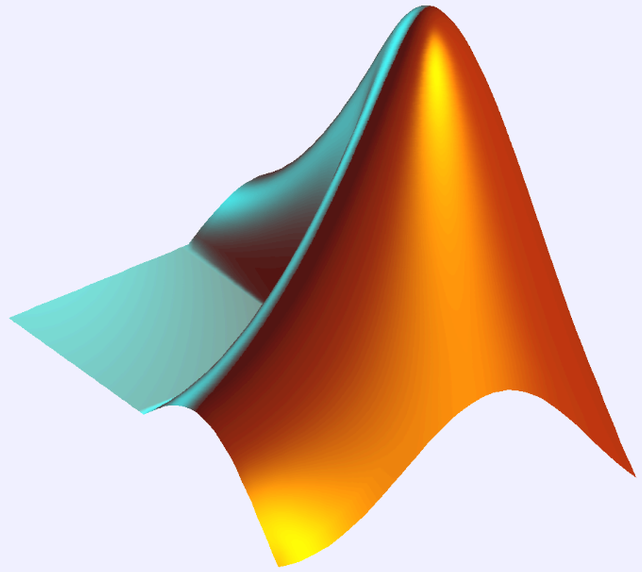

Introduction to MatLab™

Oznur Mete

(CERN)

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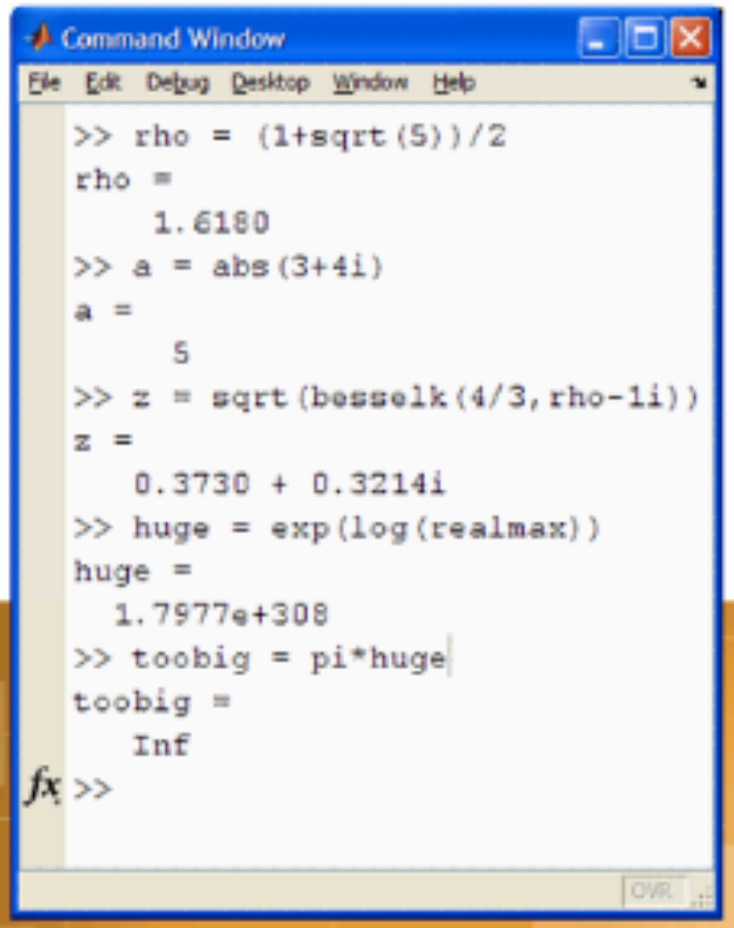
This document includes material about MatLab to be discussed in HPFBU 2012 school.
More info about the product is provided by MatWorks on http://www.mathworks.com/

MATLAB On-Ramp Tutorial

MATLAB Fundamentals

What will I learn in this section?

What is MATLAB, and how can it help me with my homework and projects?



- MatLab is a powerful graphical calculator.

Introduction to MatLab

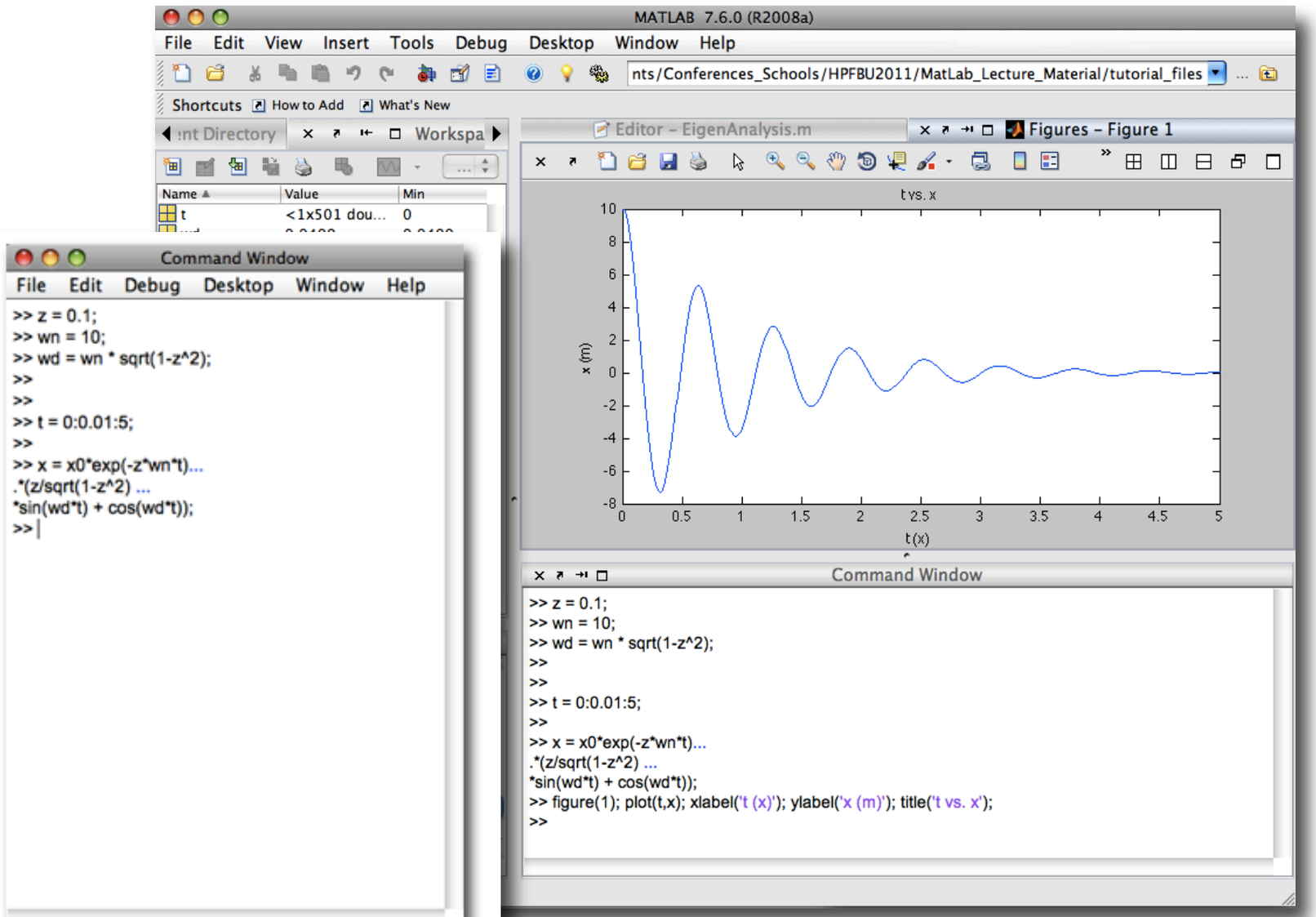
- MatLab is a powerful graphical calculator.
- Its built-in functions and libraries can be used for complicated calculations on large data sets.
- The results is visualized in the form of graphs and plots.

Given:

$$\xi = 0.1$$
$$\omega_n = 10$$
$$\omega_d = \omega_n\sqrt{1-\xi^2}$$
$$x_0 = 10$$

Plot the following function for t=0 to 5 s.

$$x(t) = x_0 e^{-\xi\omega_n t}\left(\frac{\xi}{\sqrt{(1-\xi^2)}} sin\omega_d t + cos\omega_d t\right)$$



PART 1 - Fundamentals of MATLAB

Basic Calculations in MATLAB
- MATLAB as a calculator
- Creating variables
- Locating data in MATLAB
- Inspecting contents of variables

Creating arrays
- Creating vectors
- Creating matrices

Manipulating arrays
- Indexing into arrays
- The colon (:) operator

Computing with arrays
- Matrix operations
- Eigenvalue analysis
- Array operations

Visualizing mathematical functions

Writing your function in MATLAB

PART 2 - Hands-on Practice Session

Projects

- Graphical User Interface: Building a calculator
- Under-dumped string-mass system
- Gaussian fit to a given data set (on command line and by using Fitting Toolbox)
- Quadrupole scan analysis for emittance measurement
- Fourier filtering???

PART I

FUNDAMENTALS of MATLAB

MATLAB as a calculator

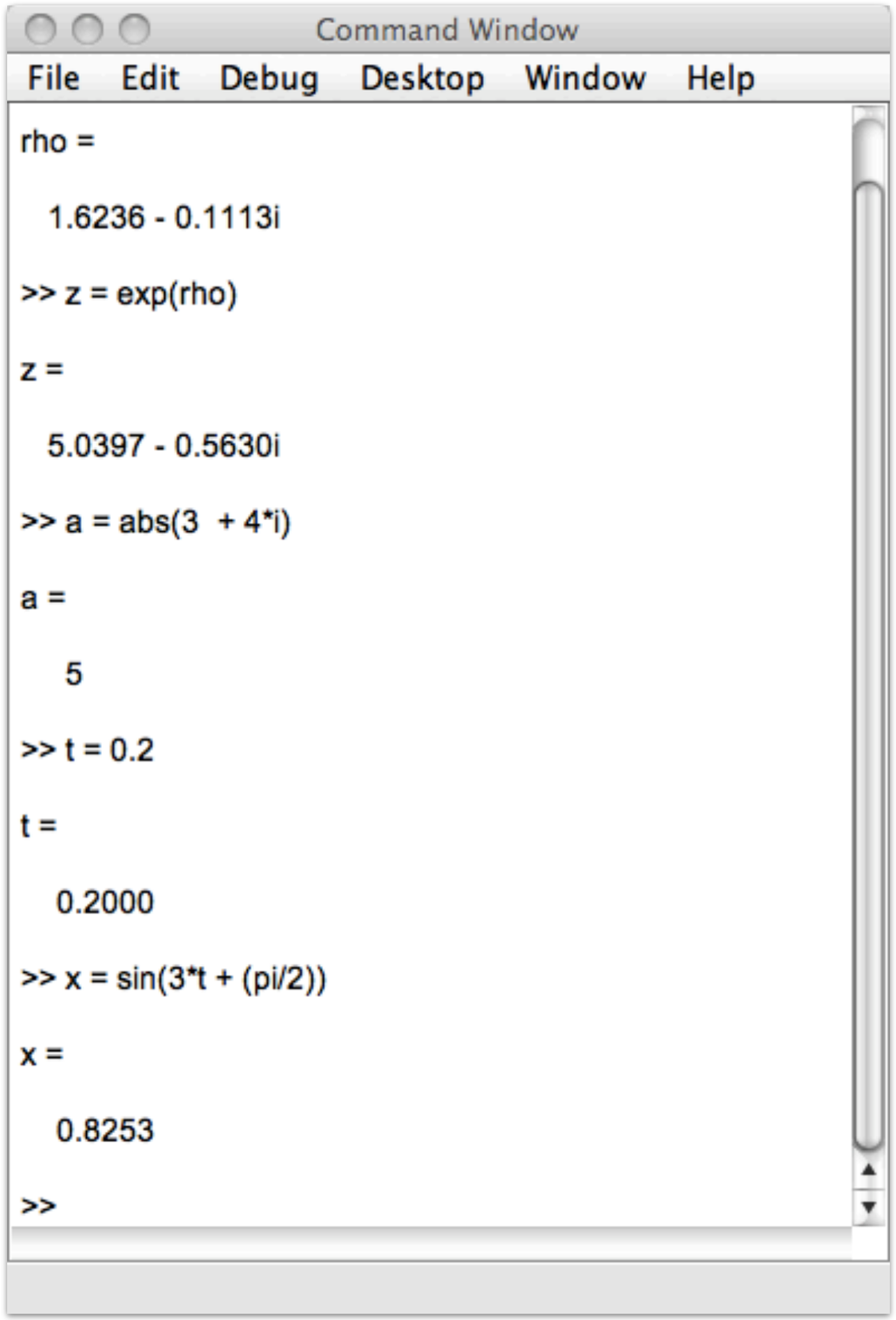
$$\rho = \frac{1 + \sqrt{(5 - i)}}{2}$$

$$z = e^{\rho}$$

$$a = |3 + 4i|$$

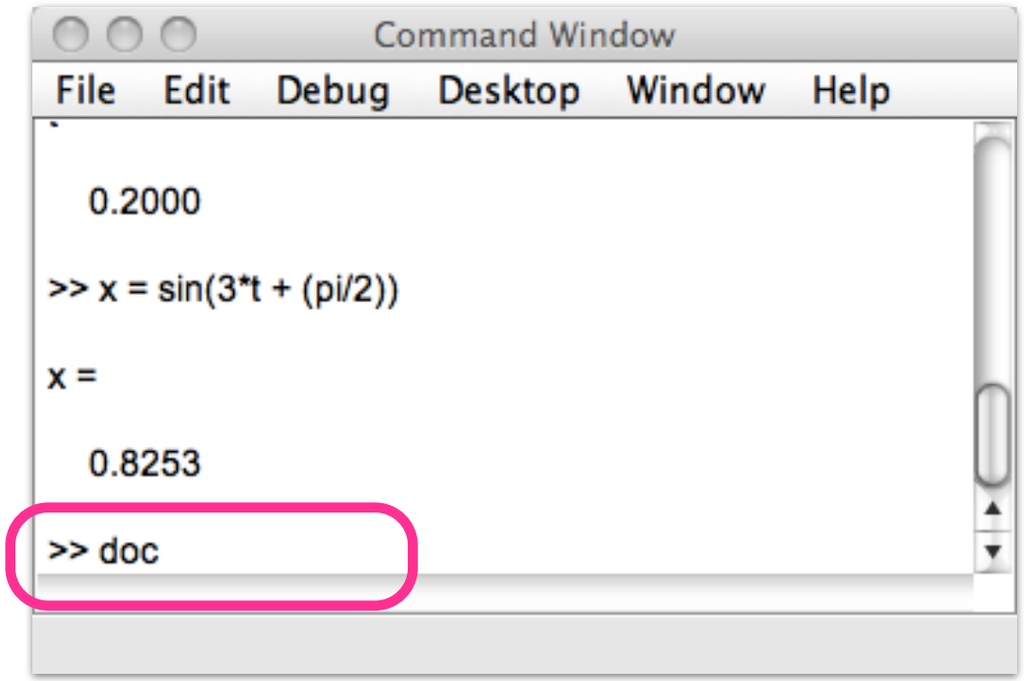
$$t = 0.2$$

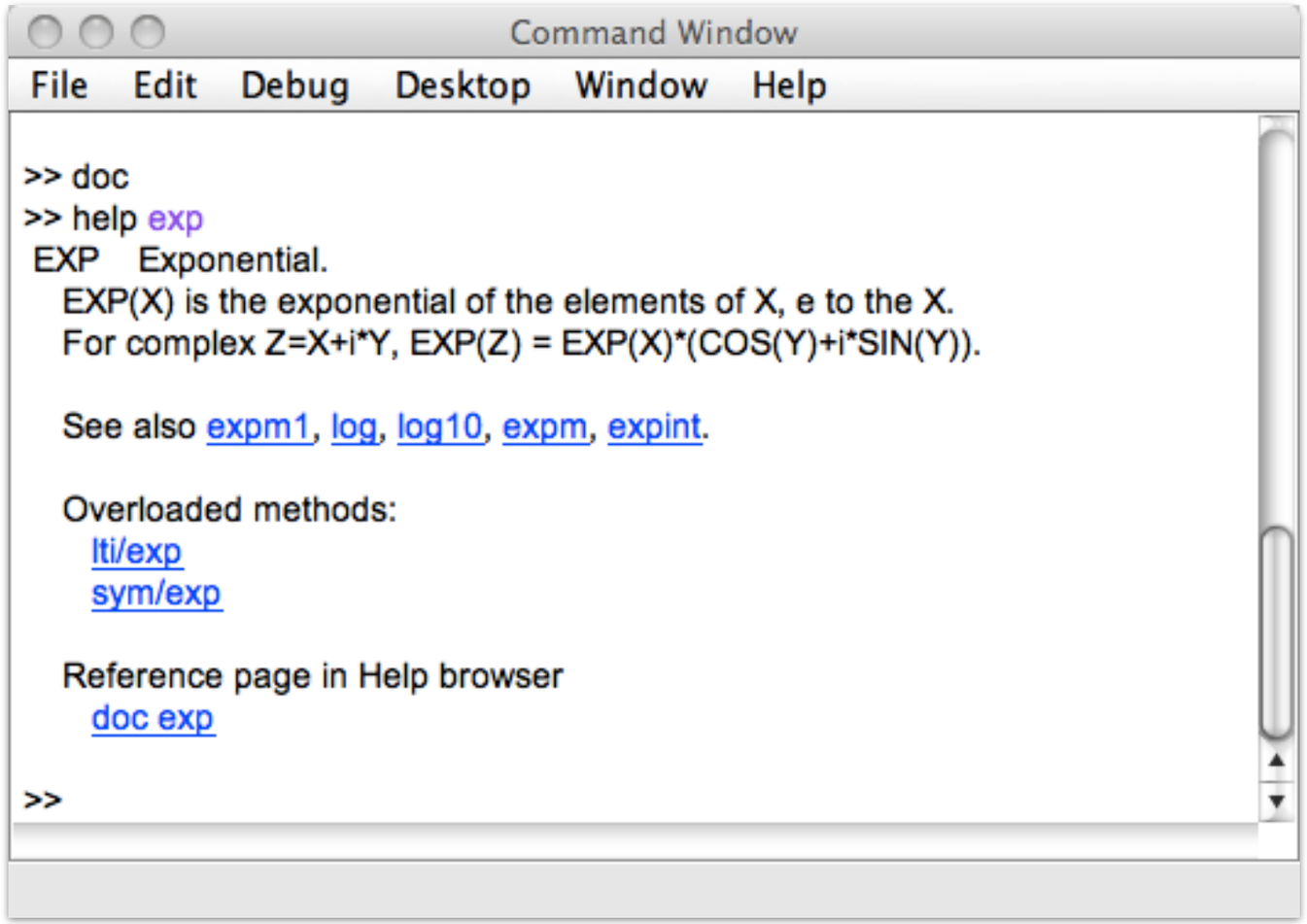
$$x = sin(3t + \frac{\pi}{2})$$



Mathematical functions

- MATLAB has many built-in functions.
- Information on MATLAB programming and the built-in functions can be found in the MATLAB documentation.





Mathematical functions

Help

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Help Navigator

Search for: Go

Example: "plot tools" OR plot* tools

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- MATLAB
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- Control System Toolbox
- Curve Fitting Toolbox
- Database Toolbox
- Embedded MATLAB
- Filter Design Toolbox
- Filter Design HDL Coder
- Fixed-Point Toolbox
- Fuzzy Logic Toolbox
- Genetic Algorithm and Direct Search Toolbox
- Image Processing Toolbox
- MATLAB Compiler
- MATLAB Report Generator
- Model Predictive Control Toolbox
- Neural Network Toolbox
- Optimization Toolbox
- Partial Differential Equation Toolbox
- RF Toolbox
- Robust Control Toolbox
- Signal Processing Toolbox
- Spline Toolbox
- Statistics Toolbox
- Symbolic Math Toolbox
- System Identification Toolbox
- SystemTest

Title: MATLAB

MATLAB®

Functions:
- By Category
- Alphabetical List

Handle Graphics:
- Object Properties

What's New

- MATLAB® Release Notes
  Summarizes new features, bug fixes, upgrade issues, etc. for MATLAB
- General Release Notes for R2008a
  For all products, highlights new features, installation notes, bug fixes, and compatibility issues

Documentation Set

- Getting Started
- User Guides
- Getting Help in MATLAB
  Provides instructions for using the Help browser and other help methods
- Examples in Documentation
  Lists major examples in the MATLAB documentation
- Programming Tips

Mathematical functions

Help

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  - MATLAB Classes and Object-Oriented Programmi
  - Graphics
  - 3-D Visualization
  - Creating Graphical User Interfaces
  - Function Reference
  - Handle Graphics Property Browser
  - External Interfaces
  - C and Fortran API Reference
  - Release Notes
  - Printable Documentation (PDF)
- Communications Toolbox

Title: MATLAB

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Mathematical functions

Command Window

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```
rho =

   1.6236 - 0.1113i

>> z = exp(rho)

z =

   5.0397 - 0.5630i

>> a = abs(3  + 4*i)

a =

     5

>> t = 0.2

t =

    0.2000

>> x = sin(3*t + (pi/2))

x =

    0.8253

>>
```

Help

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Help Navigator

Search for: functions Go

Example: "plot tools" OR plot* tools

Contents Index Search Results Demos

A B C D E F G H I J K L M
N O P Q R S T U V W X Y Z

Enter index term: exp

Name	Product
exp	MATLAB
exp in action language	Stateflow
expand [1] [2]	Symbolic Math T...
expanders	Communications...
example	
expanders	Communications...
sample code	
expanding	
character arrays	MATLAB
code in M-files [1] [2]	MATLAB
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expanding cell arrays [1] [2]	MATLAB
expanding structure arrays [1] [2]	MATLAB
expansion	
mesh	Genetic Algorith...
expcdf	Statistics Toolbox
expectation maximization (EM) [1] [2] [3]	Statistics Toolbox
expfit	Statistics Toolbox
expint	MATLAB
expinv	Statistics Toolbox
explicit ordering	
of parallel (AND) states	Stateflow
explike	Statistics Toolbox

Title: exp :: Functions (MATLAB Function Reference)

MATLAB Function Reference

Provide feedback about this page

exp

Exponential

Syntax

```
Y = exp(X)
```

Description

The exp function is an elementary function that operates element-wise on arrays. Its domain includes complex numbers.

`Y = exp(X)` returns the exponential for each element of `X`. For complex $z = x + i*y$, it returns the complex exponential $e^z = e^x(\cos(y) + i\sin(y))$.

Remark

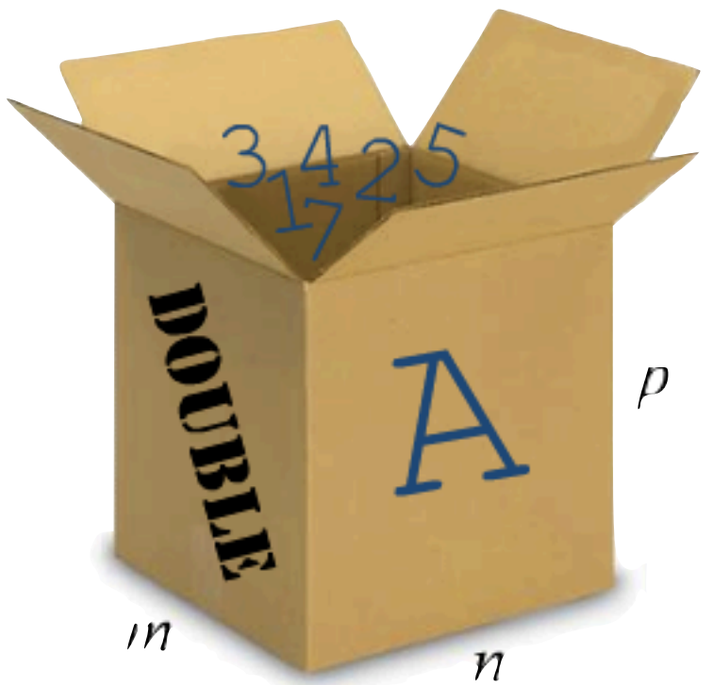
Use `expm` for matrix exponentials.

See Also

`expm`, `log`, `log10`, `expint`

Provide feedback about this page

Data Containers



- MATLAB variables are data containers
- All variables are **arrays**
- Variables come in different **sizes** mxnxp ...
- Variables come in different **types** double, single, cell, ...

Nota Bene:

- In MATLAB, fundamental data type is matrix.
- Even scalar variables are treated as 1x1 arrays.
- Different data types are available for data storage for different architectures.
- The default numerical data type is double.

Creating Variables

Assign Operator

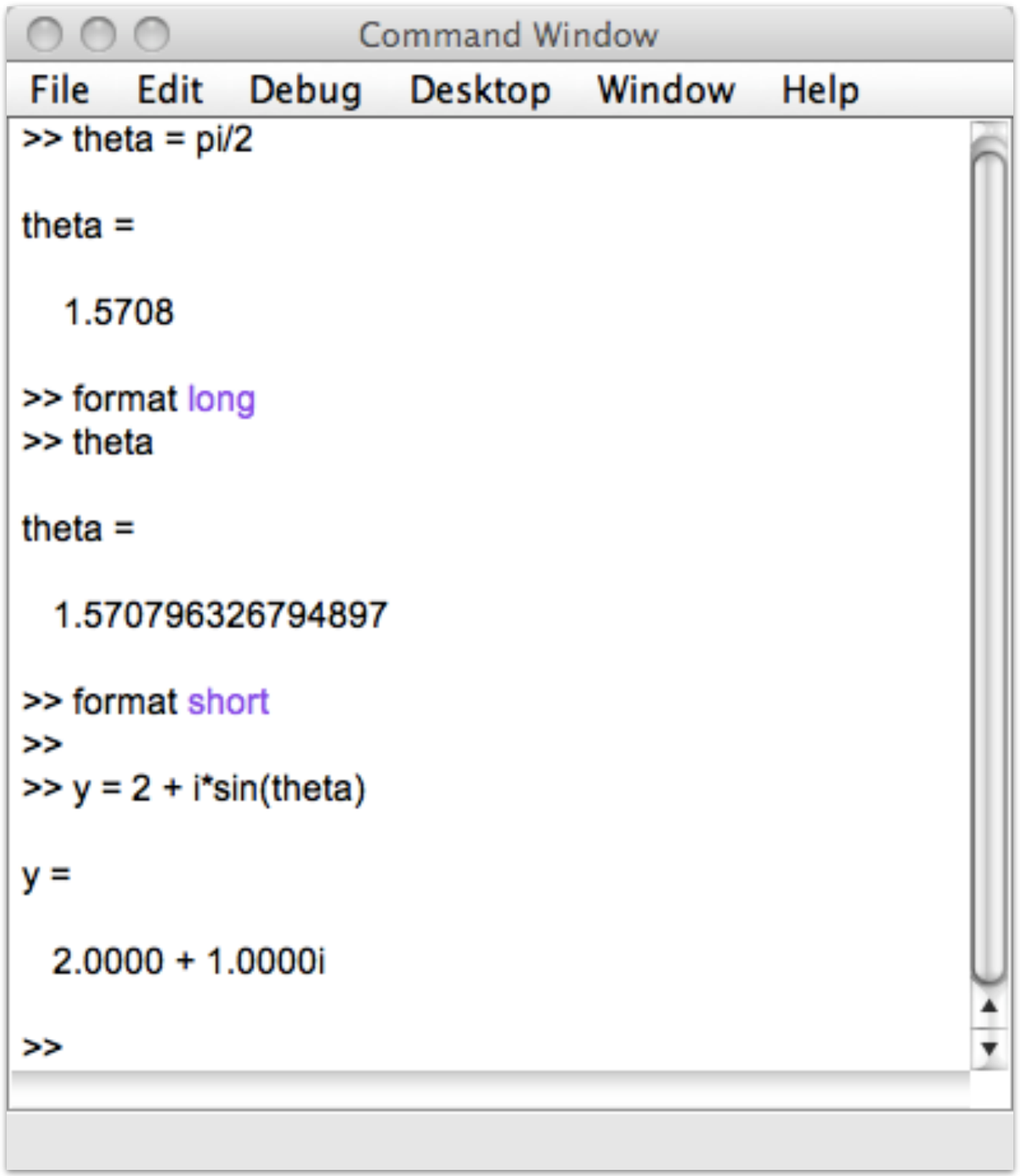
lumi_CLIC = 5.9e34

Variable Name

Value

$$\theta = \frac{\pi}{2}$$

$$y = 2 + isin(\theta)$$



Creating Variables

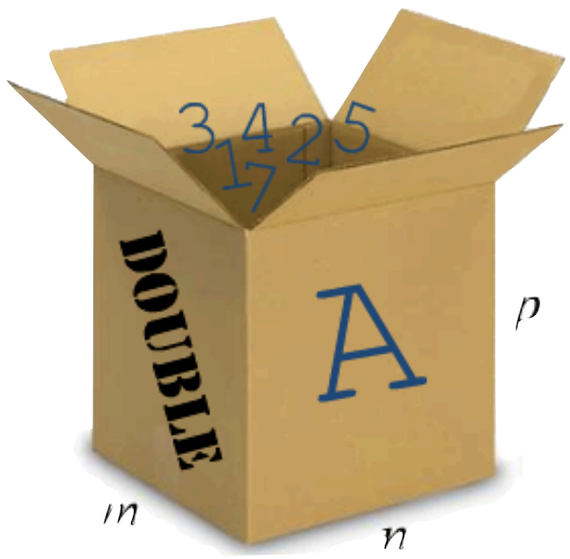
Exercise 02 - Creating variables in MATLAB

- A variable is a container for the data in MATLAB. True or false?

- ☑ True
- ☐ False

That's right!

In MATLAB, data can be placed in areas like containers, also referred to as **variables.**



Once created, the **name** of a variable is used as a **tag**, allowing access and manipulation of the data assigned to it.

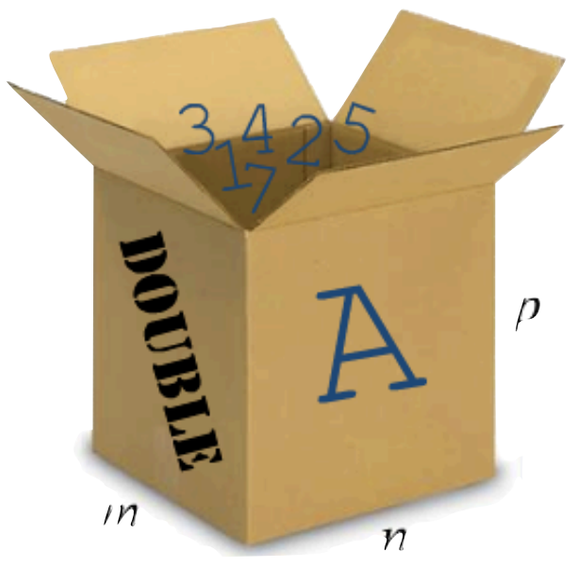
Creating Variables

Exercise 02 - Creating variables in MATLAB

- Which of the following are legitimate ways of assigning data to a variable?

Please try them in the MATLAB command line!

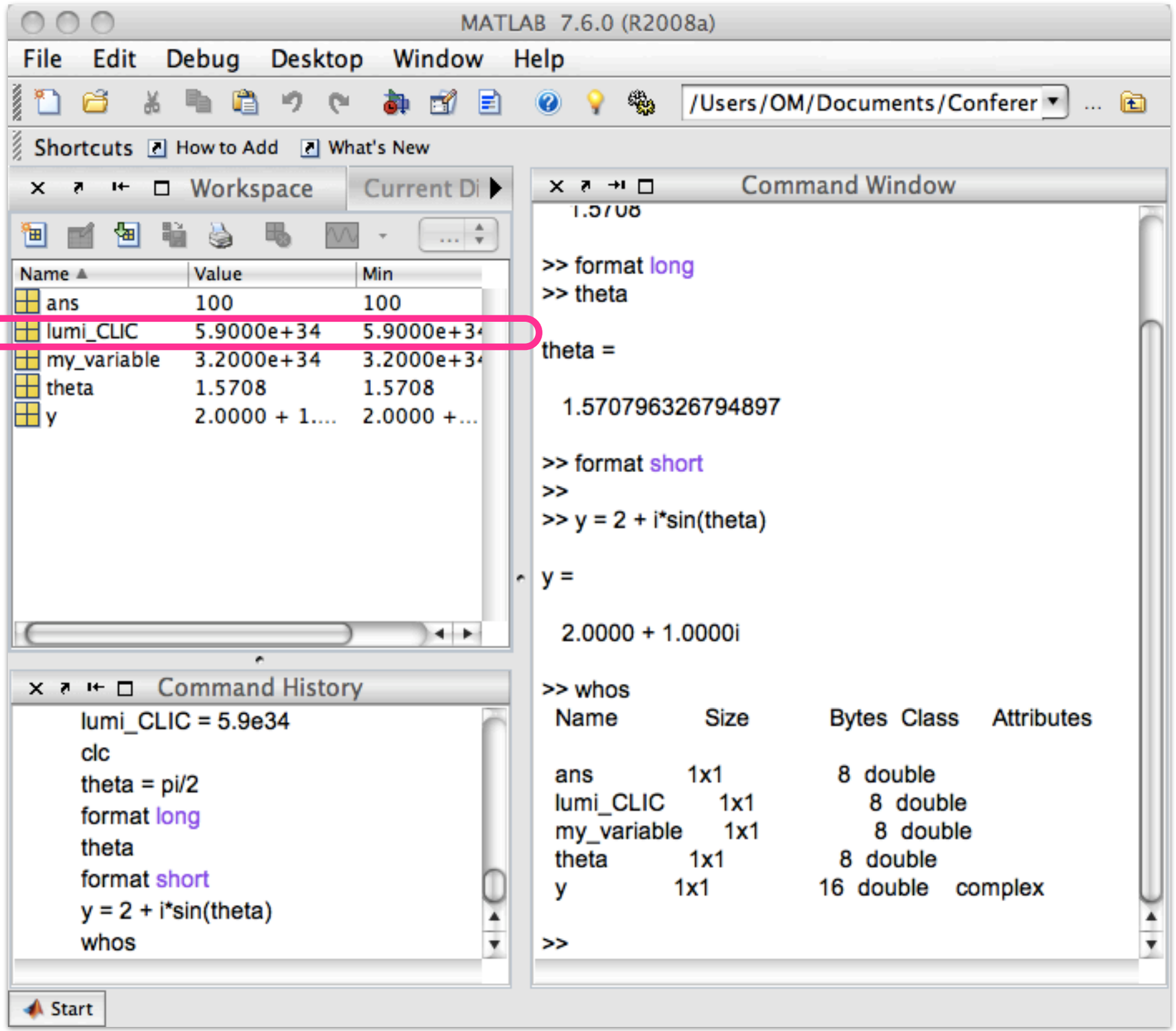
- ☐ a) a = b = 1
- ☐ b) 8*x + 2 = y
- ☑ c) temp_variable = (a + 1)/2



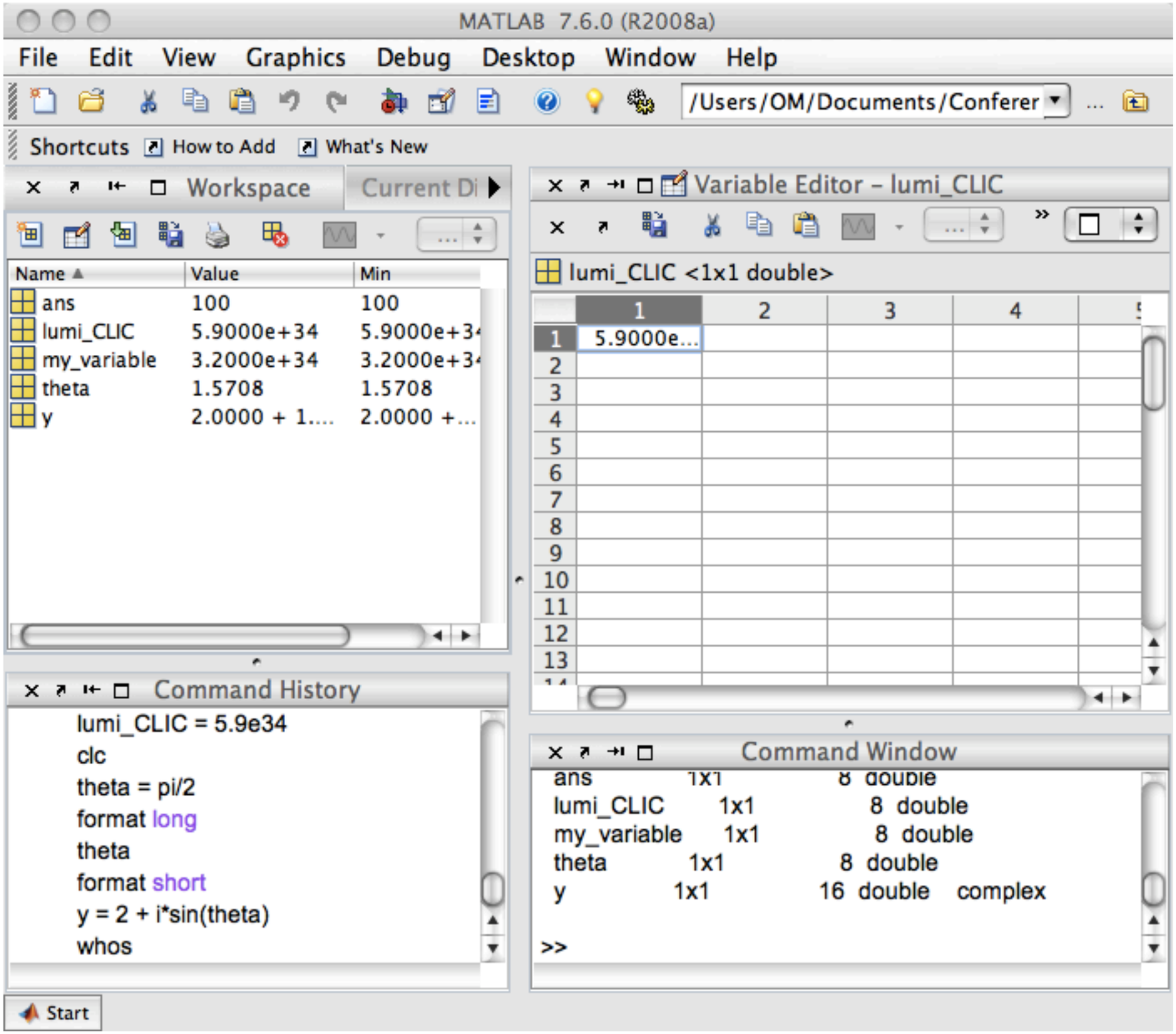
That's right!
The right-hand-side of the equals sign can be a value, another variable or the result of a calculation.
Also, multiple assignments are not allowed in a single command.

Accessing Data in MATLAB

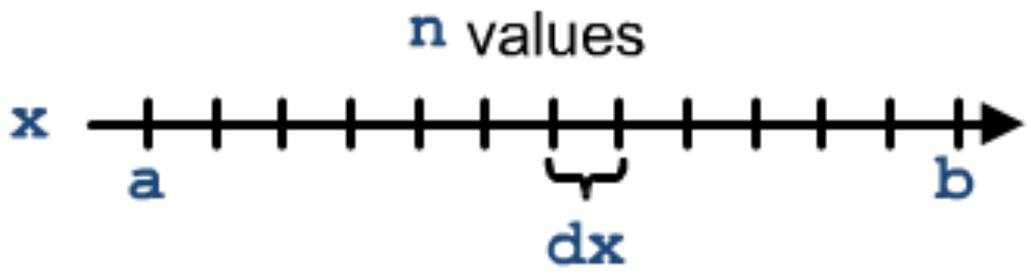
click on a variable within the workspace



Accessing Data in MATLAB



Creating Vectors

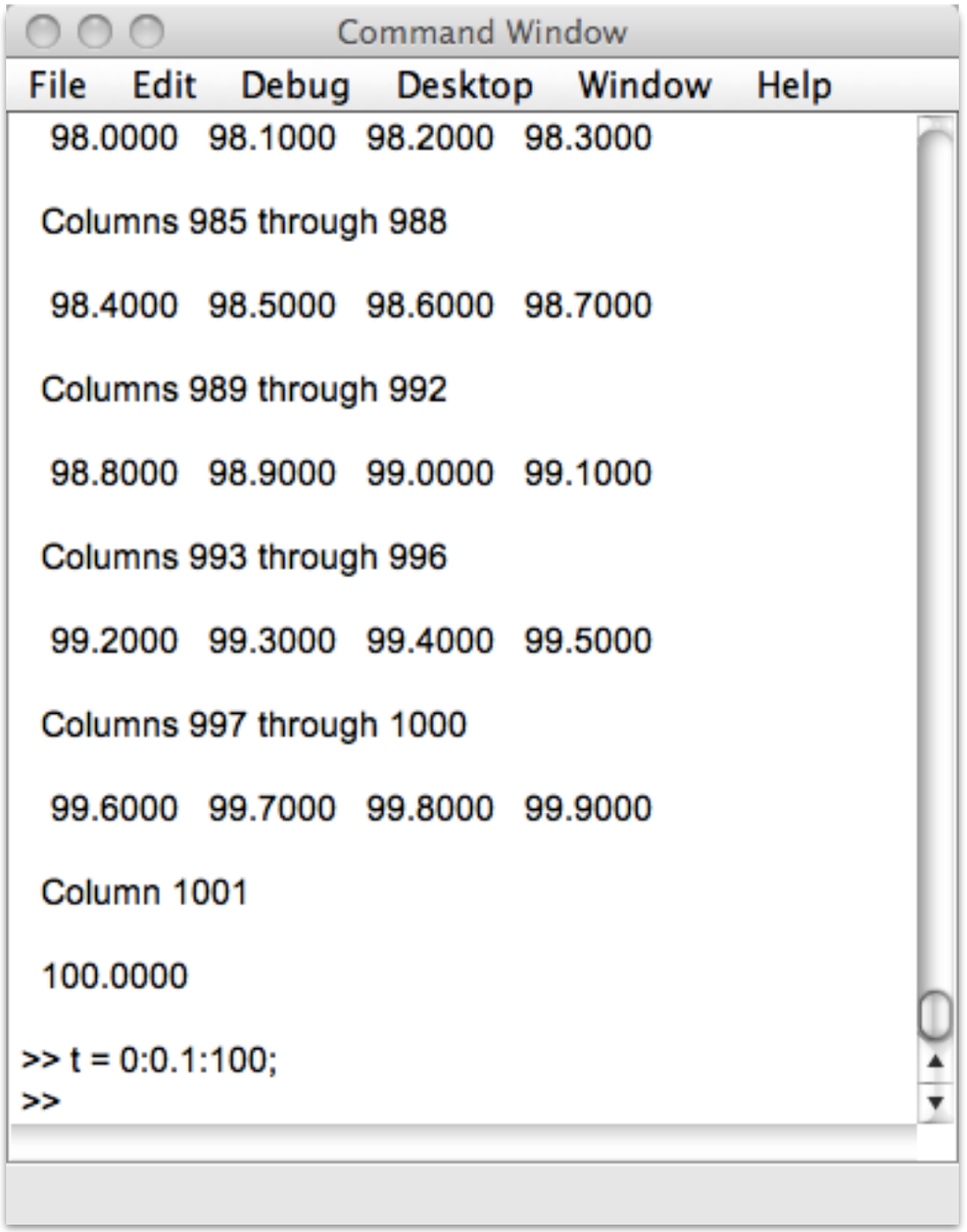



```
>> x = a:dx:b
>> x = linspace(a,b,n)
```

} row vectors

```
>> x = x'
```

← transpose to column vector



Creating Matrices

$$\begin{pmatrix} 1 & 2 & 3 \\ 4 & 5 & 6 \\ 7 & 8 & 9 \end{pmatrix}$$

```
>> A = [1,2,3; 4,5,6; 7,8,9]
```

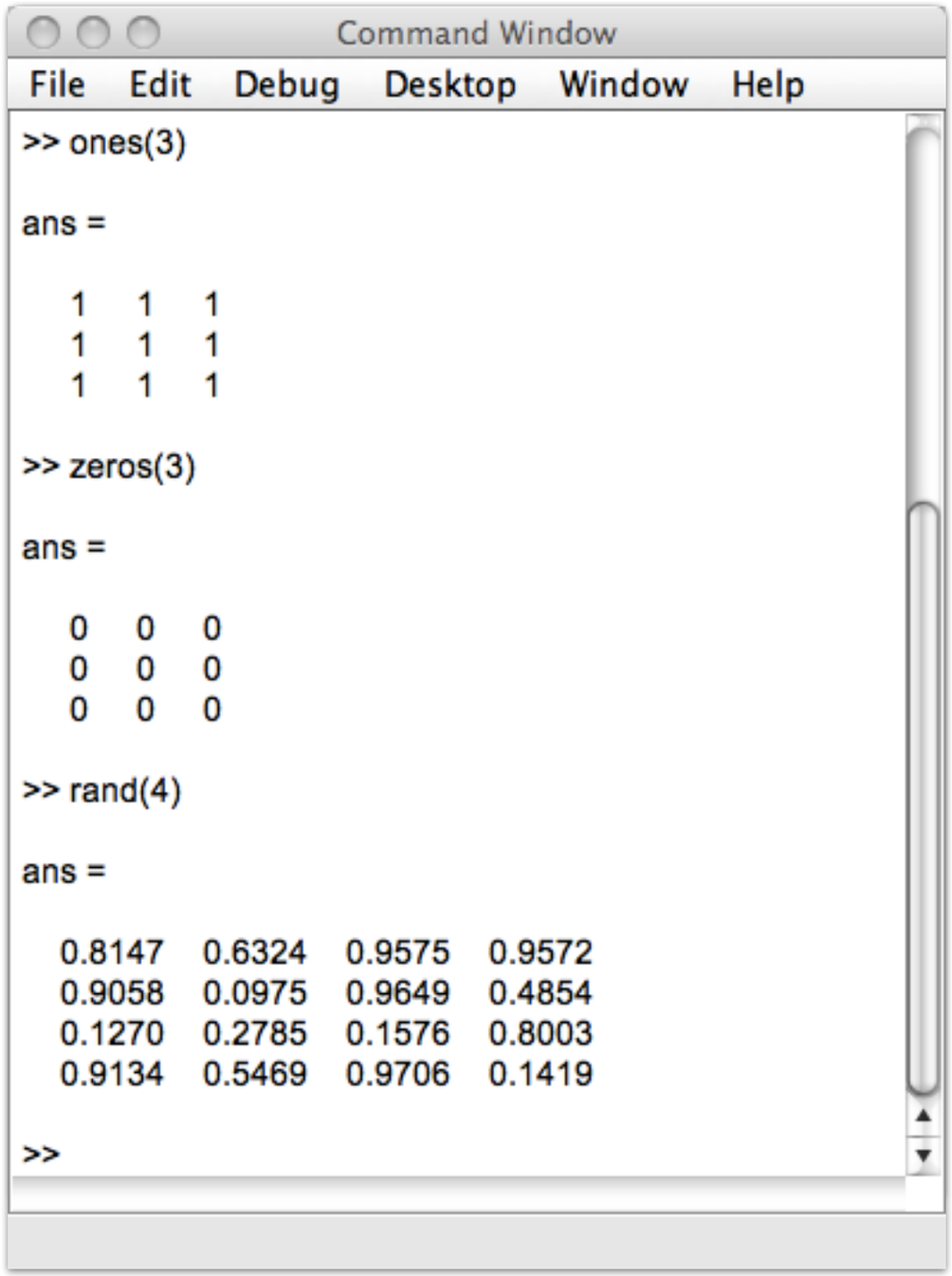
```
>> A = [1 2 3; 4 5 6; 7 8 9]
```

```
>> A = [1 2 3
        4 5 6
        7 8 9]
```

data entry mode

Column separator – , or space

Row separator – ; or enter



Creating Arrays

Exercise 03 - Creating arrays in MATLAB

- Create the array below in MATLAB:

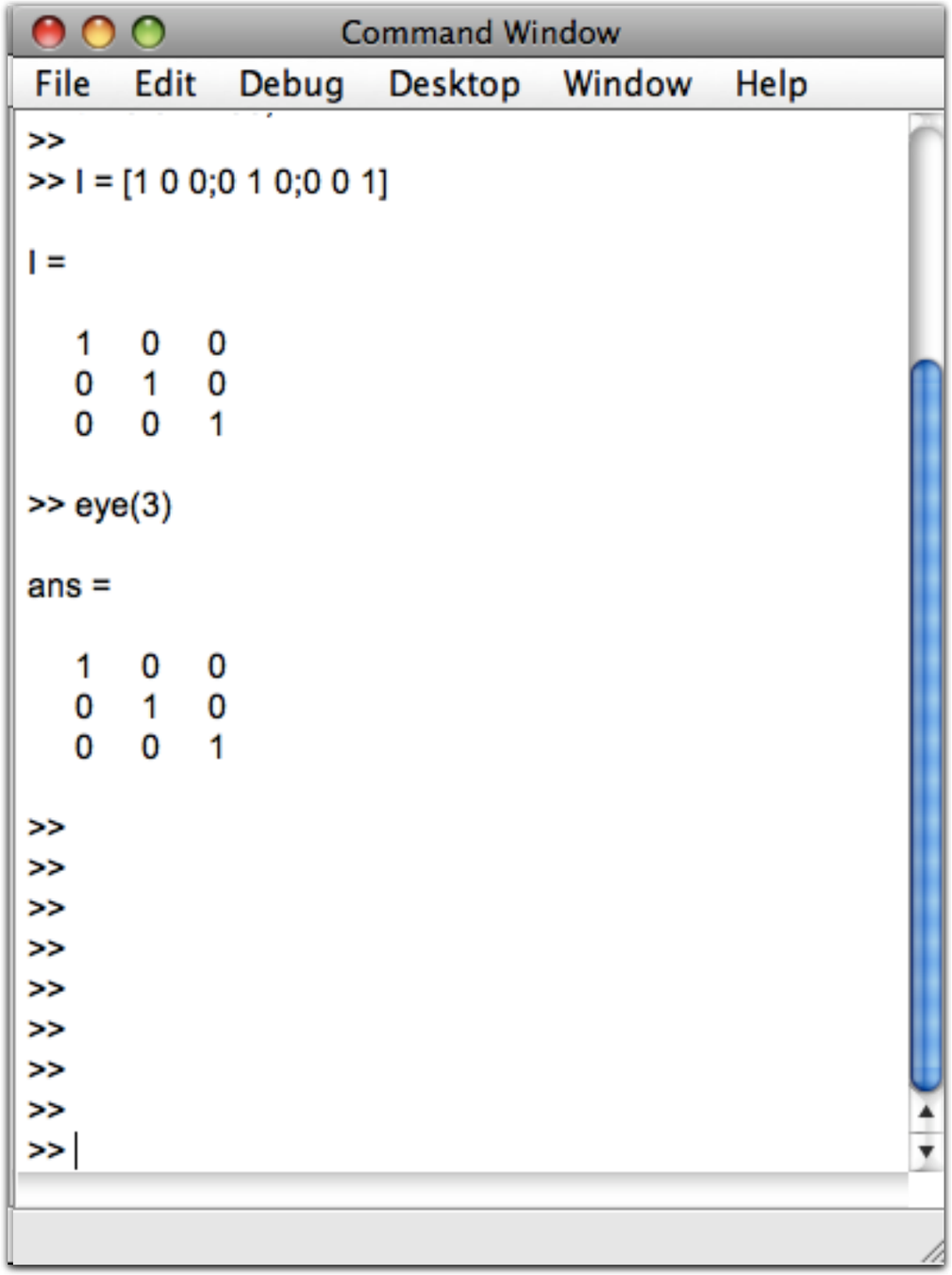
$$x = [2 \quad 4 \quad 6 \quad 8]$$

- Complete the command to suppress the command line output when the vector t is created.

$$>> t = 0 : 0.1 : 100$$

- Create this matrix:

$$I = \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix}$$



Manipulating Arrays

```
>> A = [1 2 3 ; 4 5 6 ; 7 8 9]
```

- Indexing

```
>> k = A(2,3)
>> block1 = A(2, [1 2])
```

- Colon operator

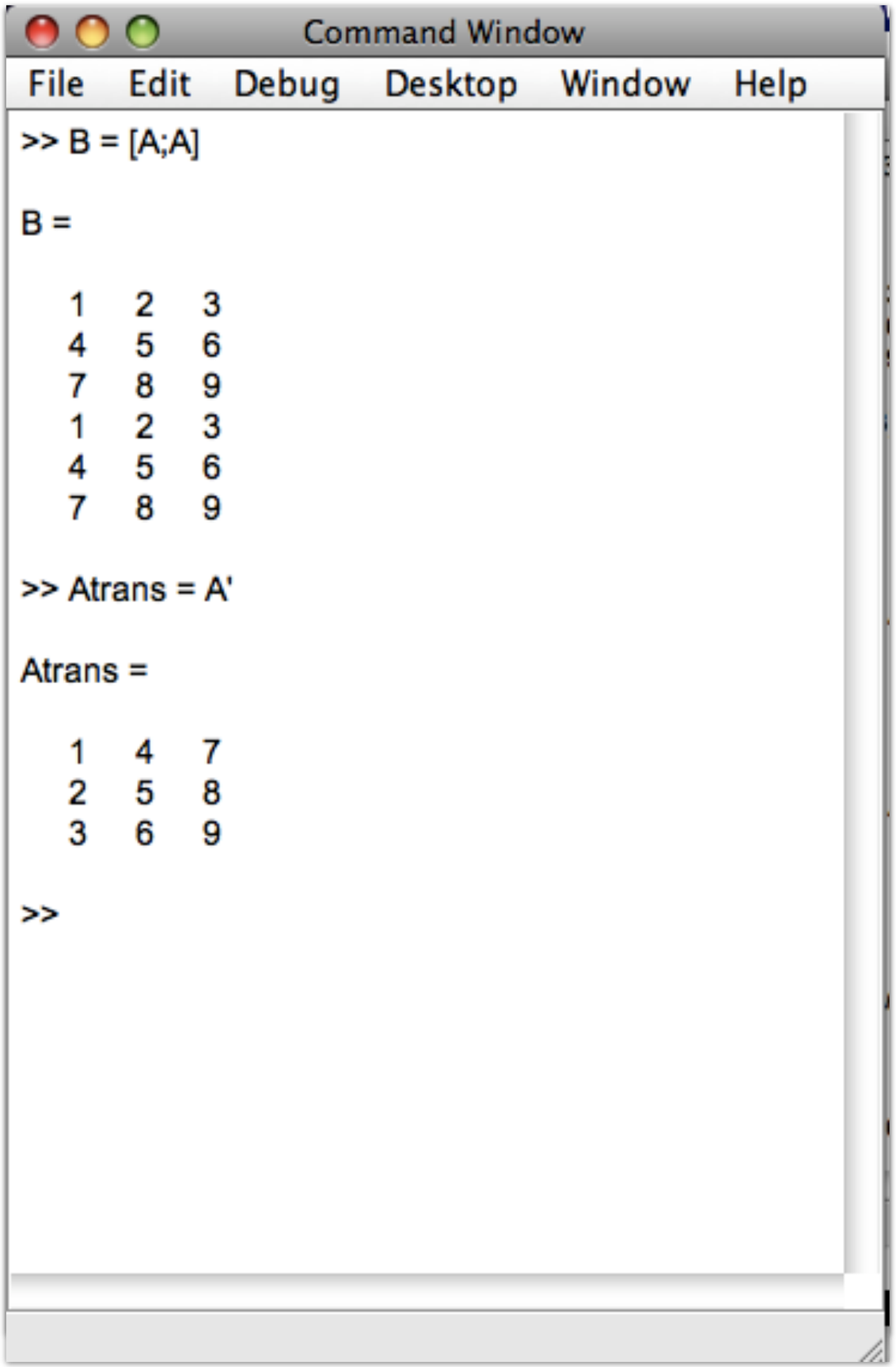
```
>> block2 = A(2, 1:2)
>> row2 = A(2,:)
```

- Concatenating matrices

```
>> B = [A;A]
```

- Transposing

```
>> Atrans = A'
```



Exercise 04 - Creating arrays in MATLAB

- Which of the following can be achieved in MATLAB using colon operator?

- [x] a) Indexing into a whole row or column of an array
- [x] b) Indexing regularly spaced elements in an array
- [ ] c) Specifying a ternary conditional expression
- [x] d) Creating an evenly spaced row vector

The colon operator can be used to **create an evenly spaced vector**, and **to index multiple values** in an array.

Matrix Operations


```
>> A
A =
     1   2
     4   5
     7   8

>> B = 2 * A
B =
     2   4
     8   10
     14  16
```

Scalar multiplication

```
>> A
A =
     1   2
     4   5
     7   8

>> B = A + 2
B =
     3   4
     6   7
     9   10
```

Scalar expansion

```
>> A
A =
     1   2
     4   5
     7   8

>> B
B =
     1   0   1
     1   1   0

>> C = A * B
C =
     3   2   1
     9   5   4
     15  8   7
```

Matrix multiplication

- MATLAB considers operands as matrices. (regular matrix algebra is valid)
- However multiplication with a scalar is a special case.
- For multiplication of two matrices the inner dimensions must agree.
- During addition/subtraction both matrices must have the same dimensions.
- For addition/subtraction with a scalar, the scalar expansion is automatically performed.

System of Linear Equations

- We have a set of linear equations and we want to find out the .... of this system.

$$x_1 + x_2 - x_3 = 0$$
$$2x_1 + x_2 + x_3 = 1$$
$$x_1 - x_3 = -1$$

$$\underbrace{\begin{pmatrix} 1 & 1 & -1 \\ 2 & 1 & 1 \\ 1 & 0 & -1 \end{pmatrix}}_{\mathbf{A}} \underbrace{\begin{pmatrix} x_1 \\ x_2 \\ x_3 \end{pmatrix}}_{\mathbf{x}} = \underbrace{\begin{pmatrix} 0 \\ 1 \\ -1 \end{pmatrix}}_{\mathbf{b}}$$

$$Ax = b$$

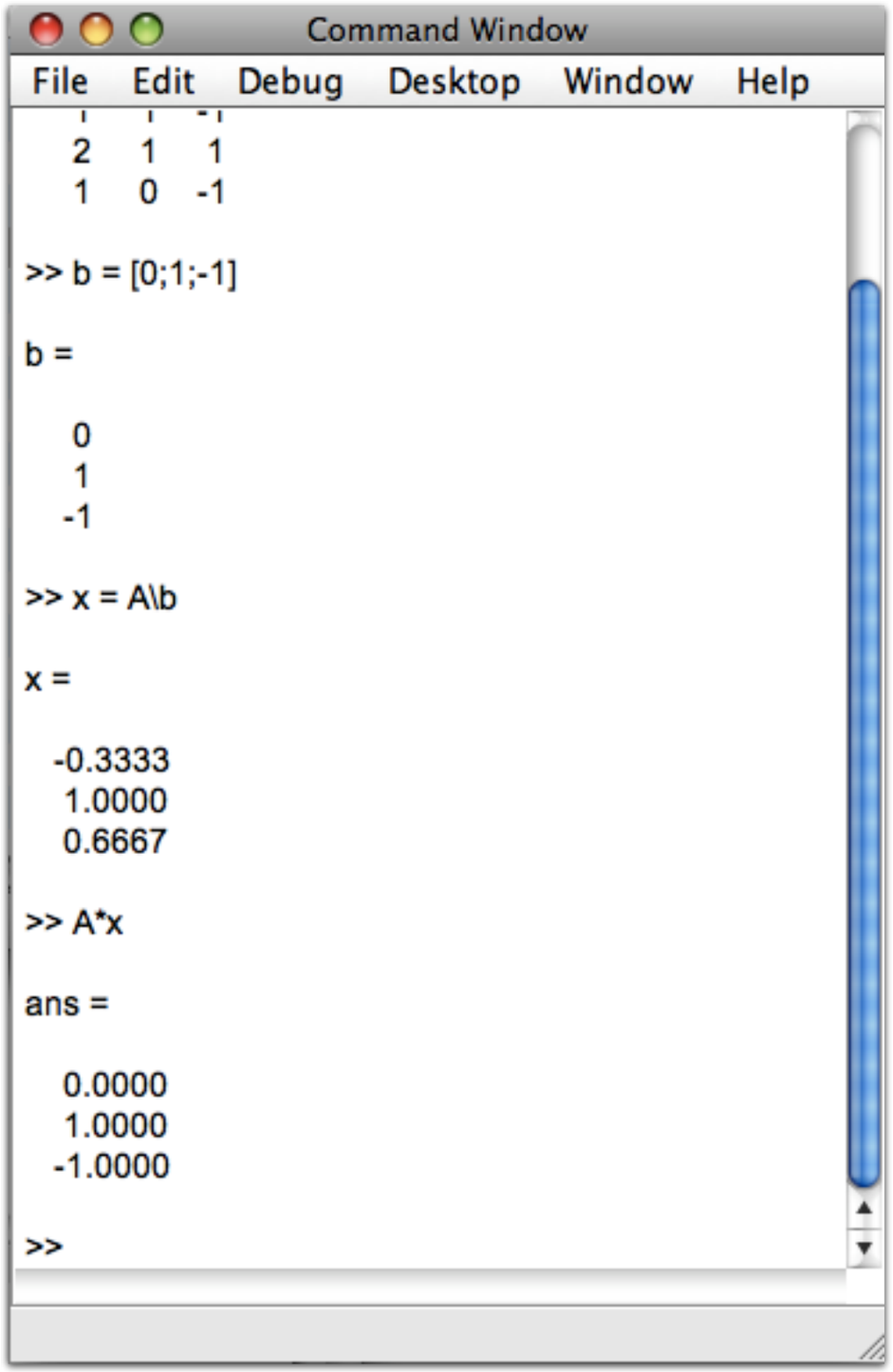
System of Linear Equations

- How we calculate this by using MATLAB?

$$x_1 + x_2 - x_3 = 0$$
$$2x_1 + x_2 + x_3 = 1$$
$$x_1 - x_3 = -1$$

$$\begin{pmatrix} 1 & 1 & -1 \\ 2 & 1 & 1 \\ 1 & 0 & -1 \end{pmatrix} \begin{pmatrix} x_1 \\ x_2 \\ x_3 \end{pmatrix} = \begin{pmatrix} 0 \\ 1 \\ -1 \end{pmatrix}$$

$$Ax = b$$



Eigenvalue Analysis

- Eigenvalue decomposition is a type of matrix operation that can be carried out to determine the eigenvalues and the eigenvectors of a matrix.

$$\begin{pmatrix} 2 & -1 \\ 1 & 3 \end{pmatrix}$$

↓

- Obtain the characteristic polynomial by extending the characteristic equation.

$$det(A - \lambda I) = 0$$

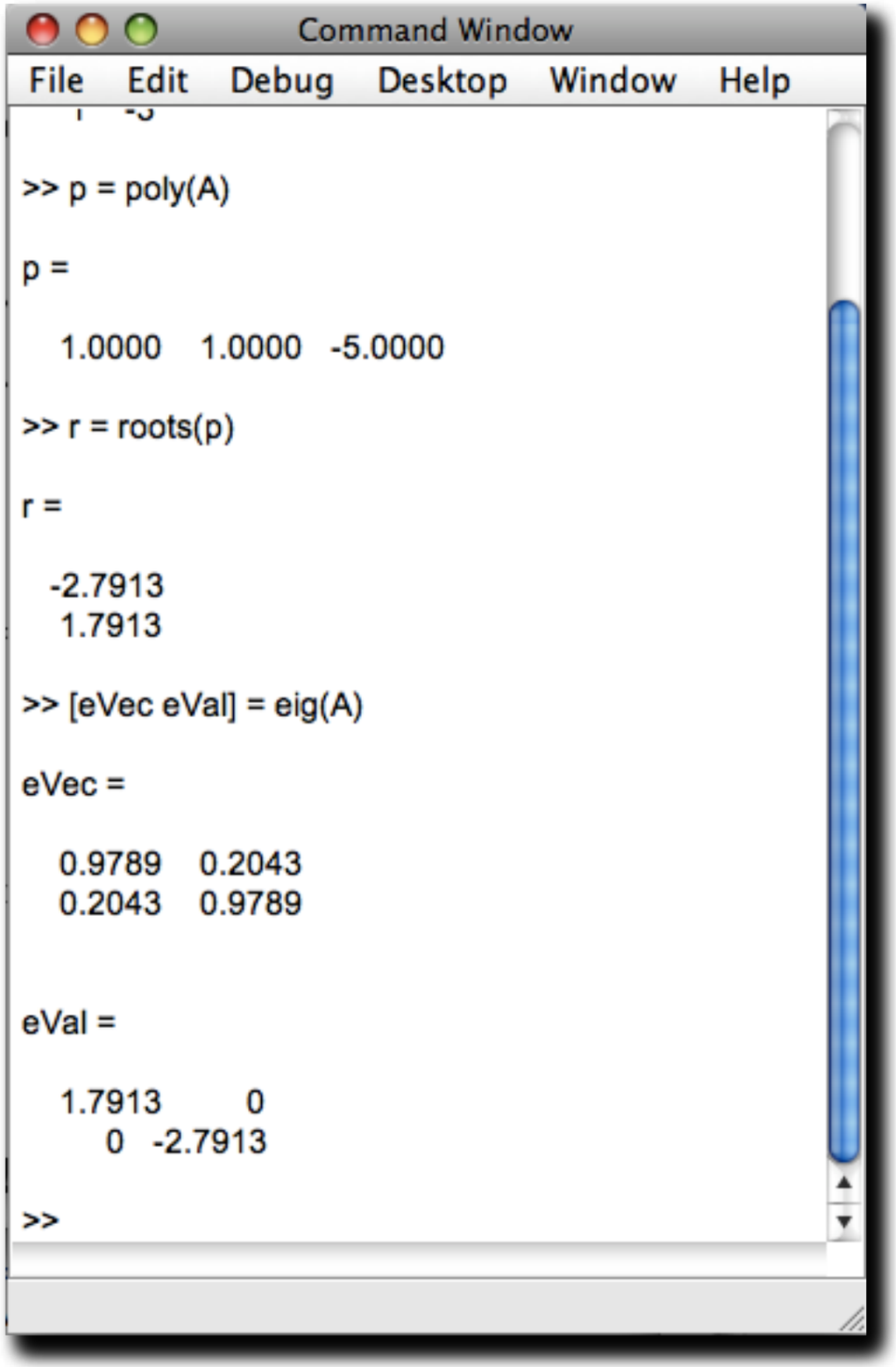
↓

- Obtain the coefficients of the characteristic polynomial by using "poly" function.

$$c_n\lambda^n + ... + c_2\lambda^2 + c_1\lambda + c_0 = 0$$

- The eigenvalues can be computed by obtaining the roots of the function.

- One can also use **the "eig" function** in MATLAB, which returns the **eigenvalues** and the **eigenvectors** of a matrix.



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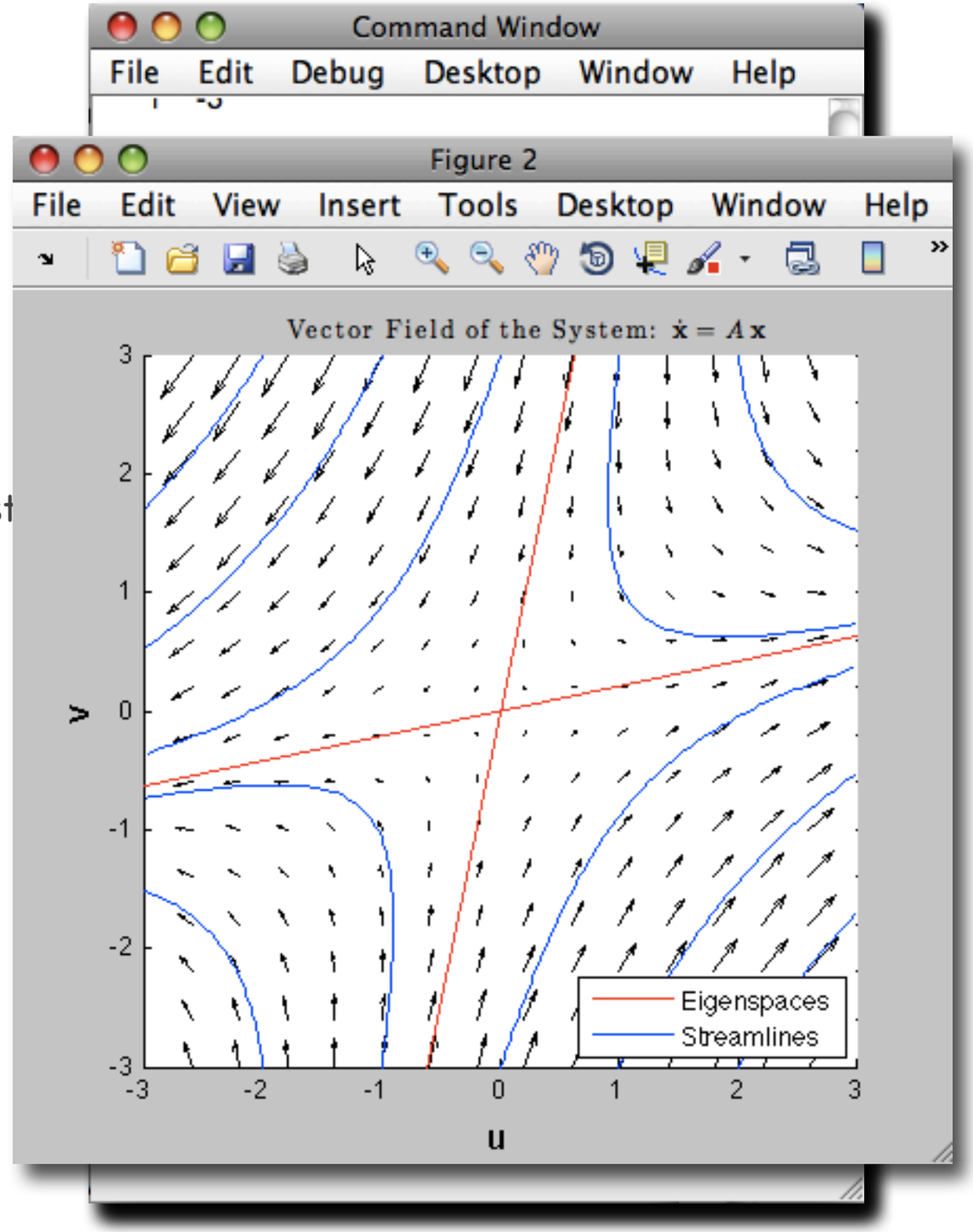
$$c_n\lambda^n + \ldots + c_2\lambda^2 + c_1\lambda + c_0 = 0$$

- The eigenvalues can be computed by obtaining the roots of the function.

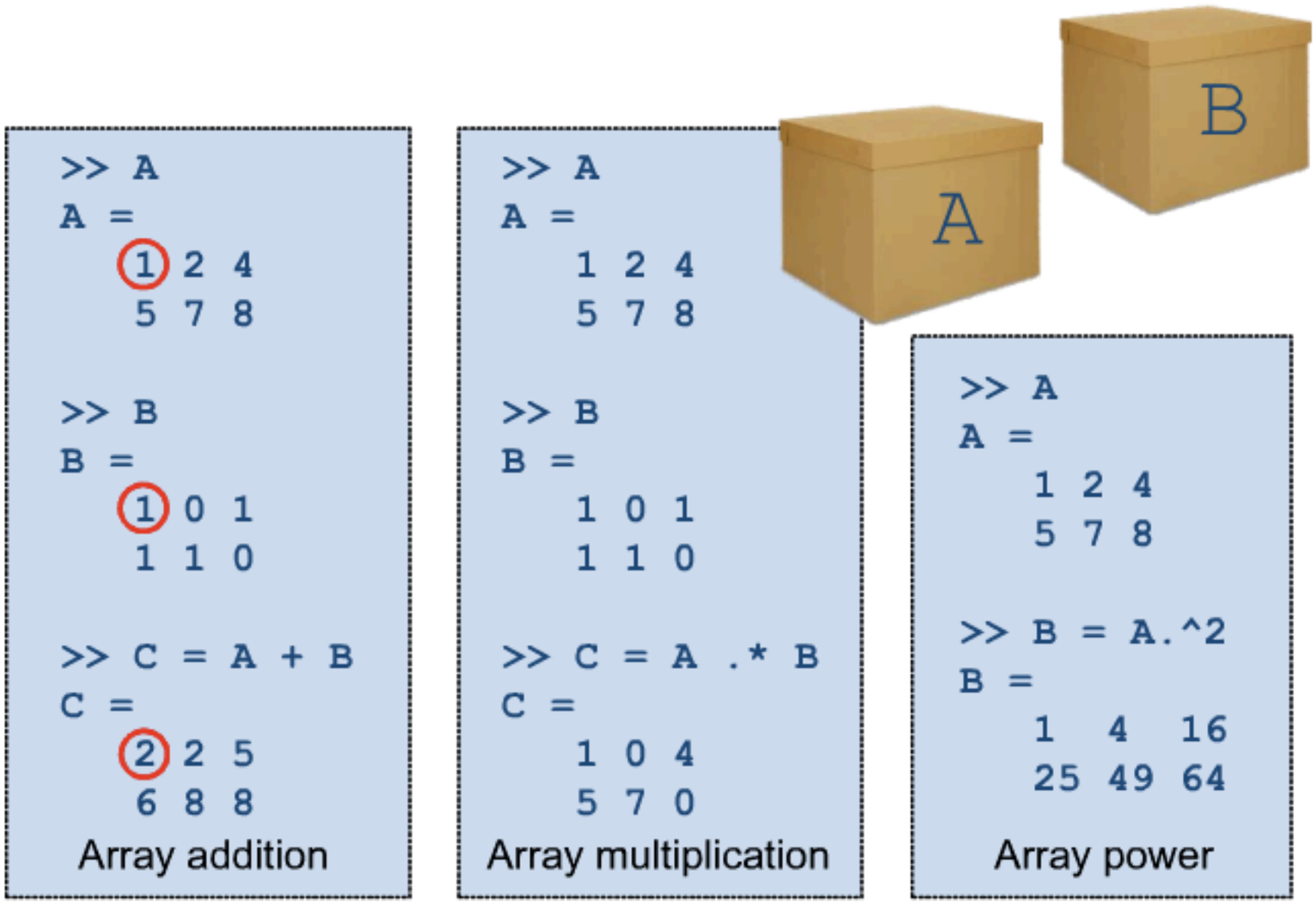
- One can also use **the "eig" function** in MATLAB, which returns the **eigenvalues** and the **eigenvectors** of a matrix.

- One can visualize the vector field of the system represented by A, and plot the space which is spanned by its eigenvectors.



Array Operations

- Operands have to be in the same size and shape.
- The array operators operate element by element.



Array Operations

- Operands have to be in the same size and shape.
- The array operators operate element by element.

```
>> A
A =
     1  2  4
     5  7  8

>> B
B =
     1  0  1
     1  1  0

>> C = A + B
C =
     2  2  5
     6  8  8
```

Array addition

```
>> A
A =
     1  2  4
     5  7  8

>> B
B =
     1  0  1
     1  1  0

>> C = A .* B
C =
     1  0  4
     5  7  0
```

Array multiplication

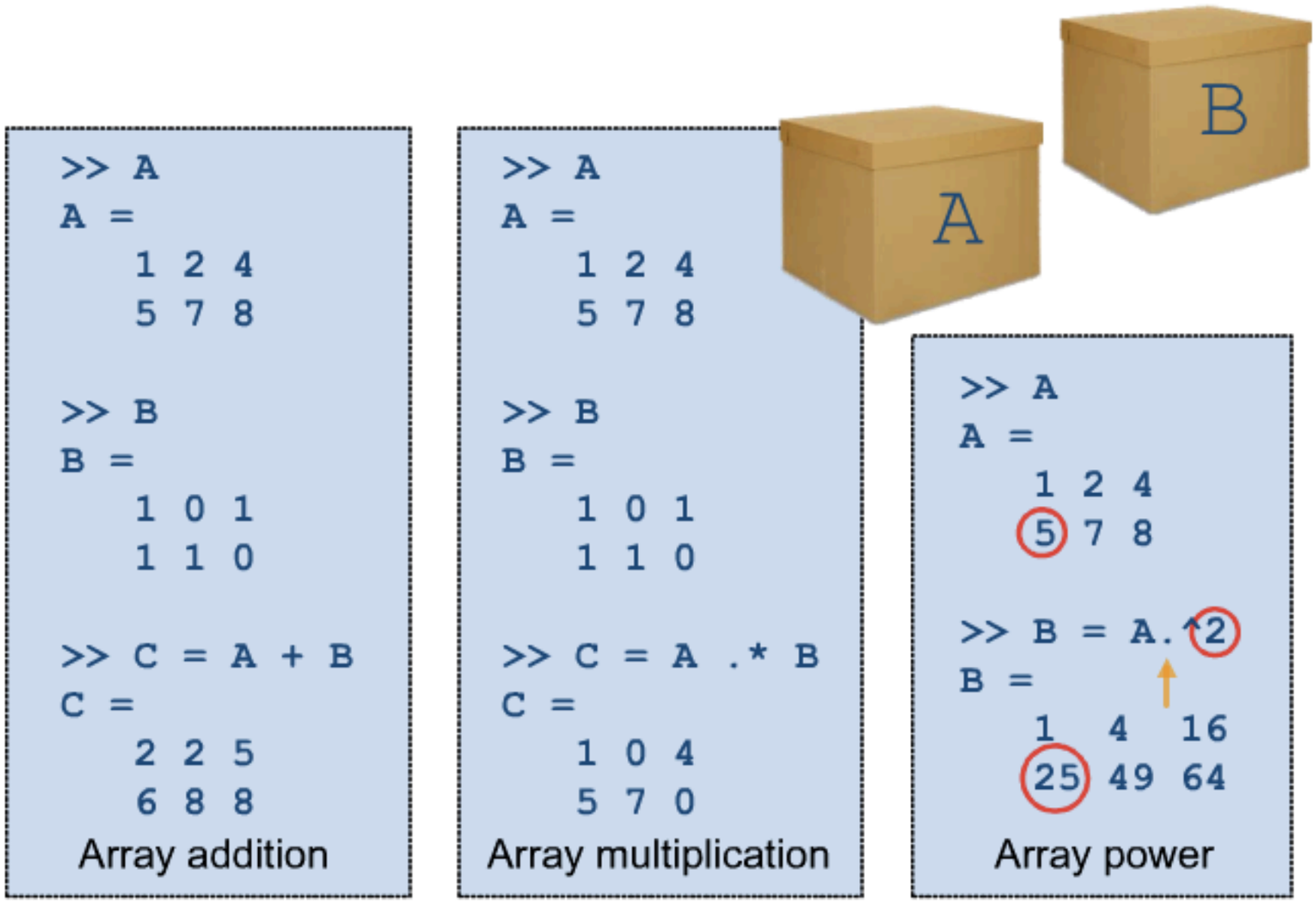

```
>> A
A =
     1  2  4
     5  7  8

>> B = A.^2
B =
     1   4   16
    25  49  64
```

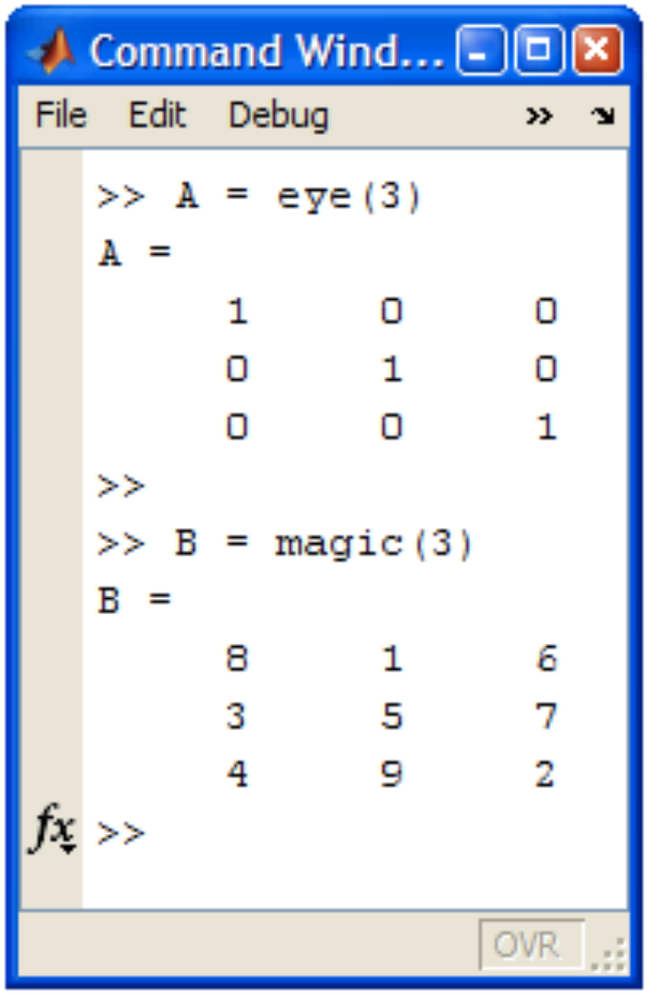
Array power

Array Operations

- Operands have to be in the same size and shape.
- The array operators operate element by element.

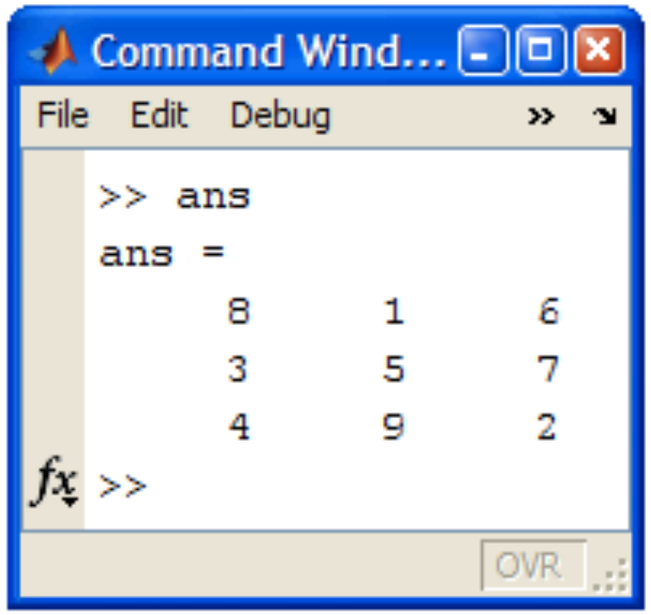


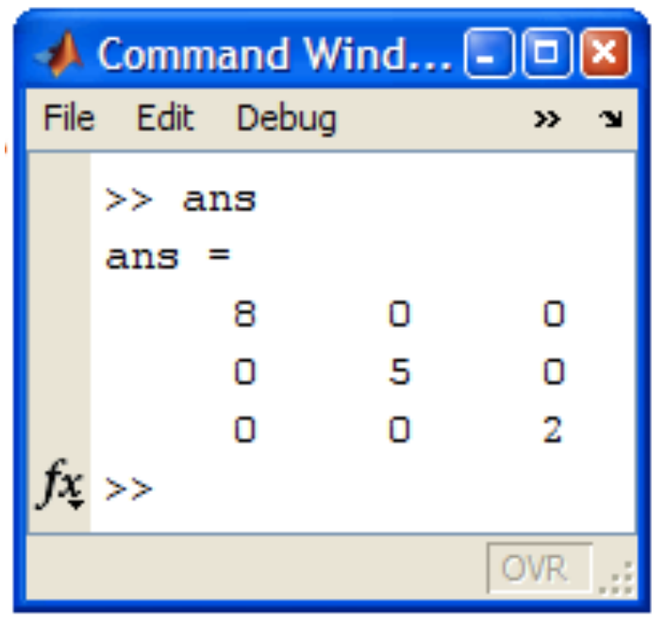
Exercise 05 - Match the expected outcome to the operators used.




```
>> A .* B
```

```
>> A * B
```





Visualizing the Mathematical Functions

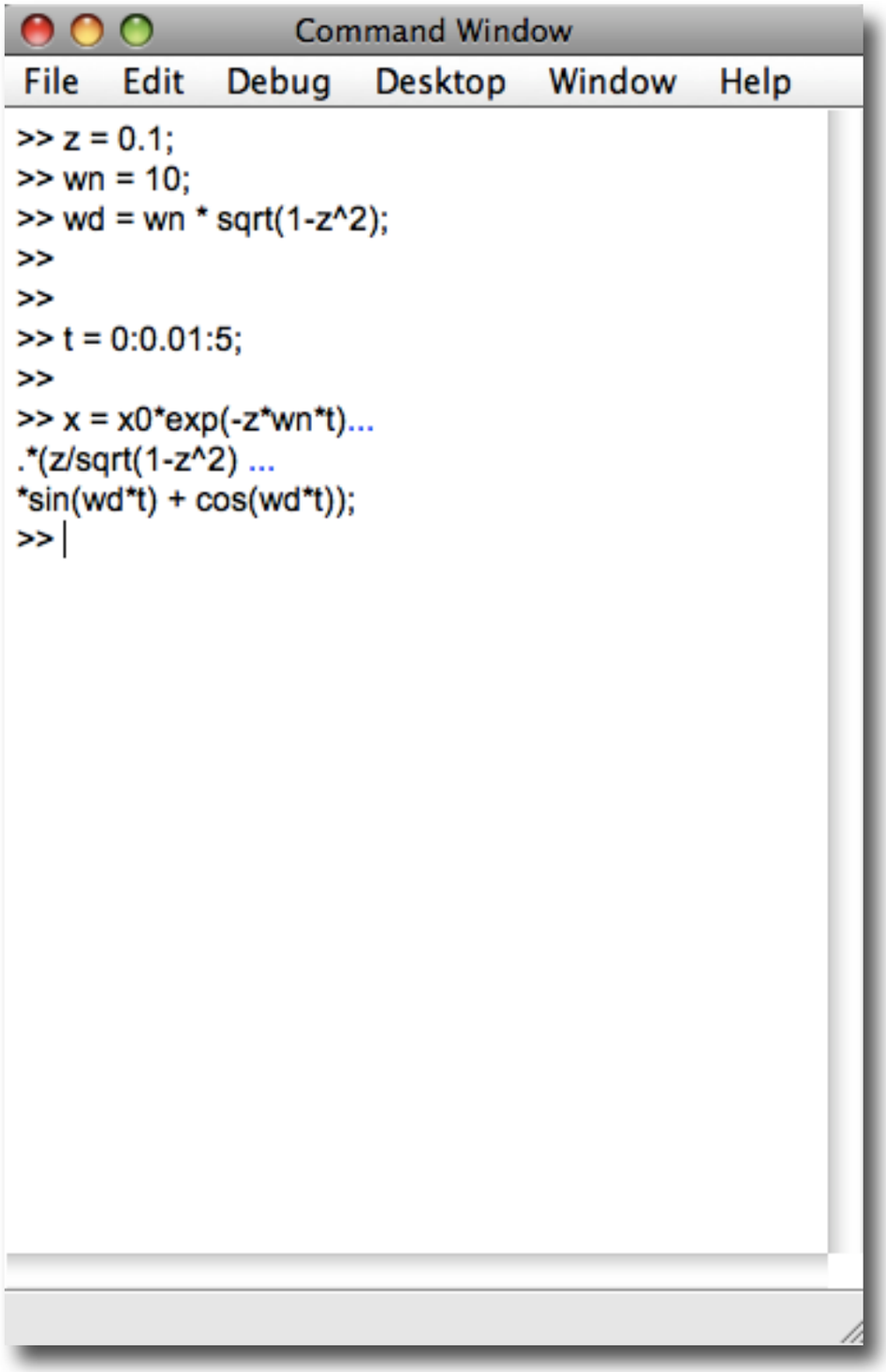
- Displacement of an under-damped spring-mass system.

Given:

$$\xi = 0.1$$
$$\omega_n = 10$$
$$\omega_d = \omega_n \sqrt{1 - \xi^2}$$
$$x_0 = 10$$

Plot the following function for t=0 to 5 s.

$$x(t) = x_0 e^{-\xi \omega_n t} \left(\frac{\xi}{\sqrt{(1 - \xi^2)}} sin\omega_d t + cos\omega_d t \right)$$



Visualizing the Mathematical Functions

MATLAB 7.6.0 (R2008a)

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nts/Conferences_Schools/HPFBU2011/MatLab_Lecture_Material/tutorial_files

Shortcuts How to Add What's New

Workspace

Name	Value	Min
t	<1x501 dou...	0
wd	9.9499	9.9499
wn	10	10
x	<1x501 dou...	-7.2859
x0	10	10
z	0.1000	0.1000

Command History

```
t =0:0.01:5;
clc
z = 0.1;
wn = 10;
wd = wn * sqrt(1-z^2);
t = 0:0.01:5;
x = x0*exp(-z*wn*t)...
.*(z/sqrt(1-z^2) ...
*sin(wd*t) + cos(wd*t));
```

Editor - /Users/OM/Documents/Conferences_Schools/HPFBU2011/MatLab_Lec...

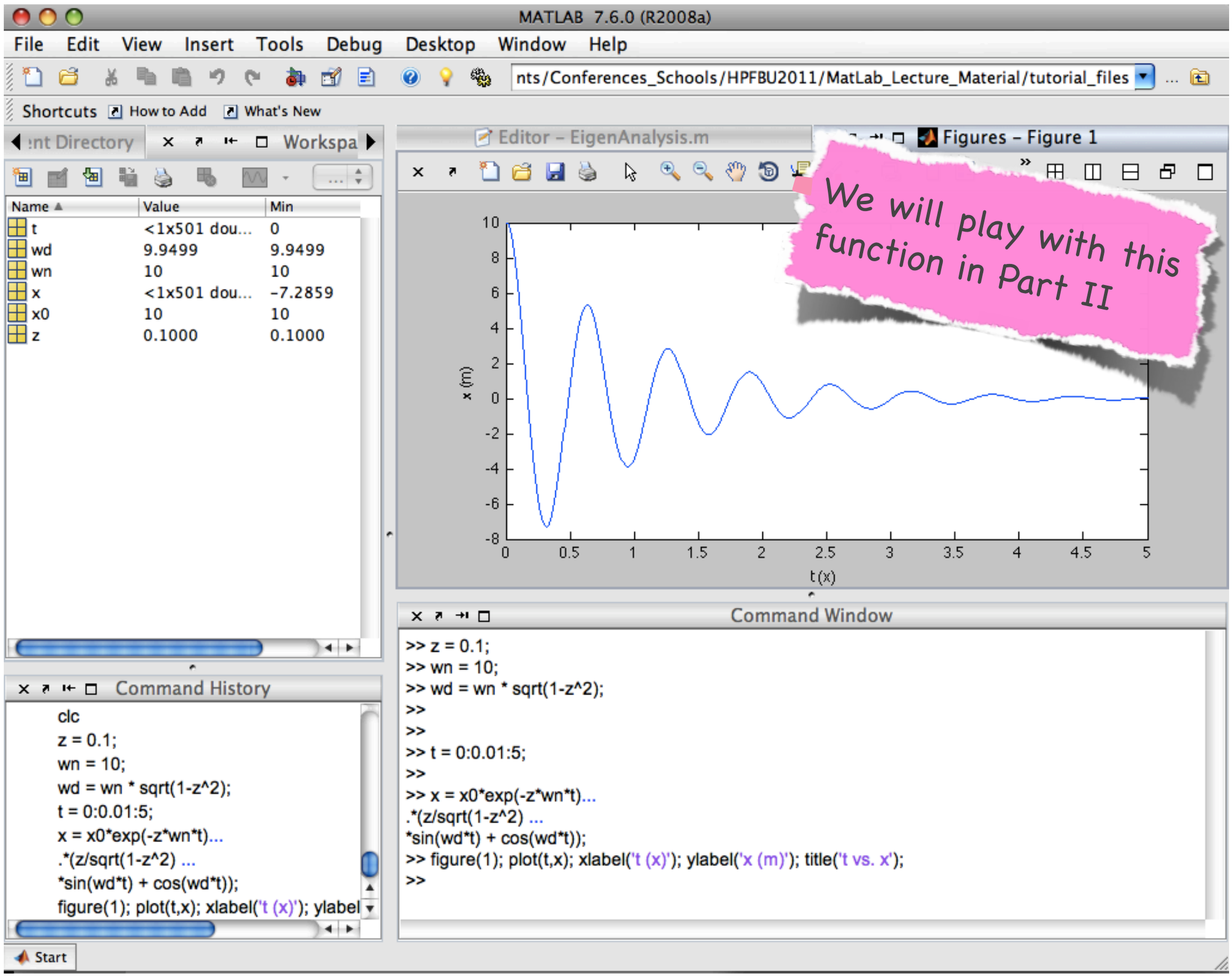
calchep_plot.m | EigenAnalysis.m

Command Window

```
>> z = 0.1;
>> wn = 10;
>> wd = wn * sqrt(1-z^2);
>>
>>
>> t = 0:0.01:5;
>>
>> x = x0*exp(-z*wn*t)...
.*(z/sqrt(1-z^2) ...
*sin(wd*t) + cos(wd*t));
>>
```

Start

Visualizing the Mathematical Functions



Writing your function in MATLAB

- We can write a function in order to perform specific jobs in MATLAB.
- It makes our life easier.
- One function - One Task!
- Let's repeat the previous exercise by using functions...

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%                Displacement of an under-damped spring-mass system.
%
%                              HPFBU 2011 - MATLAB Tutorial
%                              Help/Questions  --> O. Mete
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

function [x, t] = damped_oscillator(z)

% Parameters
%z = 0.1;
wn = 10;
x0 =  10;
wd = wn * sqrt(1-z^2);

% Time range
t= 0:0.01:5;

% Position function of the spring-mass system
x = x0*exp(-z*wn*t).*(z/sqrt(1-z^2)*sin(wd*t) + cos(wd*t));

end
```

- Instead writing the all commands and assignments by hand into the command line, we can gather them all inside a ".m" file.
- We can relate them with a function.
- Functions are called by their attributes.
- Their outputs can be assigned to variables

Writing your function in MATLAB

Preparation for PART II (HOMEWORK :)

- Write a program;
  - that calls the function "damped_oscillator" recursively for different z values,
  - and draws the x-t plots on the same figure.
  - Therefore, one could monitor the behavior of the system for different z values.

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%               Displacement of an under-damped spring-mass system.
%
%                              HPFBU 2011 - MATLAB Tutorial
%                               Help/Questions  --> O. Mete
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

function [x, t] = damped_oscillator(z)

% Parameters
%z = 0.1;
wn = 10;
x0 =  10;
wd = wn * sqrt(1-z^2);

% Time range
t= 0:0.01:5;

% Position function of the spring-mass system
x = x0*exp(-z*wn*t).*(z/sqrt(1-z^2)*sin(wd*t) + cos(wd*t));

end
```

PART II

HANDS-ON PRACTICE SESSION

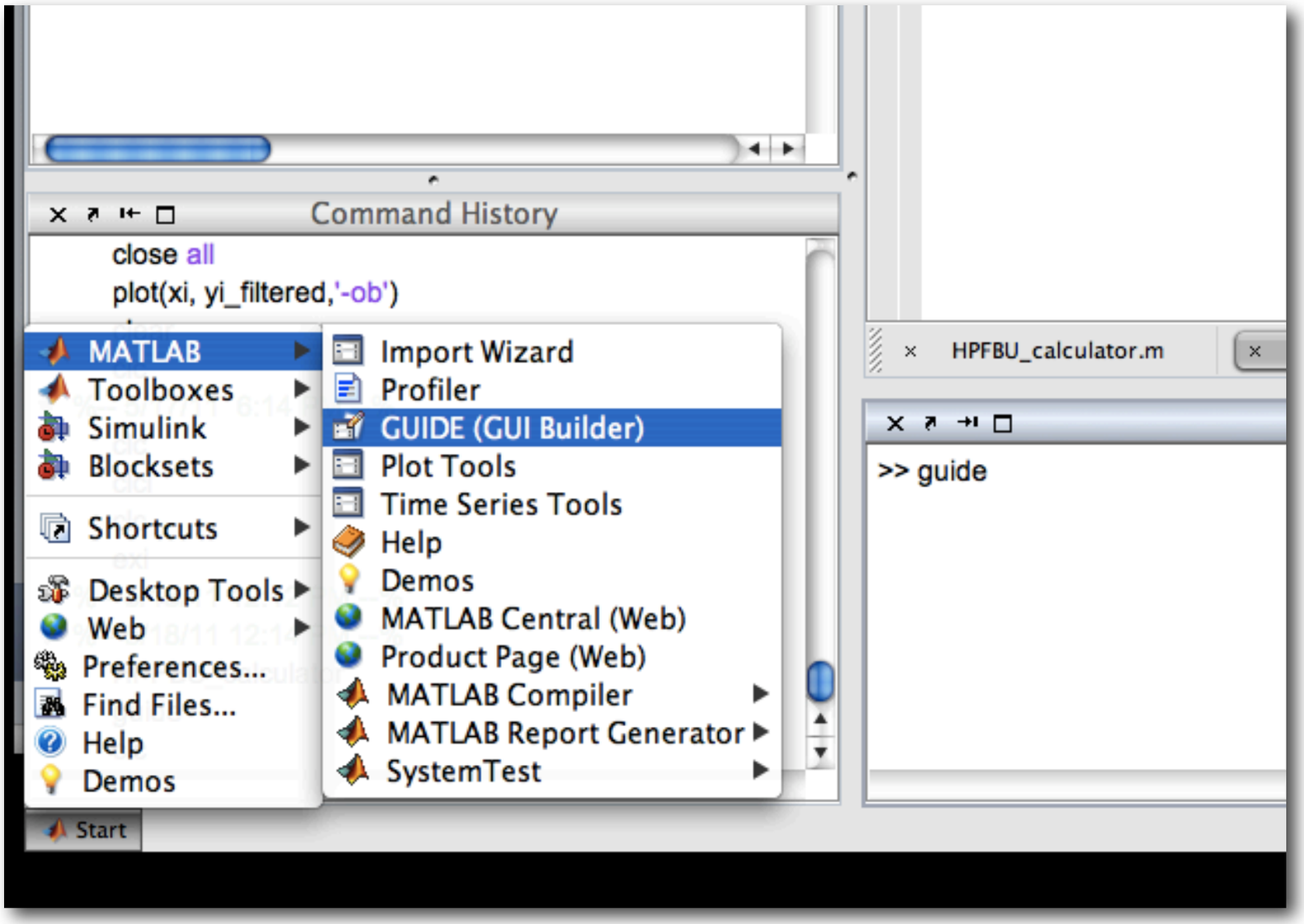
PART 2 - Hands-on Practice Session

Projects

- **Graphical User Interface: Building a calculator**
- Under-dumped string-mass system
- Gaussian fit to a given data set (on command line and by using Fitting Toolbox)
- Quadrupole scan analysis for emittance measurement
- Fourier filtering???

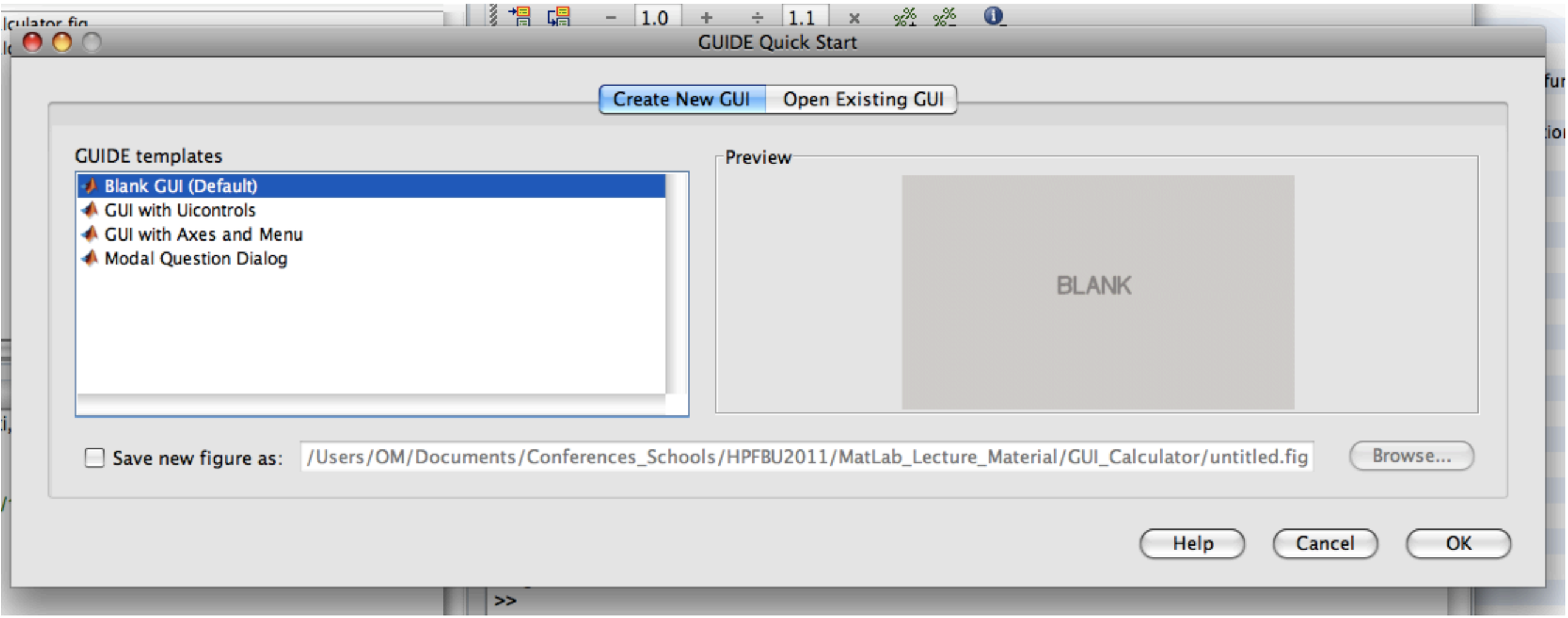
Graphical User Interface: Building a Calculator

- Let's create a GUI that does basic mathematical calculations, interactively.
- Call the MATLAB GUI builder by typing "guide" in the command window,
- or from MATLAB start menu as shown:



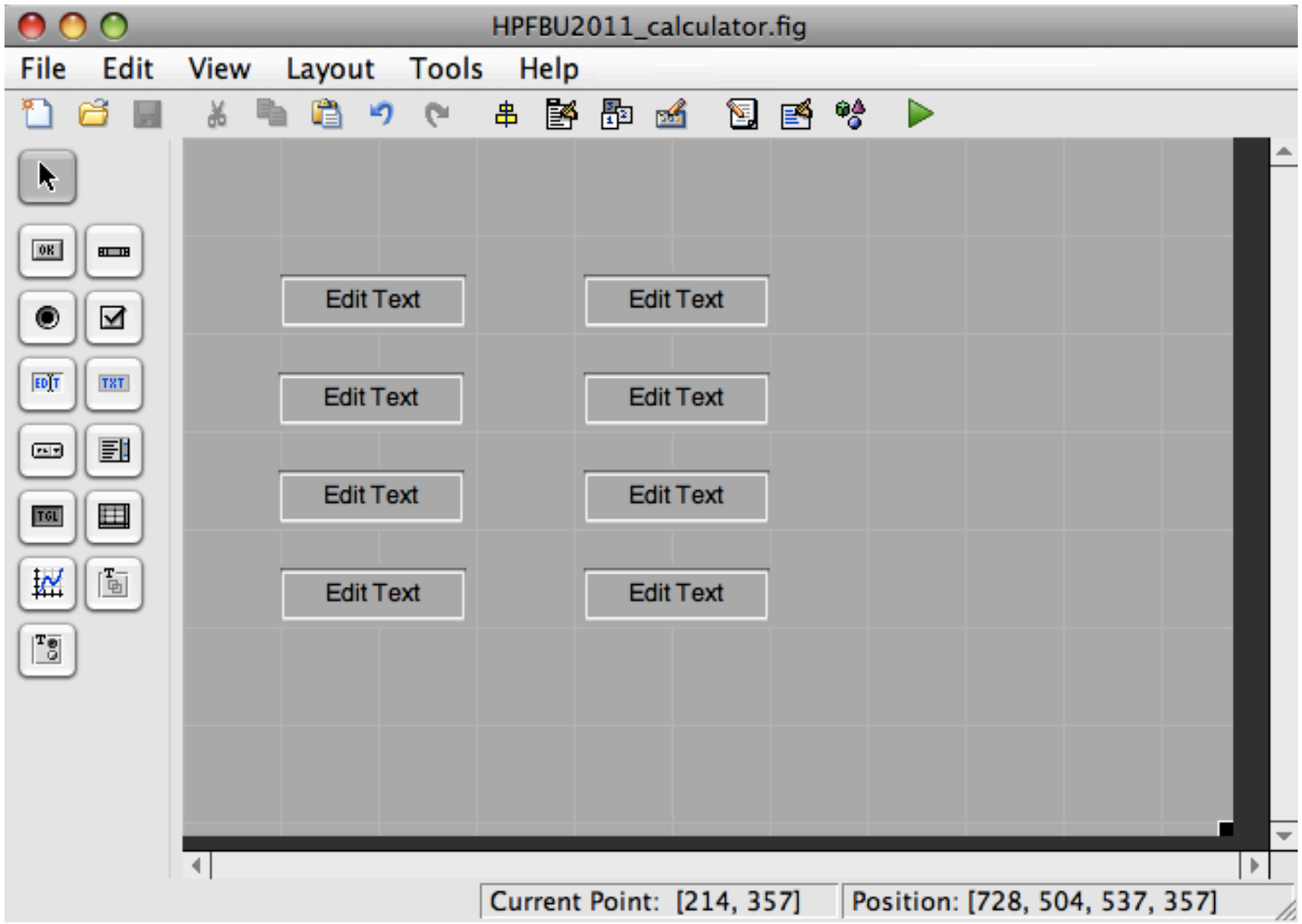
Graphical User Interface: Building a Calculator

- Choose one of the templates of the GUI builder.



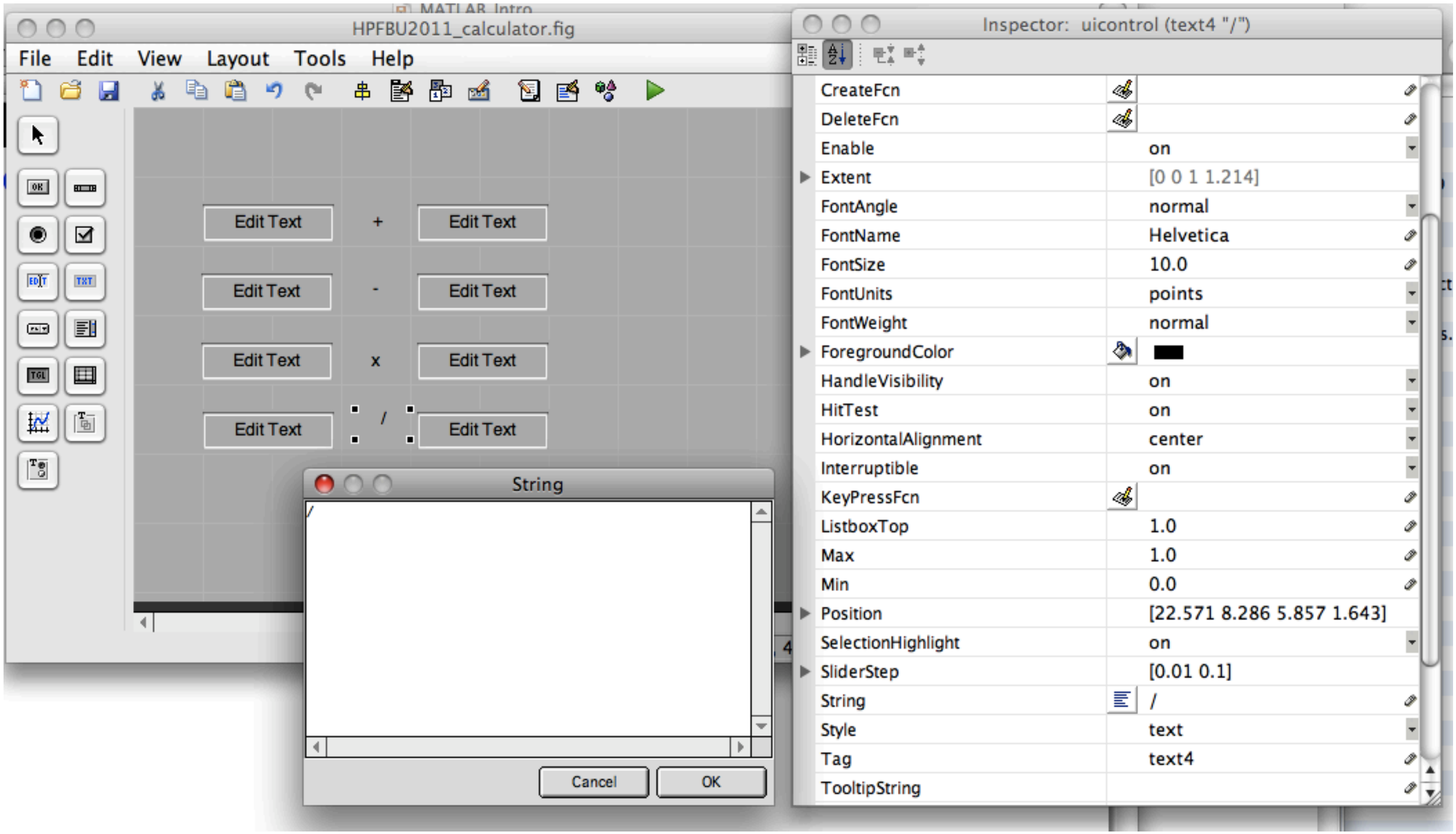
Graphical User Interface: Building a Calculator

- Add 8 "Edit Text" objects on the GUI panel to form our input boxes.



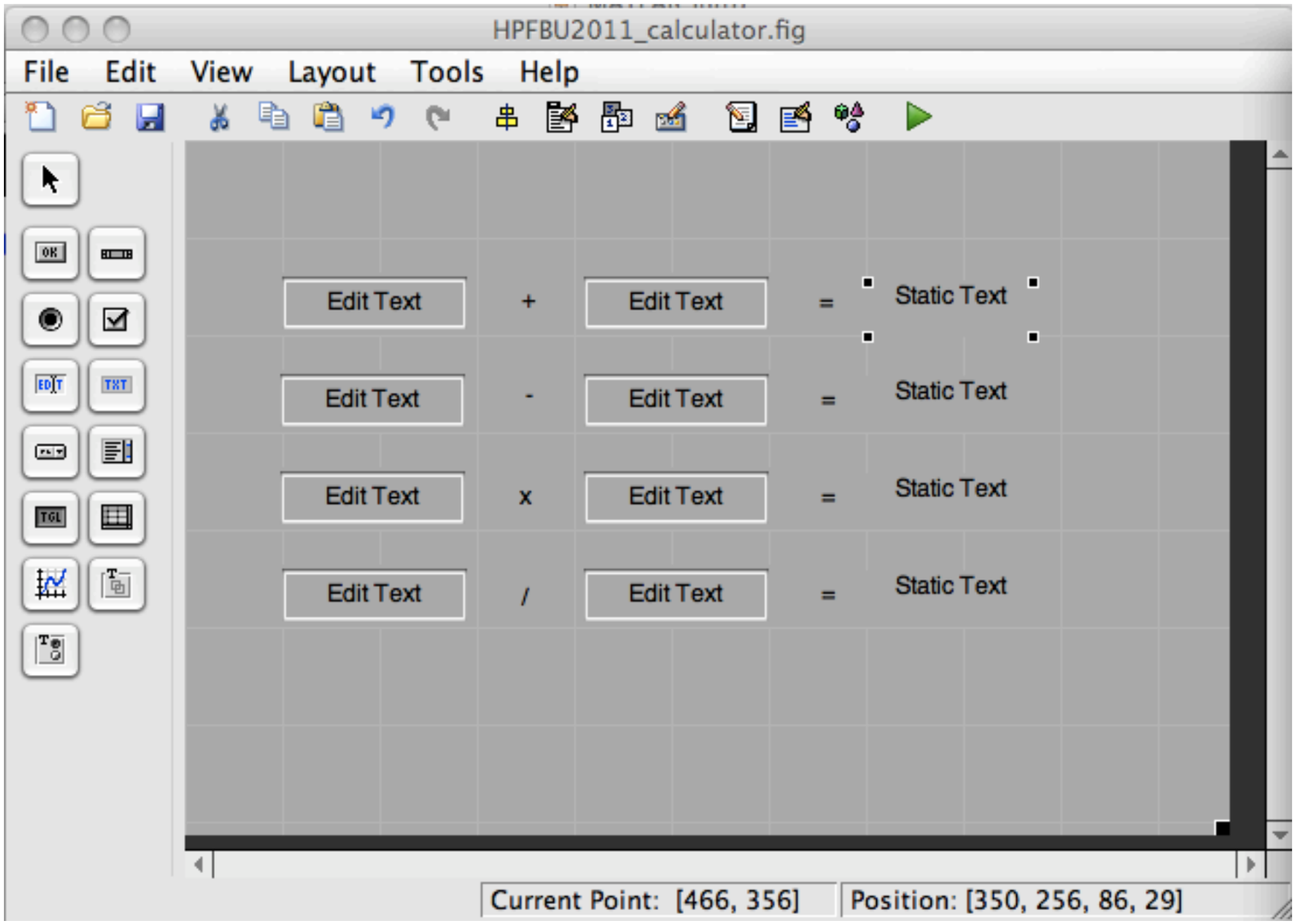
Graphical User Interface: Building a Calculator

- Add 4 "static text" objects on the panel to indicate the mathematical operators.
- You can edit each text box by using the "String" property from the "Inspector".



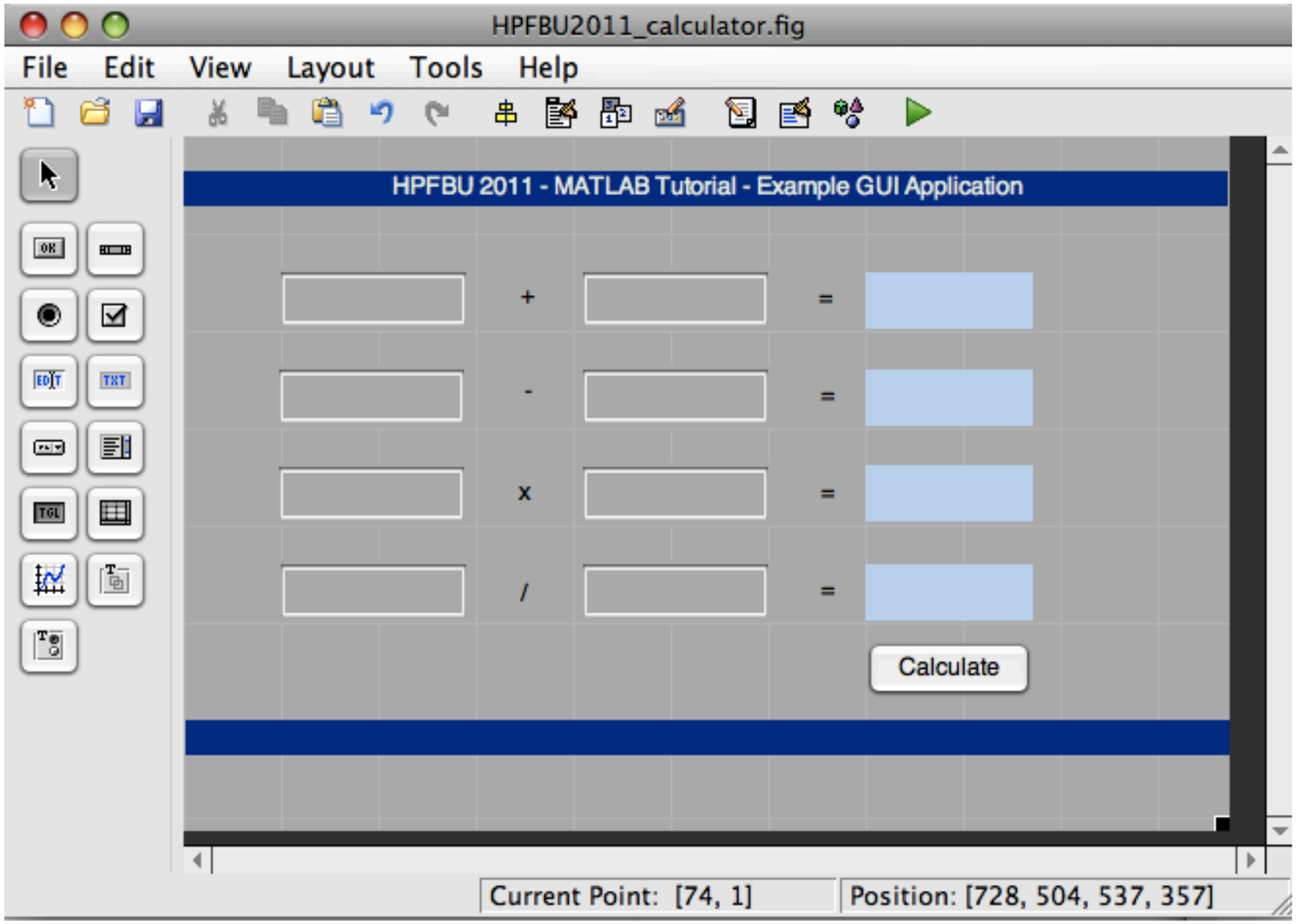
Graphical User Interface: Building a Calculator

- Add "equals" signs and 4 additional "static text" boxes to display the results of the calculations.



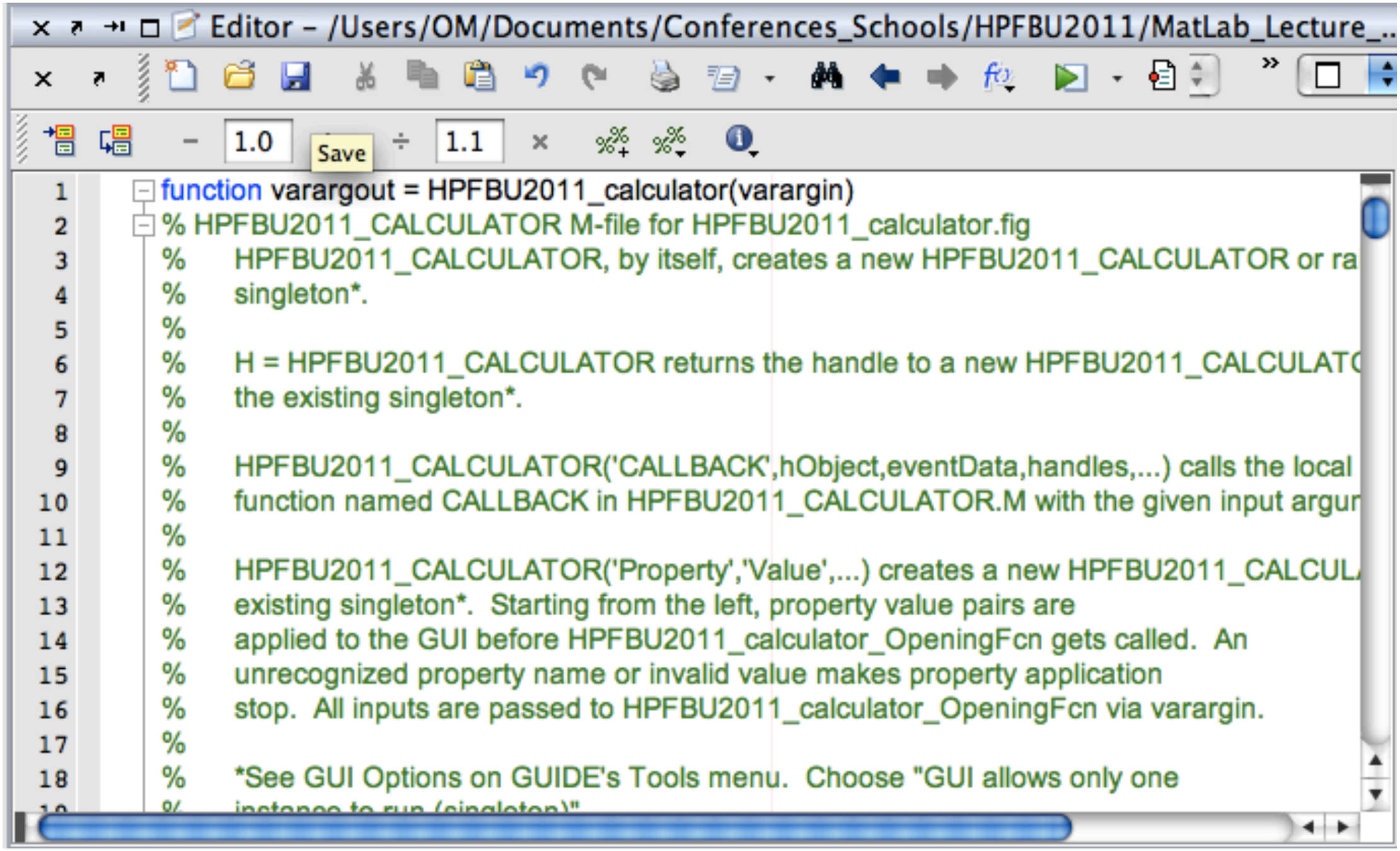
Graphical User Interface: Building a Calculator

- Some make-up for your panel :)



Graphical User Interface: Building a Calculator

- The script for the GUI will be automatically generated when we save our project.



Graphical User Interface: Building a Calculator

- First, we will edit the "callback" functions of the objects.
- Repeat the same for all edit box callback functions that will be used for the data entry.

/Users/OM/Documents/Conferences_Schools/HPFBU2011/MatLab_Lecture_Material/GUI_Calculator/HPFBU2011_calculator.m*

File Edit Text Go Cell Tools Debug Desktop Window Help

```
75
76
77      function edit1_Callback(hObject, eventdata, handles)
78      % hObject    handle to edit1 (see GCBO)
79      % eventdata  reserved - to be defined in a future version of MATLAB
80      % handles    structure with handles and user data (see GUIDATA)
81
82      % Hints: get(hObject,'String') returns contents of edit1 as text
83      %        str2double(get(hObject,'String')) returns contents of edit1 as a doubl
84
85      % We will add our code here!
86
87
88
89      % --- Executes during object creation, after setting all properties.
90      function edit1_CreateFcn(hObject, eventdata, handles)
91      % hObject    handle to edit1 (see GCBO)
92      % eventdata  reserved - to be defined in a future version of MATLAB
93      % handles    empty - handles not created until after all CreateFcns called
94
95      % Hint: edit controls usually have a white background on Windows.
96      %       See ISPC and COMPUTER.
97      if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBa
98          set(hObject,'BackgroundColor','white');
99      end
100
101
102
103     function edit2_Callback(hObject, eventdata, handles)
104     % hObject    handle to edit2 (see GCBO)
```

/Users/OM/Documents/Conferences_Schools/HPFBU2011/MatLab_Lecture_Material/GUI_Ca

File Edit Text Go Cell Tools Debug Desktop Window Help

```
75
76
77      function edit1_Callback(hObject, eventdata, handles)
78      % hObject    handle to edit1 (see GCBO)
79      % eventdata  reserved - to be defined in a future version of MATLAB
80      % handles    structure with handles and user data (see GUIDATA)
81
82      % Hints: get(hObject,'String') returns contents of edit1 as text
83      %        str2double(get(hObject,'String')) returns contents of edit1 as a double
84
85      % We will add our code here!
86
87      %store the contents of edit1 as a string. if the string
88      %is not a number then input will be empty
89      input = str2num(get(hObject,'String'));
90
91      %checks to see if input is empty. if so, default input1_editText to zero
92      if (isempty(input))
93          set(hObject,'String','0')
94      end
95      guidata(hObject, handles);
96
97
98
99
100     % --- Executes during object creation, after setting all properties.
101     function edit1_CreateFcn(hObject, eventdata, handles)
102     % hObject    handle to edit1 (see GCBO)
103     % eventdata  reserved - to be defined in a future version of MATLAB
104     % handles    empty - handles not created until after all CreateFcns called
```

HPFBU2011_c

Graphical User Interface: Building a Calculator

- Edit the callback function for the "Calculate" "pushbutton" object.

/Users/OM/Documents/Conferences_Schools/HPFBU2011/MatLab_Lecture_Material/GUI_Calculator/HPFBU2011_calculator.m

File Edit Text Go Cell Tools Debug Desktop Window Help

```
% Hint: edit controls usually have a white b
%       See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'Background
    set(hObject,'BackgroundColor','white');
end


% --- Executes on button press in calculate
function calculate_pushbutton1_Callback(h
% hObject    handle to calculate_pushbutto
% eventdata  reserved - to be defined in a
% handles    structure with handles and us

% We will add our code here!
```

/Users/OM/Documents/Conferences_Schools/HPFBU2011/MatLab_Lecture_Material/GUI_Calculator/HPFBU2011_calculator.m*

File Edit Text Go Cell Tools Debug Desktop Window Help

```
% eventdata  reserved - to be defined in a future versio
% handles    structure with handles and user data (see

% We will add our code here!

% Toplama islemi
sayi1 = get(handles.edit1,'String');
sayi2 = get(handles.edit2,'String');
% sayi1 and sayi2 are variables of Strings type, and nee
% to variables of Number type before they can be adde

toplam = str2num(sayi1) + str2num(sayi2);
c = num2str(toplam);
% need to convert the answer back into String type to d
set(handles.text9,'String',c);
guidata(hObject, handles);

% Cikarma islemi
cikar1 = get(handles.edit3,'String');
cikar2 = get(handles.edit4,'String');
% cikar1 and cikar2 are variables of Strings type, and n
% to variables of Number type before they can be adde

cikarma_sonucu = str2num(cikar1) - str2num(cikar2);
e = num2str(cikarma_sonucu);
% need to convert the answer back into String type to d
set(handles.text10,'String',e);
guidata(hObject, handles);
```

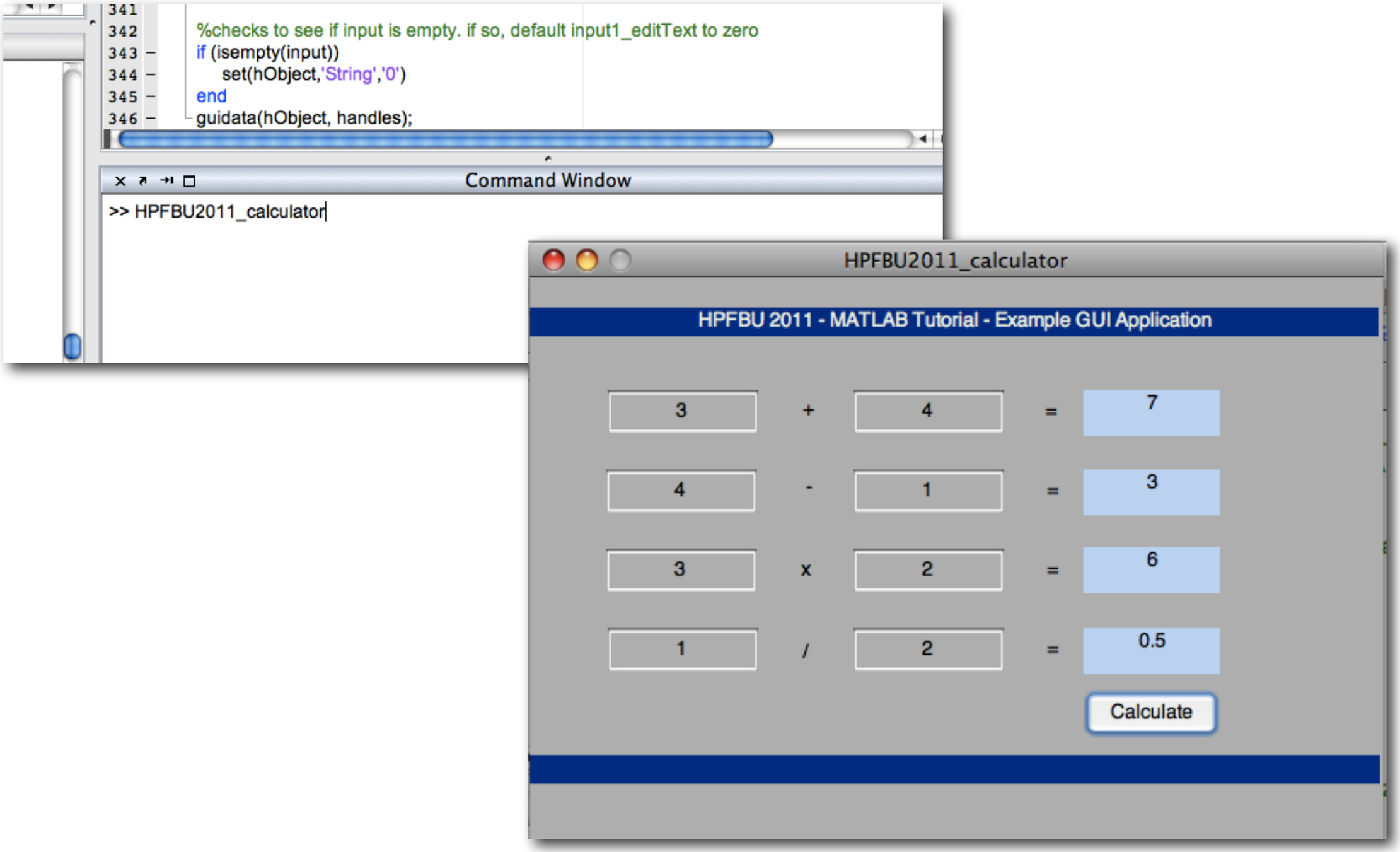
/Users/OM/Documents/Conferences_Schools/HPFBU2011/MatLab_Lect

File Edit Text Go Cell Tools Debug Desktop Window Help

```
% need to convert the answer back into String type to display it
set(handles.text10,'String',e);
guidata(hObject, handles);

% Carpma islemi
carp1 = get(handles.edit5,'String');
carp2 = get(handles.edit6,'String');
% a and b are variables of Strings type, and need to be converted
% to variables of Number type before they can be added together

carpim = str2num(carp1) * str2num(carp2);
carp3 = num2str(carpim);
% need to convert the answer back into String type to display it
set(handles.text11,'String',carp3);
guidata(hObject, handles);


% Bolme islemi
bol1 = get(handles.edit7,'String');
bol2 = get(handles.edit8,'String');
% a and b are variables of Strings type, and need to be converted
% to variables of Number type before they can be added together

bolum = str2num(bol1) / str2num(bol2);
bol3 = num2str(bolum);
% need to convert the answer back into String type to display it
set(handles.text12,'String',bol3);
guidata(hObject, handles);
```

Graphical User Interface: Building a Calculator

- Call your GUI by using its name in the command window.
- And, try a few calculations!



PART 2 - Hands-on Practice Session

Projects

- Graphical User Interface: Building a calculator
- **Under-dumped string-mass system**
- Gaussian fit to a given data set (on command line and by using Fitting Toolbox)
- Quadrupole scan analysis for emittance measurement
- Fourier filtering???

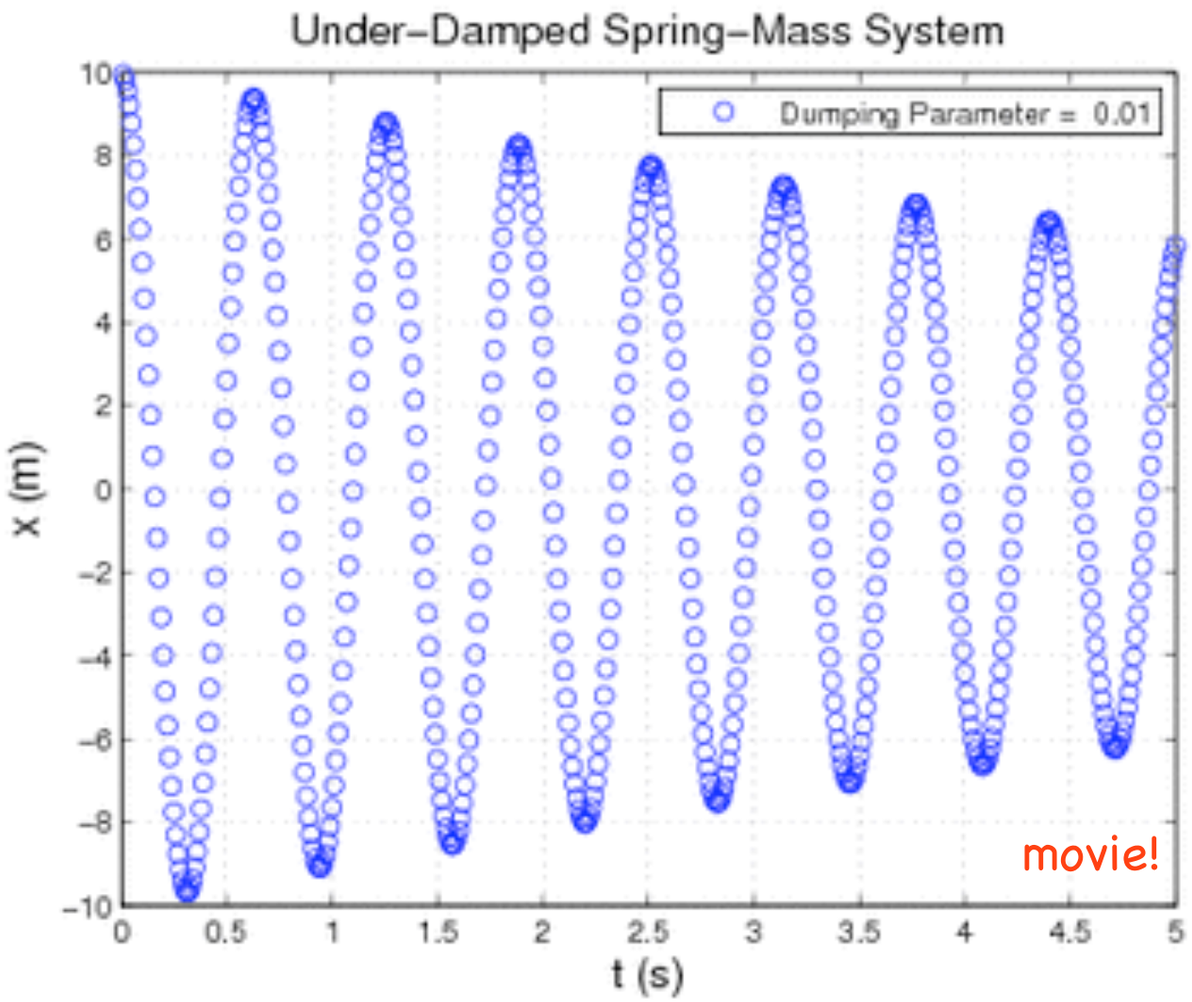
Under-damped Spring-Mass System

- ...continued.

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%                Displacement of an under-damped spring-mass system.
%
%                                HPFBU 2011 - MATLAB Tutorial
%                                Homework Solution
%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% Call the dumped_oscillator function within a "for loop" in order to plot the x-t graphs for
% different damping parameters.

for i=1:5
    z(i) = 0.01 * i;
    [x, t] = damped_oscillator(z(i));

    % Plot the x-t graphs on the same canvas every time you call the function.
    figure(1)
    plot(t,x,'ob');     %  "o" for the data point type on the plot, "b" for the blue data points
    ylabel('x (m)','fontsize',14);
    xlabel('t (s)','fontsize',14);
    title('Under-Damped Spring-Mass System','fontsize',14)
    grid on;
    legend(['Dumping Parameter =  ' num2str(z(i))])
    pause(2)          %  wait 2 seconds before updating the plot for a new damping parameter.
end
```

Under-damped Spring-Mass System

- Visualization of the behavior of the system...



PART 2 - Hands-on Practice Session

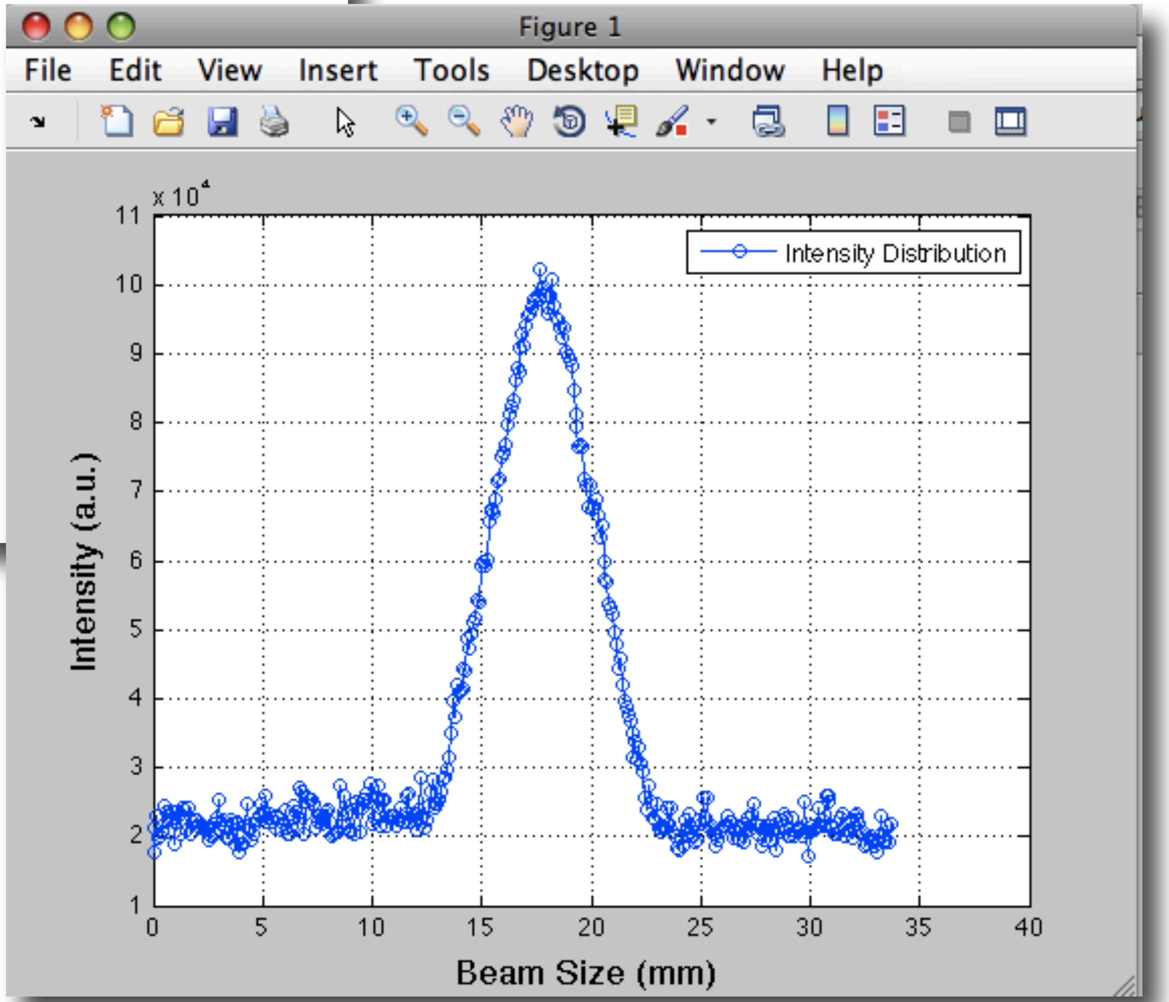
Projects

- Graphical User Interface: Building a calculator
- Under-dumped string-mass system
- **Gaussian fit to a given data set (on command line and by using Fitting Toolbox)**
- Quadrupole scan analysis for emittance measurement
- Fourier filtering???

Gaussian fit to a given data set by using MATLAB

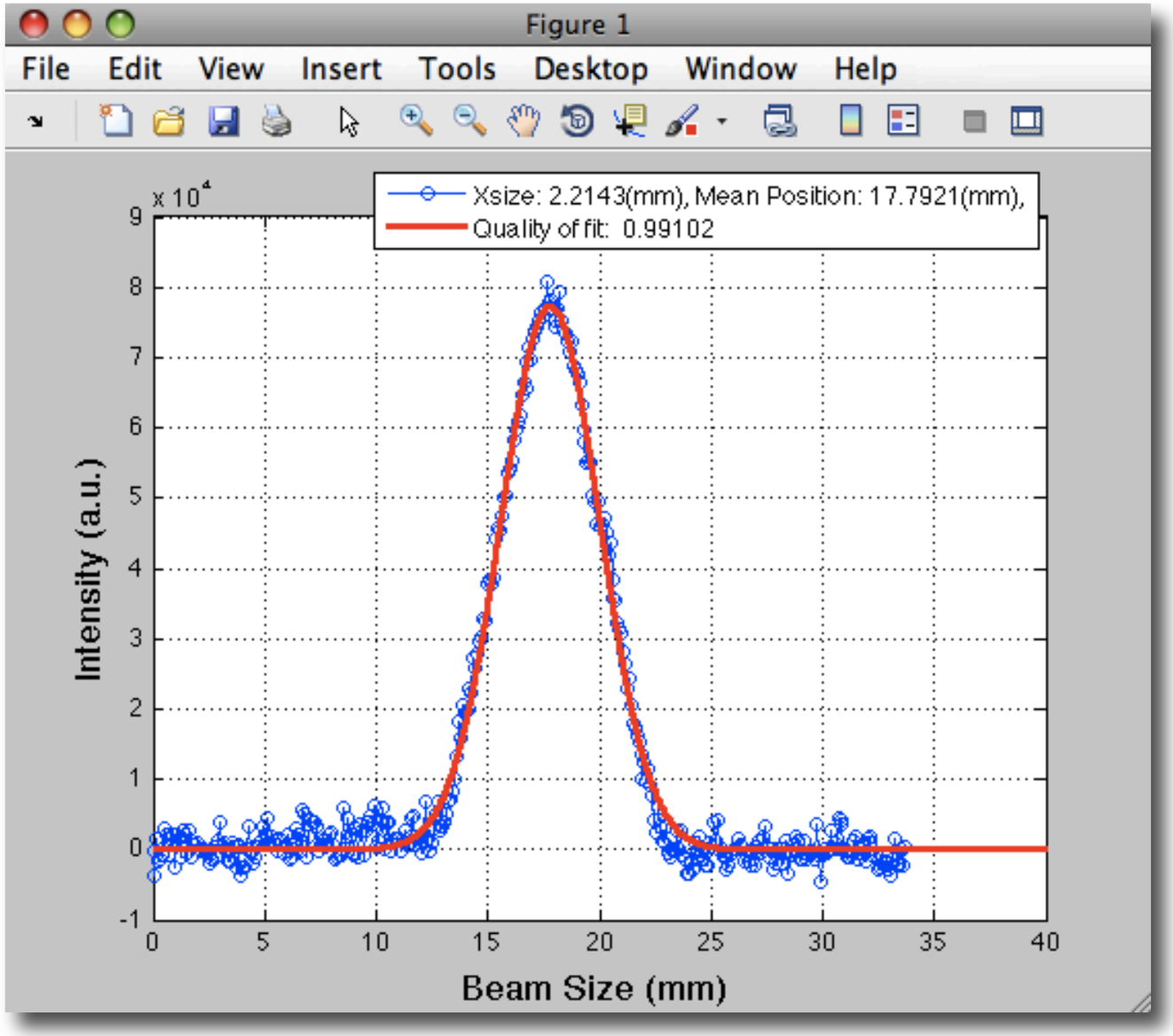
- Load a data set into the MATLAB workspace.
- Visualize the data set to be fit.

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%                    Loading and Plotting a Data Set with MATLAB
%
%                    HPFBU 2011 - MATLAB Tutorial
%
%                    Help/Questions O.Mete
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

load('data_to_be_fit.mat');

figure(1)
plot(x_ax-x_ax(1),y_ax,'-ob');
xlabel('Beam Size (mm) ','fontsize',14);
ylabel('Intensity (a.u.)','fontsize',14);
legend('Intensity Distribution')
grid on;
xlim([0 40]);
```



Gaussian fit to a given data set by using MATLAB

- Load a data set into the MATLAB workspace.
- Visualize the data set to be fit.
- How is the "fit" built-in function used in MATLAB? Please search within the documentation.



- Determine the initial fit parameters for the fit.
- Find the background to be subtracted before the fit (in this case zeroth order polynomial).
- Fit the data to a Gaussian curve.
- Extract the fit parameters.
- Plot the data and the Gaussian fit curve on top of each other.
- Transform your fitting script into a MATLAB function. Use the x and y data as the function arguments. Function should return the mean and 1sigma of the distribution as well as the Chi^2 value.

PART 2 - Hands-on Practice Session

Projects

- Graphical User Interface: Building a calculator
- Under-dumped string-mass system
- Gaussian fit to a given data set (on command line and by using Fitting Toolbox)
- **Quadrupole scan analysis for emittance measurement**
- Fourier filtering???

Quadrupole scan analysis for emittance measurement

From the diagnostics lecture...

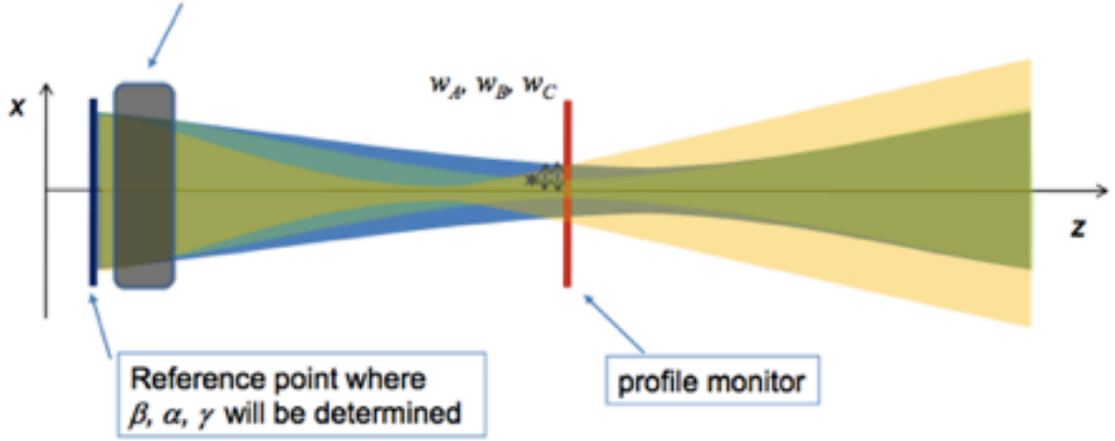
More on Emittance Diagnostics

Why we measure the emittance?

- to guide tune-up of accelerator for overall performance
  - **luminosity** of the colliders
  - **brightness** of synchrotron radiation sources
  - **wavelength range** of free electron lasers
  - **resolution** of the fixed target experiments
- closely linked with the measurement of the **Twiss parameters**
- to identify, understand and mitigate the **emittance growth mechanisms**

How we measure the emittance?

- transverse beam profiling
- slit and pepperpot methods
- Schottky signal analysis
- directly measuring the transv. profiles and divergences



Derivation of the Twiss parameters for the beam width measurement:

$$\sigma_{i,11} = C_i^2\,\sigma_{11} + 2S_iC_i\,\sigma_{12} + S_i^2\,\sigma_{22}$$

$$\begin{bmatrix}\sigma_{1,11}\\ \sigma_{2,11}\\ \sigma_{3,11}\end{bmatrix} = \begin{bmatrix}C_1^2 & 2C_1S_1 & S_1^2\\ C_2^2 & 2C_2S_2 & S_2^2\\ C_3^2 & 2C_3S_3 & S_3^2\end{bmatrix}\begin{bmatrix}\sigma_{11}\\ \sigma_{12}\\ \sigma_{22}\end{bmatrix} = \mathcal{M}_\sigma\begin{bmatrix}\sigma_{11}\\ \sigma_{12}\\ \sigma_{22}\end{bmatrix}$$

$$\sigma_{1,11}(k) = C^2(k)\,\sigma_{11} + 2C(k)\,S(k)\,\sigma_{12} + S^2(k)\,\sigma_{22}$$

$$\boldsymbol{\sigma} = \begin{bmatrix}\sigma_{11} & \sigma_{12}\\ \sigma_{12} & \sigma_{22}\end{bmatrix} = \epsilon\begin{bmatrix}\beta & -\alpha\\ -\alpha & \gamma\end{bmatrix} \qquad V_2 = \pi\sqrt{\det\boldsymbol{\sigma}} = \pi\sqrt{\sigma_{11}\,\sigma_{22} - \sigma_{12}^2} = \pi\,\epsilon$$

- to determine the emittance and Twiss parameters one needs at least **3 w measurements** with different transfer matrices between the reference point and the w measurement location.
- different matrices can be achieved with **different profile monitor locations, different magnet settings** or combinations of both.

Quadrupole scan analysis for emittance measurement

$$\sigma_{1,11} = C_A(k)^2\sigma_{11} - 2C_A(k)S_A(k)\sigma_{12} + S_A(k)^2\sigma_{22}$$

$$\sigma_{11} = \beta\epsilon$$
$$\sigma_{12} = \alpha\epsilon$$
$$\sigma_{22} = \gamma\epsilon$$

For a system of a quadrupole + drift the transfer matrix:

$$M = M_D M_{QF} = \begin{pmatrix} 1 & l \\ 0 & 1 \end{pmatrix}\begin{pmatrix} 1 & 0 \\ \frac{1}{f(k)} & 1 \end{pmatrix} = \begin{pmatrix} \frac{l}{f(k)}+1 & l \\ \frac{1}{f(k)} & 1 \end{pmatrix} \Leftrightarrow \begin{pmatrix} C(k) & S(k) \\ C'(k) & S'(k) \end{pmatrix}$$

$$\sigma_{1,11} = (\frac{l}{f(k)}+1)^2\sigma_{11} - 2(\frac{l}{f(k)}+1)l\sigma_{12} + l^2\sigma_{22}$$

$$C(k) = \frac{l}{f(k)} + 1$$
$$S(k) = l$$

Second order polynomial with respect to (1/f + 1).

Quadrupole scan analysis for emittance measurement

Second order polynomial with respect to (1/f + 1).

$$W_A = (\frac{l}{f(k)} + 1)^2 \sigma_{11} - 2(\frac{l}{f(k)} + 1) l \sigma_{12} + l^2 \sigma_{22}$$

Fit parameters (a,b,c):

$a = \sigma_{11}$

$b = 2l\sigma_{12}$

$c = l^2 \sigma_{22}$

Remember:

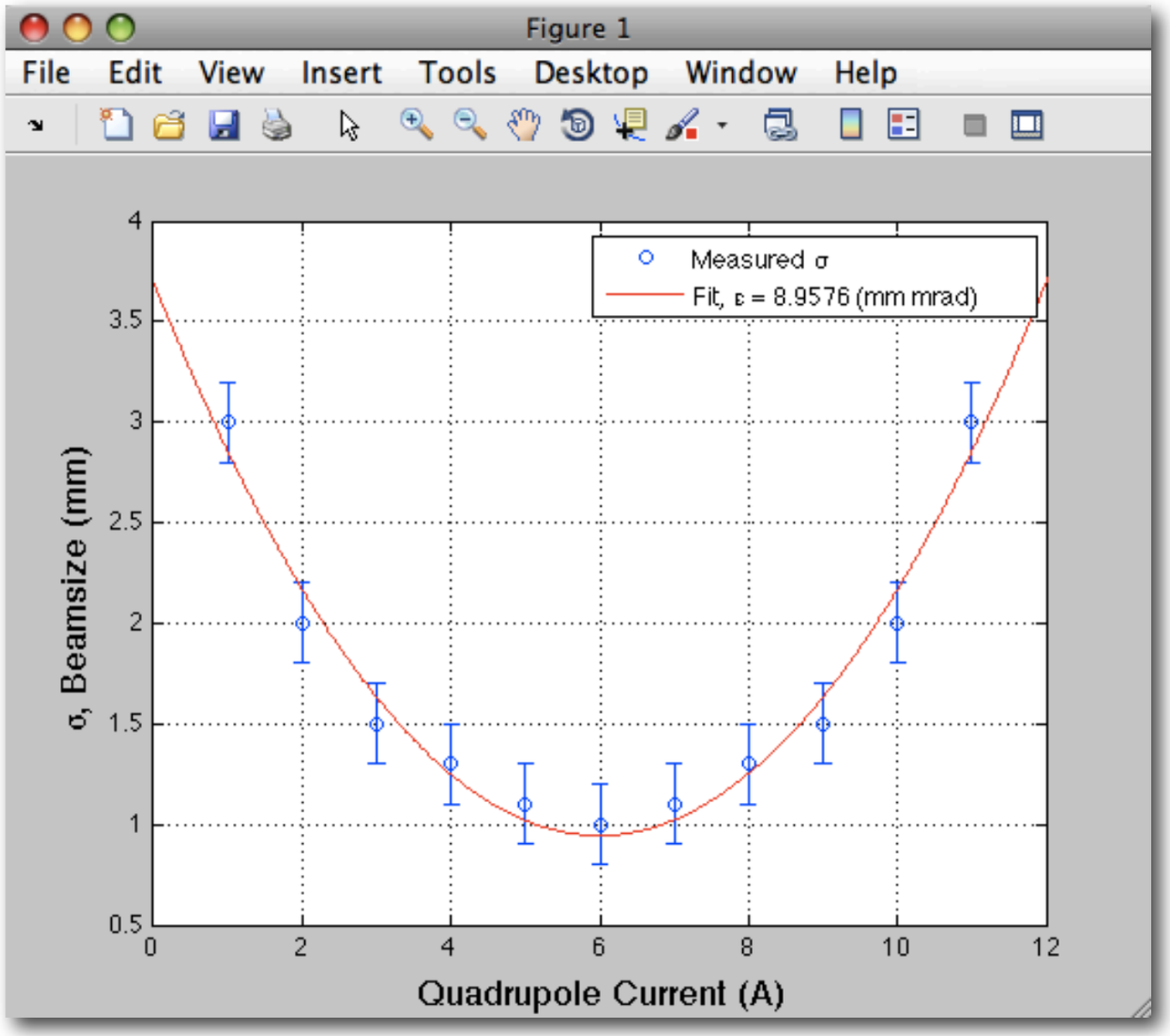
$\sigma_{11} = \beta\epsilon$

$\sigma_{12} = \alpha\epsilon$

$\sigma_{22} = \gamma\epsilon$

and,

$$\epsilon^2 = \sigma_{11}\sigma_{22} - \sigma_{12}^2$$



PART III

EXTRAS

one step further

- how to make your plots visually more representable? :)

one step further

- MATLAB toolboxes: plots, statistics, image processing, signal processing neural network...

one step further

- Importing c++ codes into matlab

one step further

- Object-oriented programming in MATLAB