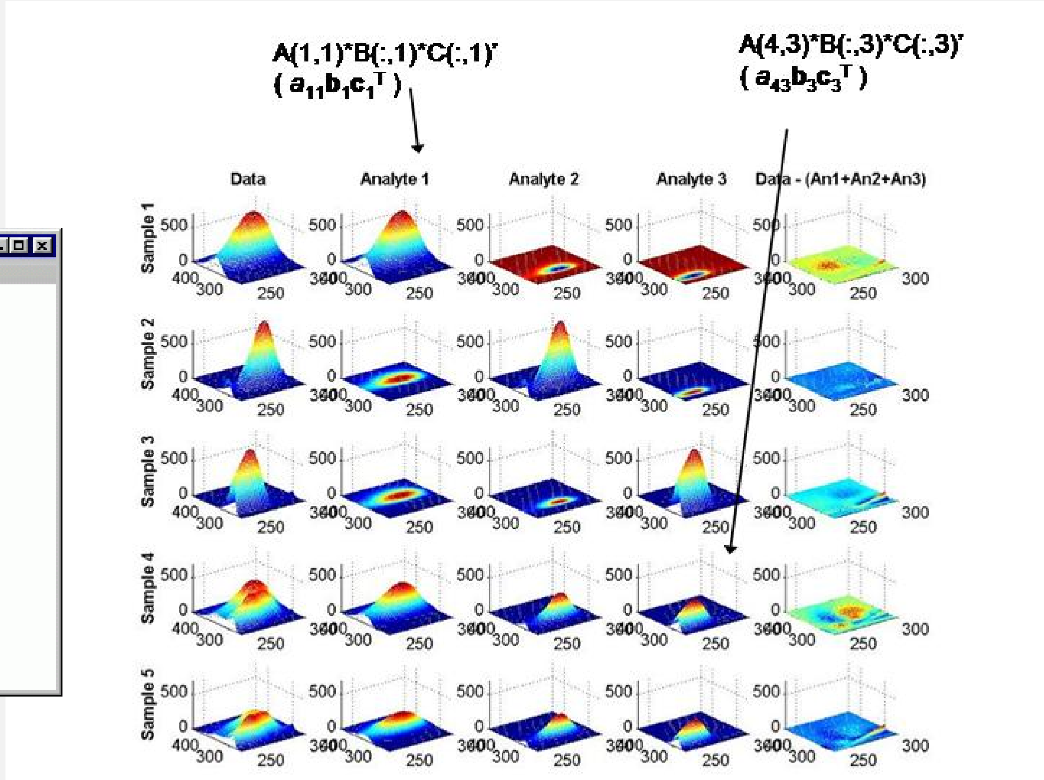




WHY MATLAB? MODELING

- Models of complex dynamic system interactions can be designed to test experimental data





MATLAB INTERFACE

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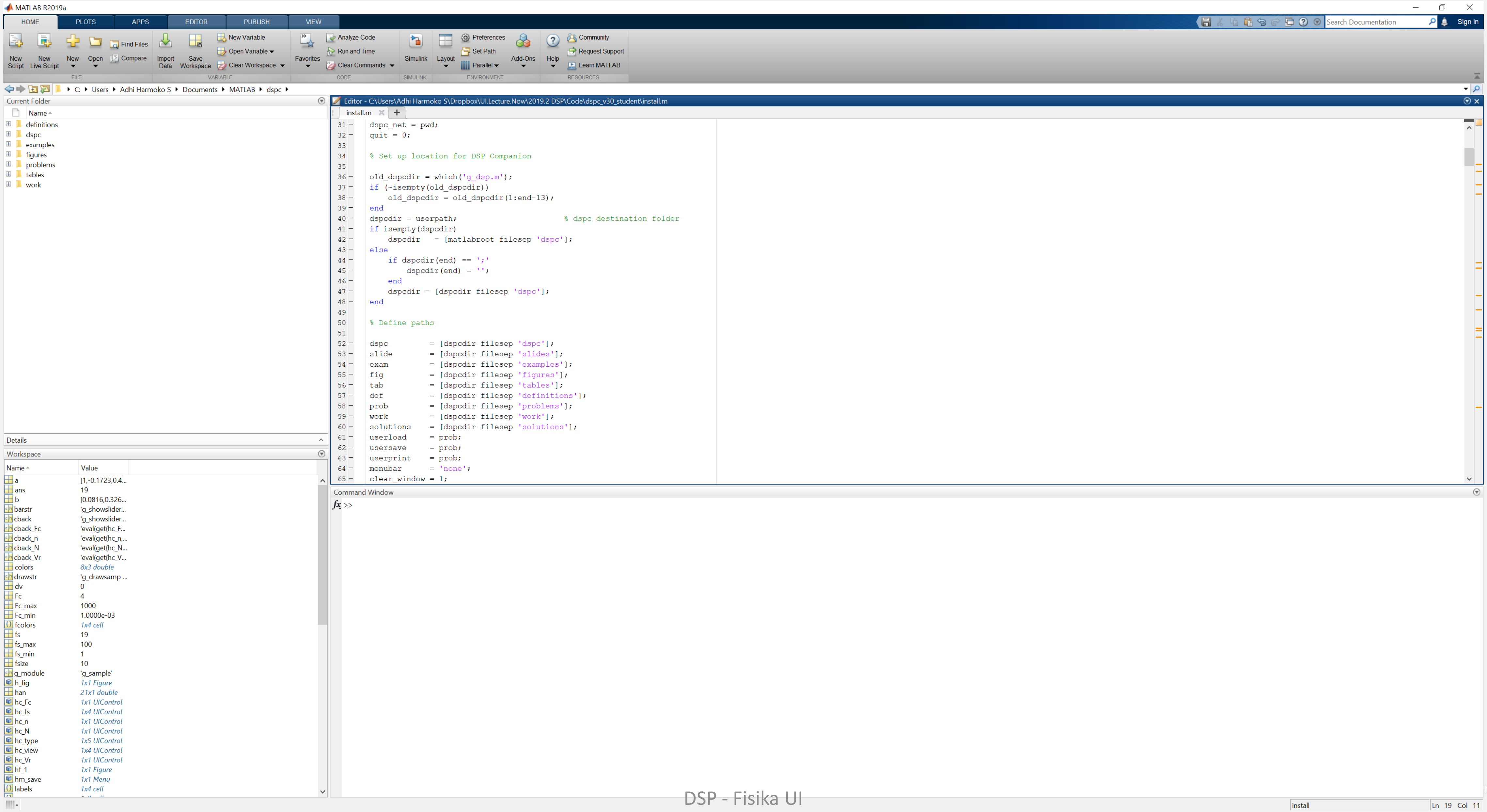
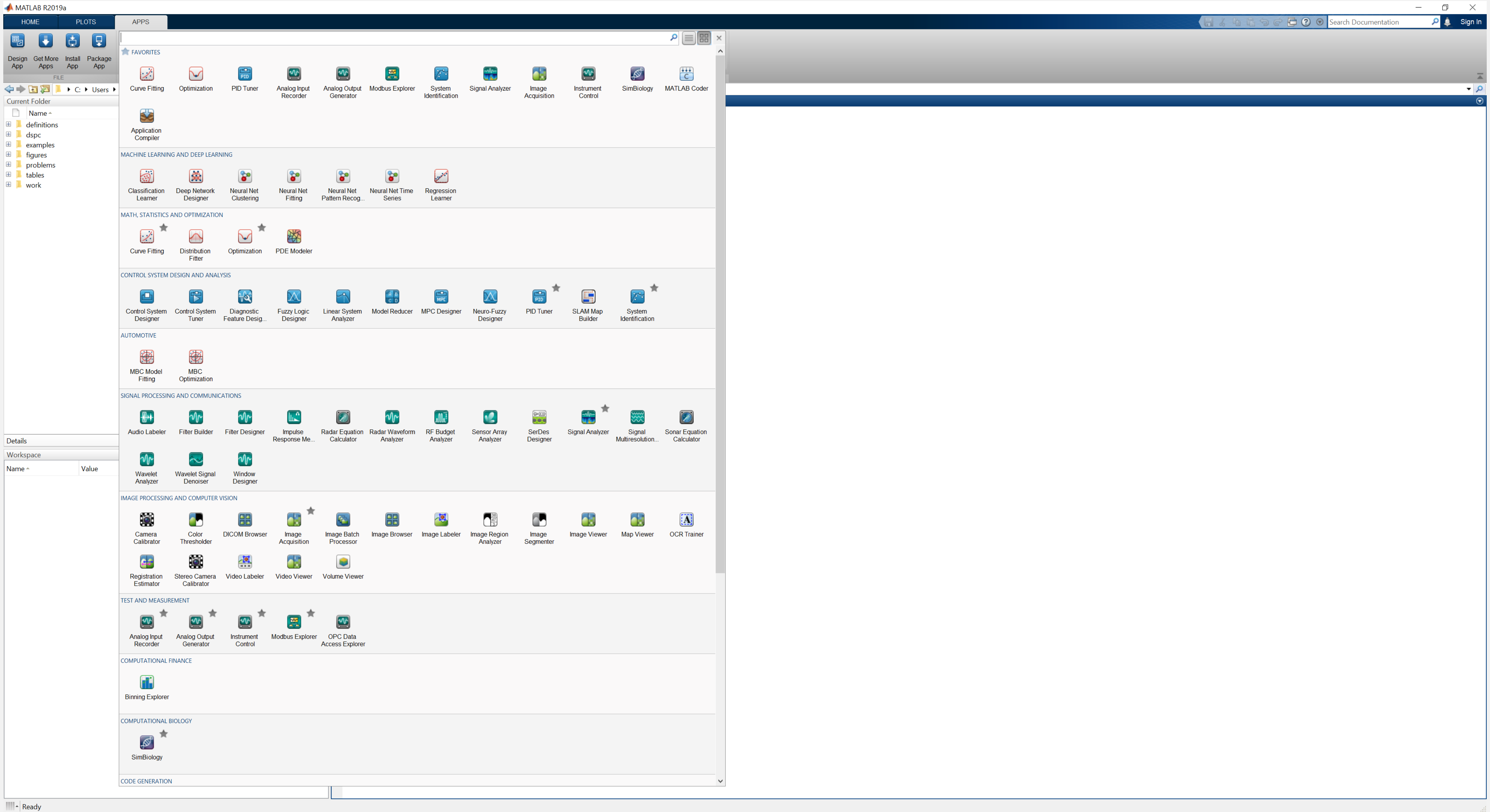
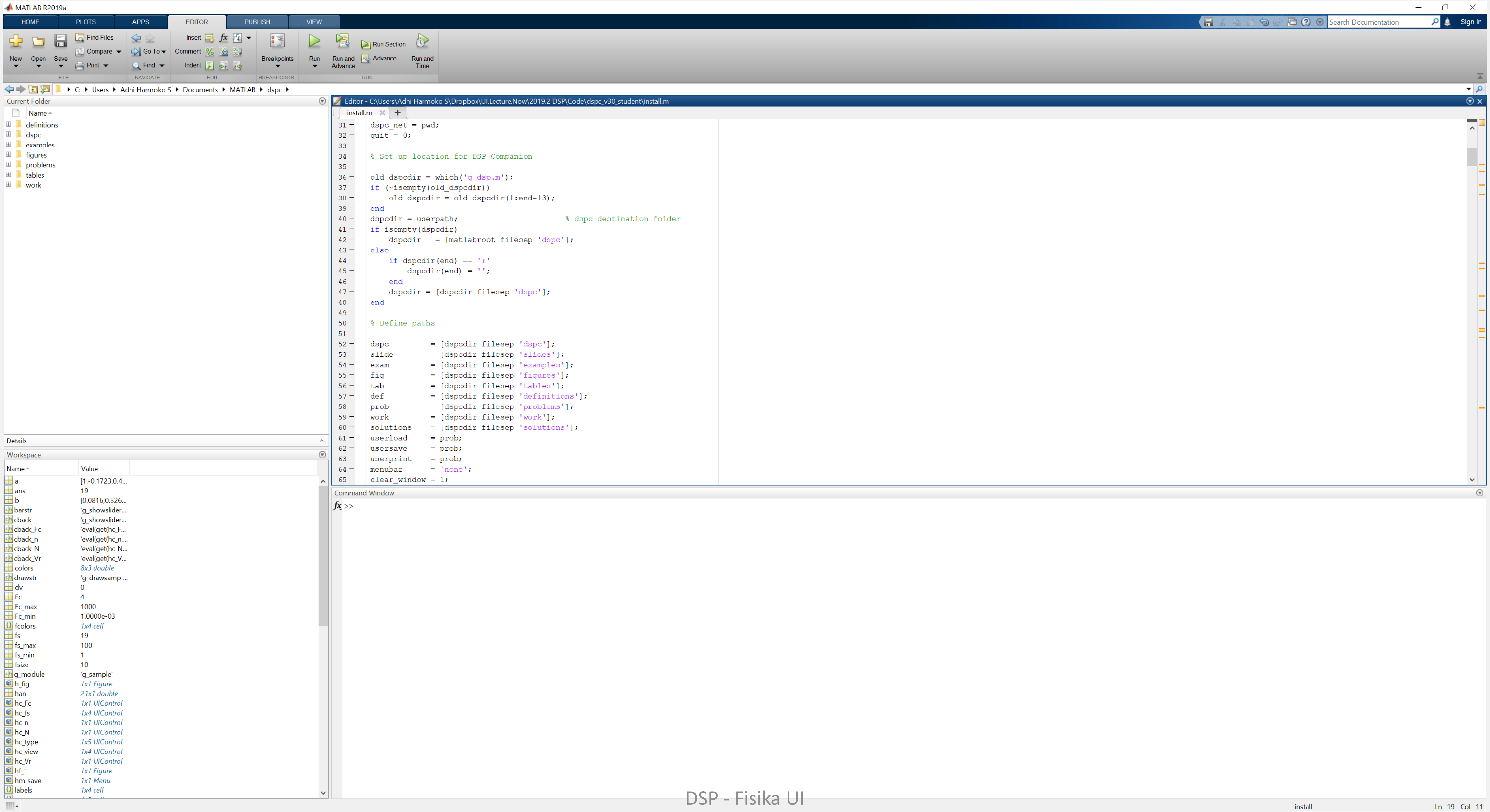
NAVIGATING THE MATLAB DESKTOP



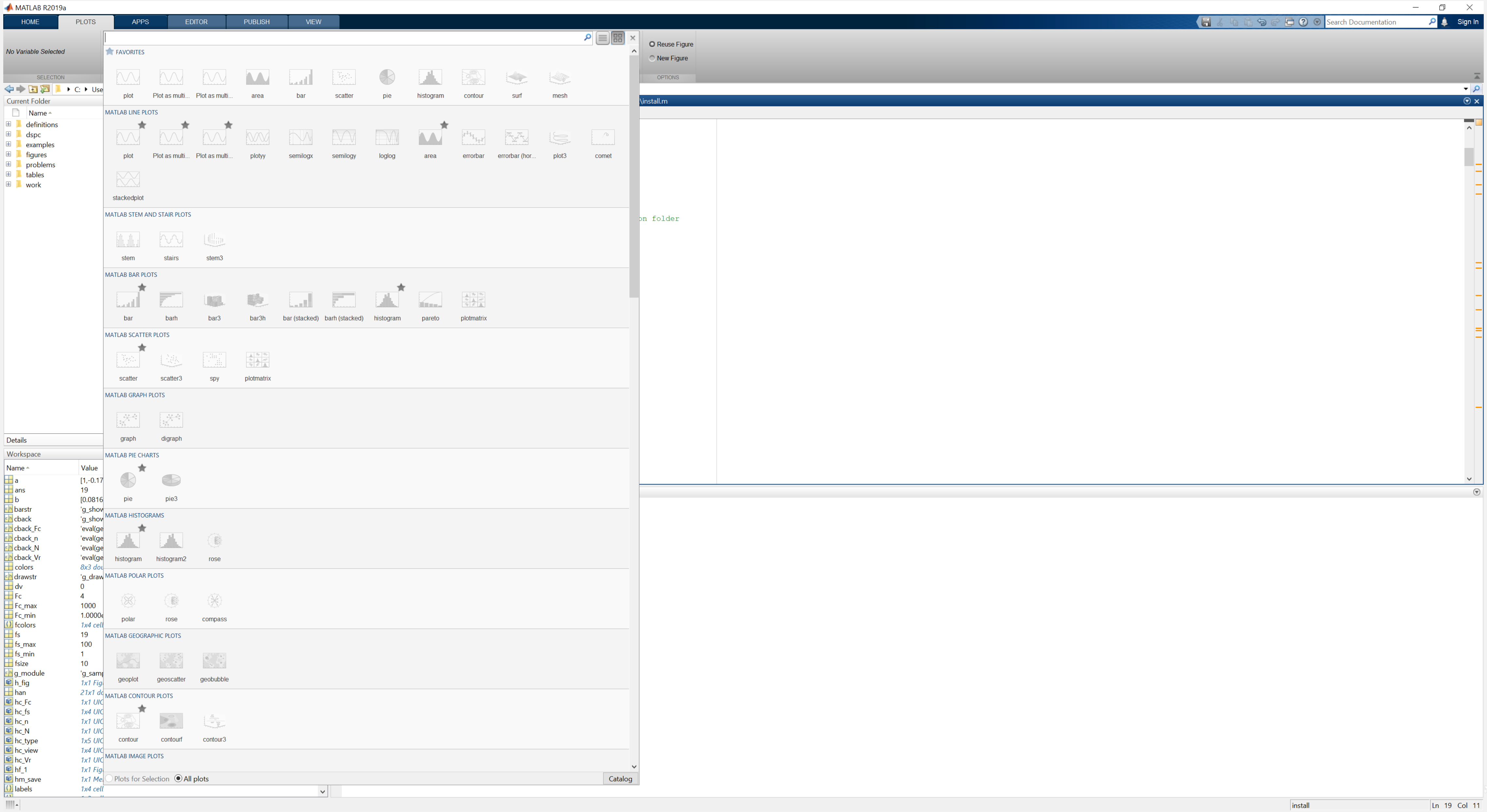
COMMONLY USED TOOLBOXES



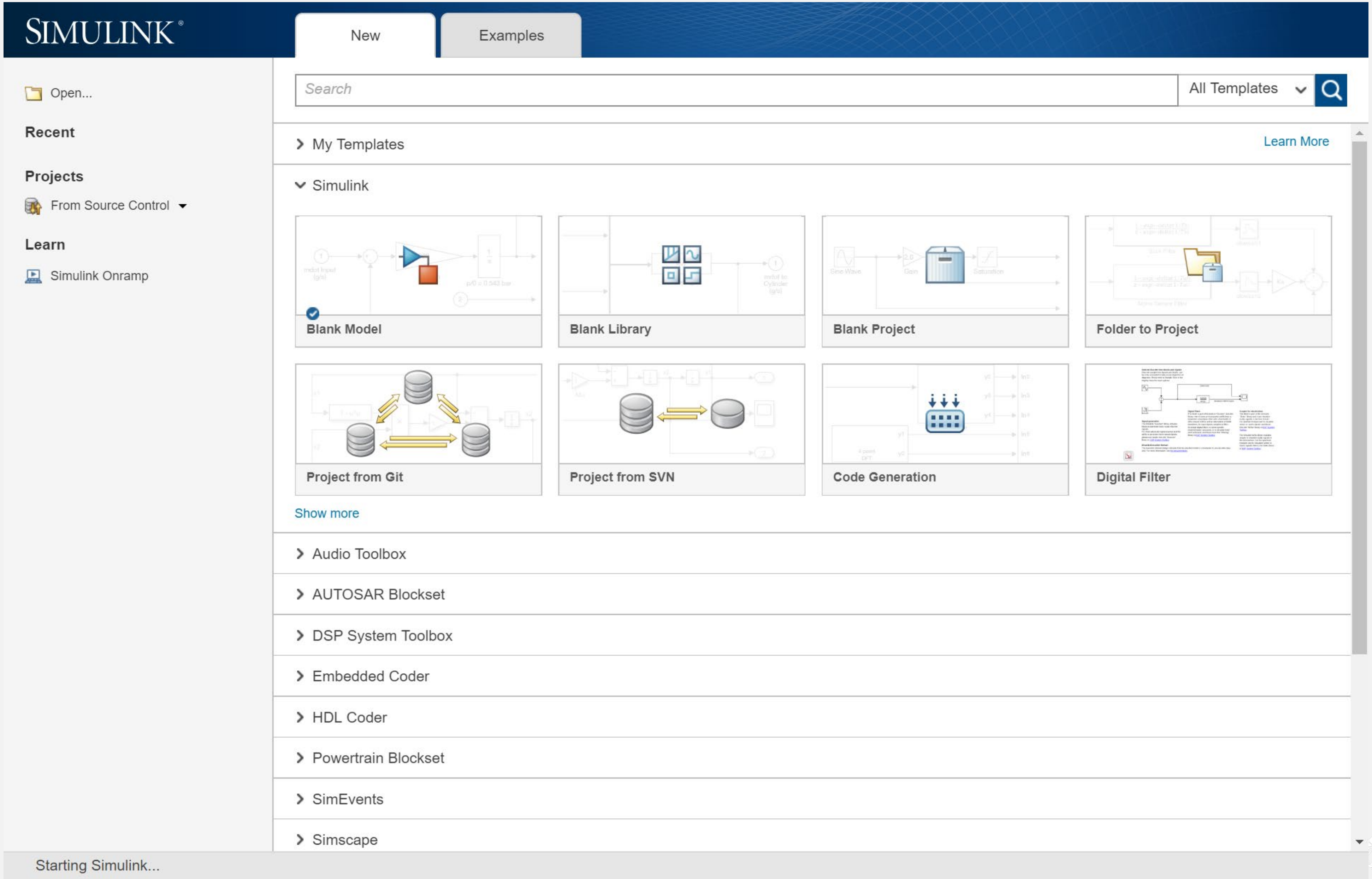
EDITOR NAVIGATION



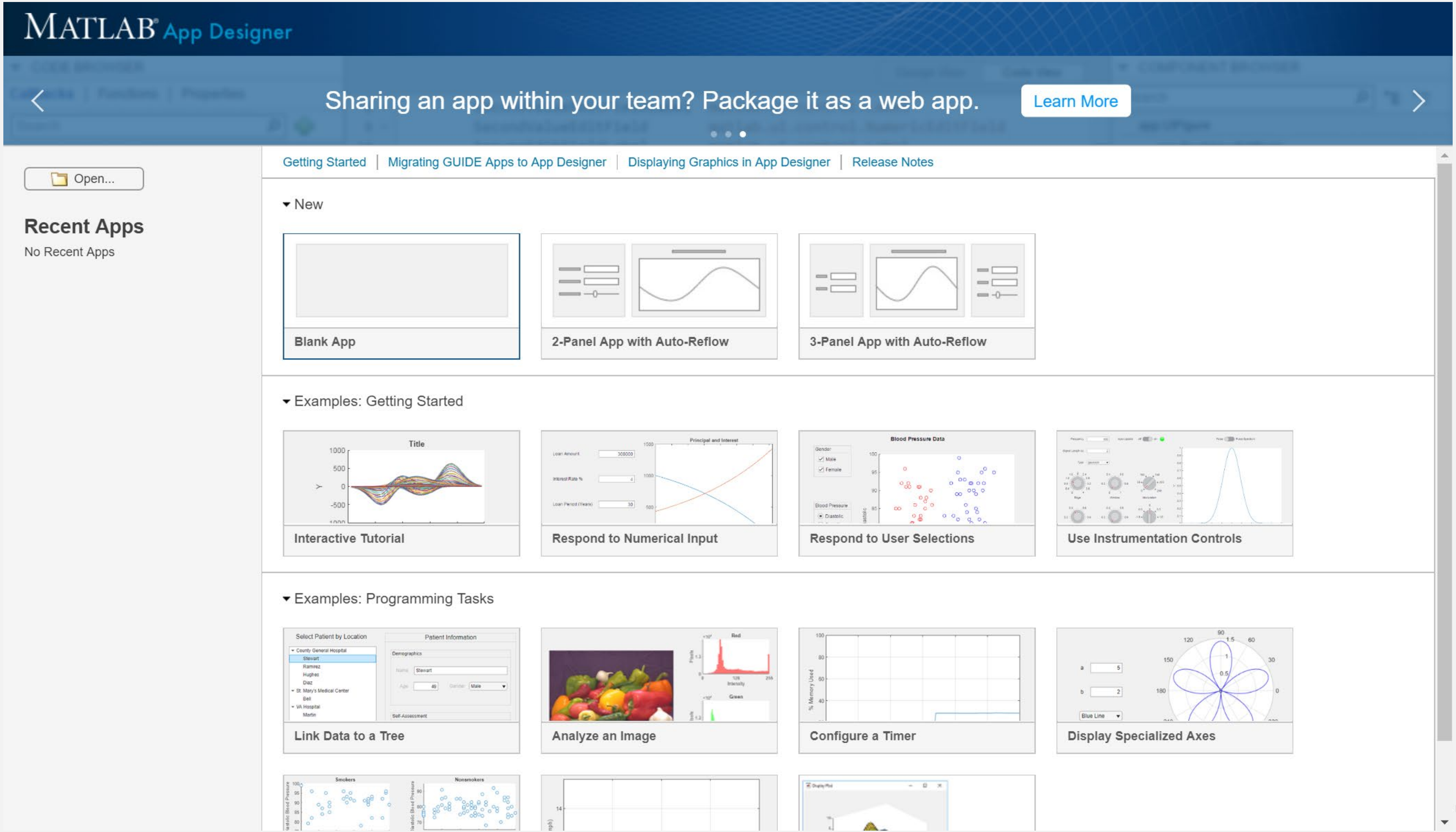
PLOTTING NAVIGATION



SIMULINK NAVIGATION



APPLICATION DESIGNER



MATLAB OPERATION

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NUMBERS

- MATLAB is a high-precision numerical engine and can handle all types of numbers, that is, integers, real numbers, complex numbers, among others, with relative ease.
- For example, the real number 1.23 is represented as simply 1.23 while the real number 4.56×10^7 can be written as 4.56e7.
- The imaginary number $\sqrt{-1}$ is denoted either by 1i or 1j, although in this book we will use the symbol 1j.
- Hence the complex number whose real part is 5 and whose imaginary part is 3 will be written as 5+1j*3.
- Other constants preassigned by MATLAB are pi for π, inf for ∞, and NaN for not a number (for example, 0/0).
- These preassigned constants are very important and, to avoid confusion, should not be redefined by users.

VARIABLES

- The basic variable is a matrix, or an array.
- MATLAB now supports multidimensional arrays
  - **Matrix:** A matrix is a two-dimensional set of numbers arranged in rows and columns. Numbers can be real- or complex-valued.
  - **Array:** This is another name for matrix. However, operations on arrays are treated differently from those on matrices. This difference is very important in implementation.

WORKING WITH MATRICES

- Matlab works with essentially only one kind of object, a rectangular numerical matrix
- A matrix is a collection of numerical values that are organized into a specific configuration of rows and columns.
- The number of rows and columns can be any number

Example

- 3 rows and 4 columns define a 3 x 4 matrix having 12 elements

WORKING WITH MATRICES

- **Scalar:** This is a 1×1 matrix or a single number that is denoted by the *variable* symbol, that is, lowercase italic typeface like

$$a = a_{11}$$

WORKING WITH MATRICES

- **Column vector:** This is an (N × 1) matrix or a vertical arrangement of numbers.
- It is denoted by the *vector* symbol, that is, lowercase bold typeface like

$$\mathbf{x} = \left[x_{i1} \right]_{i:1,\ldots,\mathrm{N}} = \begin{bmatrix} x_{11} \\ x_{21} \\ \vdots \\ x_{N1} \end{bmatrix}$$

- A typical vector in linear algebra is denoted by the column vector

WORKING WITH MATRICES

- **Row vector:** This is a (1×*M*) matrix or a horizontal arrangement of numbers.
- It is also denoted by the vector symbol, that is,

$$\mathbf{y} = \left[y_{1j} \right]_{\mathrm{j}=1,\ldots,M} = \begin{bmatrix} y_{11} & y_{12} & \cdots & y_{1M} \end{bmatrix}$$

- A one-dimensional discrete-time signal is typically represented by an array as a row vector.

WORKING WITH MATRICES

- **General matrix:** This is the most general case of an ($N \times M$) matrix and is denoted by the matrix symbol, that is, uppercase bold typeface like

$$\mathbf{A} = \left[a_{ij} \right]_{i=1,\ldots,\mathrm{N};\, \mathrm{j}=1,\ldots,\mathrm{M}} = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1M} \\ a_{21} & a_{22} & \cdots & a_{2M} \\ \vdots & \vdots & \ddots & \vdots \\ a_{N1} & a_{N2} & \cdots & a_{NM} \end{bmatrix}$$

- This arrangement is typically used for two-dimensional discrete-time signals or images

WORKING WITH MATRICES - EXAMPLE

```
c = 5.66                       %c is a scalar or a 1 x 1 matrix
x = [ 3.5, 33.22, 24.5 ]       %x is a row vector or a 1 x 3 matrix
x1 = [2
       5
      3
      -1]                      %x1 is column vector or a 4 x 1 matrix
A = [ 1  2  4
      2 -2  2
      0  3  5
      5  4  9 ]                %A is a 4 x 3 matrix
```

WORKING WITH MATRICES - EXAMPLE

Command Window

```
>> c = 5.66                    %c is a scalar or a 1 x 1 matrix
x = [ 3.5, 33.22, 24.5 ]       %x is a row vector or a 1 x 3 matrix
x1 = [2
     5
      3
      -1]                  %x1 is column vector or a 4 x 1 matrix
A = [ 1  2  4
      2 -2  2
      0  3  5
      5  4  9 ]                %A is a 4 x 3 matrix

c =
    5.6600
x =
    3.5000   33.2200   24.5000
x1 =
     2
     5
     3
    -1
A =
     1     2     4
     2    -2     2
     0     3     5
     5     4     9
fx >>
```

Workspace

Name	Value
A	*4x3 double*
c	5.6600
x	[3.5000,33.22...
x1	[2;5;3;-1]

A

PLOTS | VARIABLE | VIEW

New from Selection | Open | Print | Rows 1 | Columns 1 | Insert | Delete | Transpose | Sort

VARIABLE | SELECTION | EDIT

4x3 double

	1	2	3	4	5	6
1	1	2	4			
2	2	-2	2			
3	0	3	5			
4	5	4	9			
5						
6						
7						

WORKING WITH MATRICES

- Spaces, commas, and semicolons are used to separate elements of a matrix

- Spaces or commas separate elements of a row
  [1 2 3 4] or [1,2,3,4]

- Semicolons separate columns
  [1,2,3,4;5,6,7,8;9,8,7,6] = [1 2 3 4
  5 6 7 8
  9 8 7 6]

OPERATORS

- MATLAB provides several arithmetic and logical operators, some of which follow.

= assignment	== equality
+ addition	- subtraction or minus
* multiplication	.* array multiplication
^ power	.^ array power
/ division	./ array division
<> relational operators	& logical AND
| logical OR	~ logical NOT
’ transpose	.’ array transpose

IMPORTANT OPERATIONS ON MATRICES

- **Matrix addition and subtraction:** These are straightforward operations that are also used for array addition and subtraction. Care must be taken that the two matrix operands be *exactly* the same size.

- **Matrix conjugation:** This operation is meaningful only for complex valued matrices. It produces a matrix in which all imaginary parts are negated. It is denoted by $\mathbf{A}*$ in analysis and by conj(A) in MATLAB.

IMPORTANT OPERATIONS ON MATRICES

- **Matrix transposition:** This is an operation in which every row (column) is turned into column (row). Let **X** be an (*N* × *M*) matrix. Then

$$\mathbf{X}' = \left[x_{ij} \right]; \quad j = 1, \ldots, M, \quad i = 1, \ldots, N$$

- is an (*M* × *N*) matrix

IMPORTANT OPERATIONS ON MATRICES

- **Multiplication by a scalar:** This is a simple straightforward operation in which each element of a matrix is scaled by a constant, that is

$$ab \Rightarrow a * b \quad (\text{scalar})$$

$$a\mathrm{x} \Rightarrow a * \mathrm{x} \quad (\text{vector or array})$$

$$a\mathbf{X} \Rightarrow a * \mathrm{X} \quad (\text{matrix})$$

- This operation is also valid for an array scaling by a constant

IMPORTANT OPERATIONS ON MATRICES

- **Vector-vector multiplication:** In this operation, one has to be careful about matrix dimensions to avoid invalid results.
- The operation produces either a scalar or a matrix. Let **x** be an (N × 1) and **y** be a (1 × M) vectors.
- Then

$$x * y = xy \begin{bmatrix} x_1 \\ \vdots \\ x_N \end{bmatrix} \begin{bmatrix} y_1 & \cdots & y_M \end{bmatrix} = \begin{bmatrix} x_1 y_1 & \cdots & x_1 y_M \\ \vdots & \ddots & \vdots \\ x_N y_1 & \cdots & x_N y_M \end{bmatrix}$$

- produces a matrix.

IMPORTANT OPERATIONS ON MATRICES

- **Matrix-vector multiplication:** If the matrix and the vector are compatible (i.e., the number of matrix-columns is equal to the vector-rows), then this operation produces a column vector:

$$y = A * x \Rightarrow \mathbf{y} = \mathbf{A}\mathbf{x} = \begin{bmatrix} a_{11} & \cdots & a_{1M} \\ \vdots & \ddots & \vdots \\ a_{N1} & \cdots & a_{NM} \end{bmatrix} \begin{bmatrix} x_1 \\ \vdots \\ x_M \end{bmatrix} = \begin{bmatrix} y_1 \\ \vdots \\ y_N \end{bmatrix}$$

IMPORTANT OPERATIONS ON MATRICES

- **Matrix-matrix multiplication:** Finally, if two matrices are compatible, then their product is well-defined.
- The result is also a matrix with the number of rows equal to that of the first matrix and the number of columns equal to that of the second matrix.
- Note that the order in matrix multiplication is very important.

ARRAY OPERATIONS

- These operations treat matrices as arrays.
- They are also known as *dot operations* because the arithmetic operators are prefixed by a dot (.), that is, .*, ./, or .^.

ARRAY OPERATIONS

- **Array multiplication:** This is an element by element multiplication operation.
- For it to be a valid operation, both arrays must be the same size. Thus we have

$$x.*\,y \rightarrow \text{1D array}$$
$$\text{X.*Y} \rightarrow \text{2D array}$$

ARRAY OPERATIONS

- **Array exponentiation:** In this operation, a scalar (real- or complexvalued) is raised to the power equal to every element in an array, that is,

$$a.\hat{}\, x \equiv \begin{bmatrix} a^{x_1} \\ a^{x_2} \\ \vdots \\ a^{x_N} \end{bmatrix}$$

ARRAY OPERATIONS

- **Array transposition:** As explained, the operation A. produces transposition of real- or complex-valued array A.

INDEXING MATRICES

- A $m \times n$ matrix is defined by the number of m rows and number of n columns
- An individual element of a matrix can be specified with the notation A(i,j) or Ai,j for the generalized element, or by A(4,1)=5 for a specific element.

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

A is a 2 x 4 matrix

```
>> A(1,2)
Ans =  2
```

- The colon operator can be used to index a range of elements

```
>> A(2,1:3)
Ans = 6 3 8
```

INDEXING MATRICES

- Specific elements of any matrix can be overwritten using the matrix index

Example:

```
A = [1 2 4 5
     6 3 8 2]

A(2,1) = 9
Ans
 A = [1 2 4 5
      9 3 8 2]
```

MATRIX SHORTCUTS

- The ones and zeros functions can be used to create any m x n matrices composed entirely of ones or zeros

Example

```
a = ones(3,2)
a = [1 1
     1 1
     1 1]
b = zeros(1,5)
b = [0 0 0 0 0]
```

CONTROL-FLOW

if-elseif-else structure

```
if condition1
      command1
elseif condition2
      command2
else
      command3
end
```

CONTROL-FLOW

for..end loop

```
for index = values
     program statements
     :
end
```

EXAMPLE

- Consider the following sum of sinusoidal functions

$$x(t) = \sin(2\pi t) + \frac{1}{3}\sin(6\pi t) + \frac{1}{5}\sin(10\pi t) = \sum_{k=1}^{3} \frac{1}{k}\sin(2\pi k t), \quad 0 \le t \le 1$$

- Using MATLAB, we want to generate samples of $x(t)$ at time instances 0:0.01:1.

EXAMPLE

- **Approach 1** Here we will consider a typical C or Fortran approach, that is, we will use two for..end loops, one each on t and k.
- This is the most inefficient approach in MATLAB, but possible.

```
t = 0:0.01:1; N = length(t); xt = zeros(1,N);
for n = 1:N
        temp = 0;
        for k = 1:3
                temp = temp + (1/k)*sin(2*pi*k*t(n));
        end
        xt(n) = temp;
end
```

EXAMPLE

- **Approach 2** In this approach, we will compute each sinusoidal component in one step as a vector, using the time vector t = 0:0.01:1 and then add all components using one for..end loop.

```
t = 0:0.01:1; xt = zeros(1,length(t));
for k = 1:3
    xt = xt + (1/k)*sin(2*pi*k*t);
end
```

SCRIPTS AND FUNCTIONS

- ***Scripts***
  - implemented using a *script* file called an m-file (with an extension .m), which is only a text file that contains each line of the file as though you typed them at the command prompt.
  - built-in editor, which also provides for context-sensitive colors and indents for making fewer mistakes and for easy reading.
  - executed by typing the name of the script at the command prompt.
  - script file must be in the current directory on in the directory of the path environment.

SCRIPTS AND FUNCTIONS

- Example:
- General form of sinusoidal function is

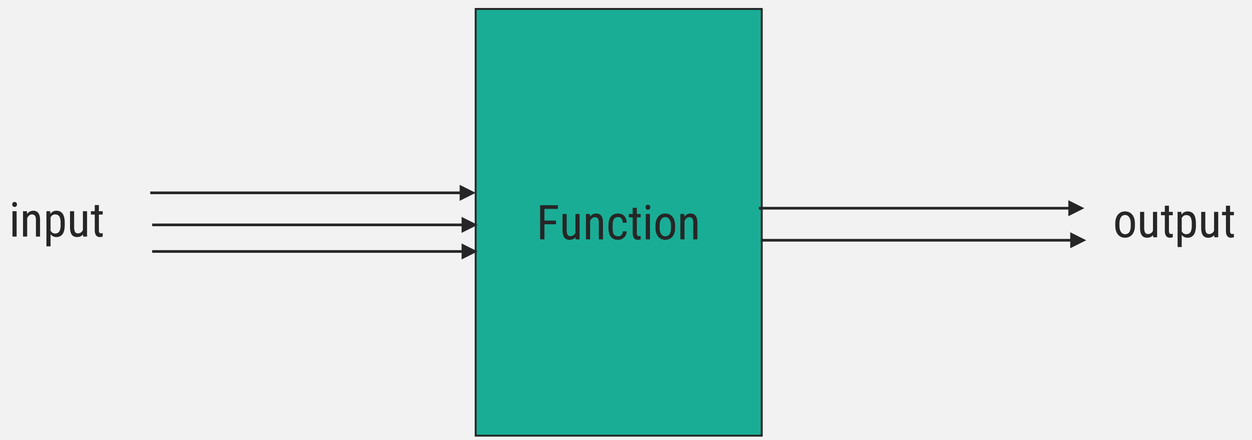
$$x(t) = \sum_{k=1}^{K} c_k \sin(2\pi kt)$$

- create a script file !

```
% Script file to implement
t = 0:0.01:1; k = 1:2:5; ck = 1./k;
xt = ck * sin(2*pi*k’*t);
```

SCRIPTS AND FUNCTIONS

- ***Functions***
  - The second construct of creating a block of code is through subroutines.
  - A major difference between script and function files is that the first executable line in a function file begins with the keyword function followed by an output-input variable declaration

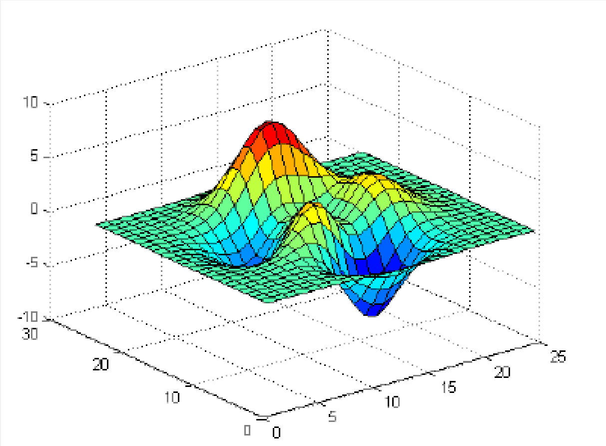


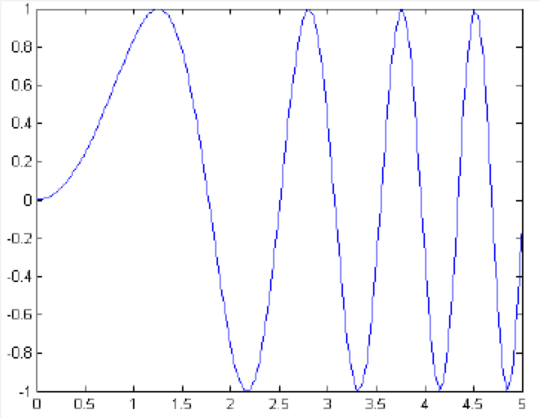
SCRIPTS AND FUNCTIONS - EXAMPLE

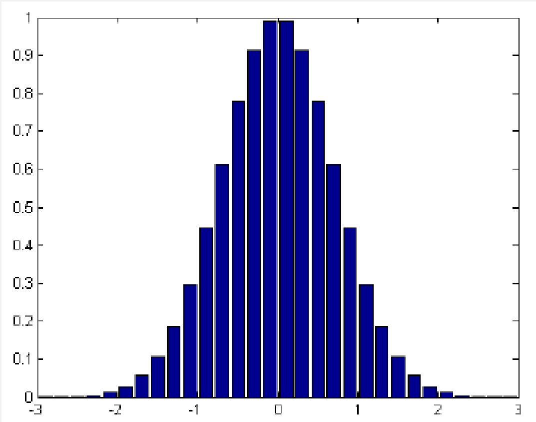
```
function xt = sinsum(t,ck)
% Computes sum of sinusoidal terms of the form in (1.1)
% x = sinsum(t,ck)
%
K = length(ck); k = 1:K;
ck = ck(:)’; t = t(:)’;
xt = ck * sin(2*pi*k’*t);
```

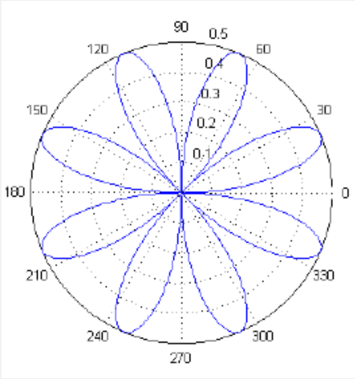
PLOTTING

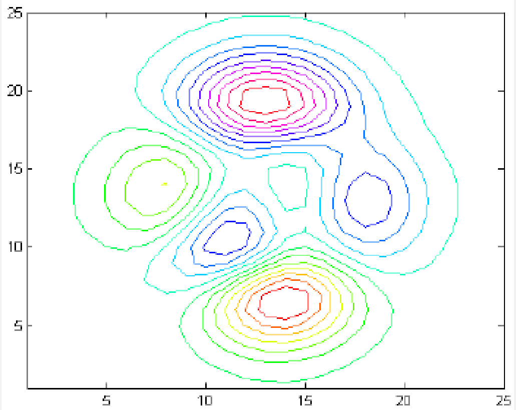
- Matlab has a powerful plotting engine that can generate a wide variety of plots.

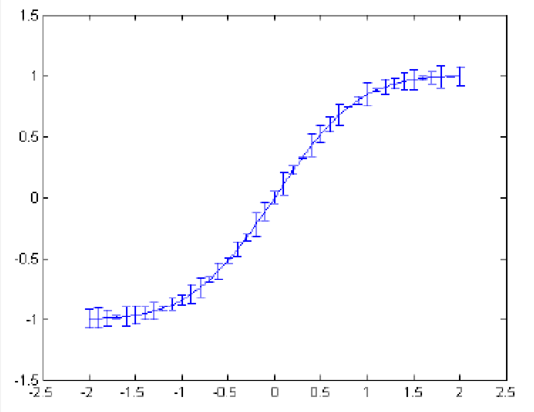












PLOTTING

- The basic plotting command is the plot(t,x) command, which generates a plot of x values versus t values in a separate figure window.
- The arrays t and x should be the same length and orientation.
- Optionally, some additional formatting keywords can also be provided in the plot function.
- The commands xlabel and ylabel are used to add text to the axis, and the command title is used to provide a title on the top of the graph.
- All aspects of a plot (style, size, color, etc.) can be changed by appropriate commands embedded in the program or directly through the GU

PLOTTING EXAMPLE

```
% Plot of a simple sinusoidal wave
% putting axis labels and title on the plot

t = 0:0.01:2; % sample points from 0 to 2 in steps of 0.01
x = sin(2*pi*t); % Evaluate sin(2 pi t)
plot(t,x,’b’); % Create plot with blue line
xlabel(’t in sec’); ylabel(‘x(t)’); % Label axis
title(’Plot of sin(2\pi t)’); % Title plot
```

PLOTTING EXAMPLE

- MATLAB provides an ability to display more than one graph in the same figure window.
- By means of the hold on command, several graphs can be plotted on the same set of axes.
- The hold off command stops the simultaneous plotting

```
plot(t,xt,’b’); hold on; % Create plot with blue line
Hs = stem(n*0.05,xn,’b’,’filled’); % Stem-plot with handle Hs
set(Hs,’markersize’,4); hold off; % Change circle size
```

PLOTTING EXAMPLE

- The subplot command, which displays several graphs in each individual set of axes arranged in a grid, using the parameters in the subplot command.

```
...
subplot(2,1,1); % Two rows, one column, first plot
plot(t,x,'b'); % Create plot with blue line
...
subplot(2,1,2); % Two rows, one column, second plot
Hs = stem(n,x,'b','filled'); % Stem-plot with handle Hs
...
```

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