Session 4: Visualization and GUI programming

Version 1.0.2

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Contents

1 Visualization

1.1 A MATLAB graph

The MATLAB environment offers a variety of data plotting functions plus a set of Graphical User Interface (GUI) tools to create, and modify graphic displays.

A *figure* is a MATLAB window that contains graphic displays (usually data plots) and UI components. You create figures explicitly with the *figure* function, and implicitly whenever you plot graphics and no figure is active.

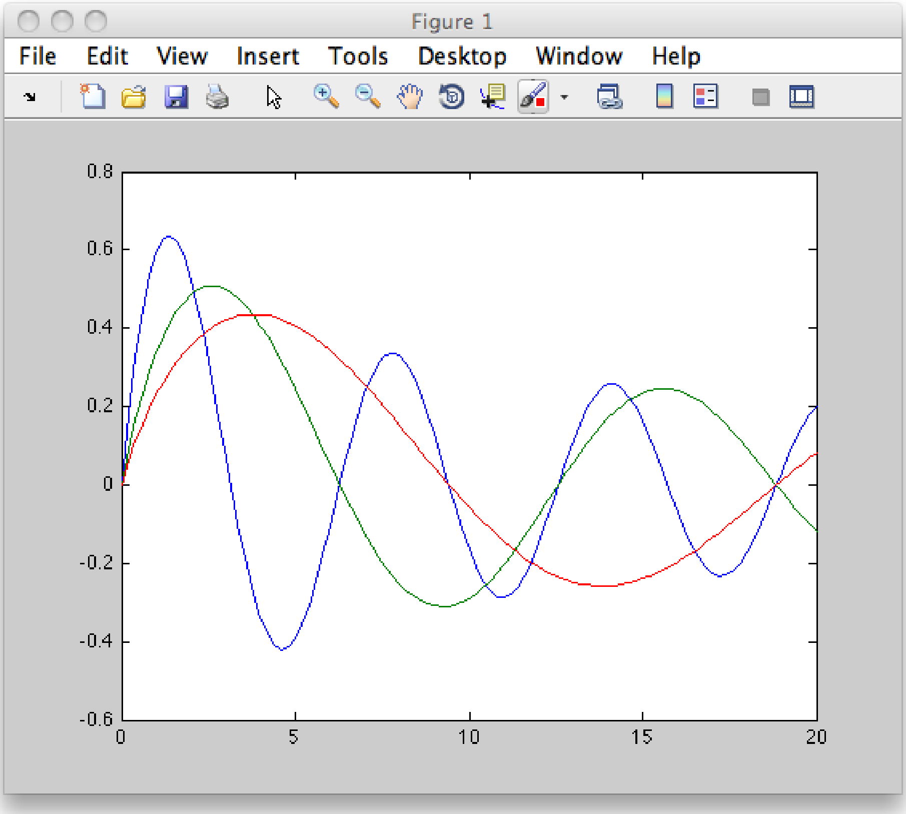
```
h = figure;
```

By default, figure windows are resizable and include pull-down menus and toolbars.

A *plot* is any graphic display you can create within a figure window. Plots can display tabular data, geometric objects, surface and image objects, and annotations such as titles, legends, and colorbars. Figures can contain any number of plots. Each plot is created within a 2-D or a 3-D data space called an *axes*. You can explicitly create axes with the *axes* or *subplot* functions.

A *graph* is a plot of data within a 2-D or 3-D axes. Most plots made with MATLAB functions and GUIs are therefore graphs. When you graph a one-dimensional variable (e.g., *rand(100,1)*), the indices of the data vector (in this case *1:100*) become assigned as x values, and plots the data vector as y values. Some types of graphs can display more than one variable at a time, others cannot.

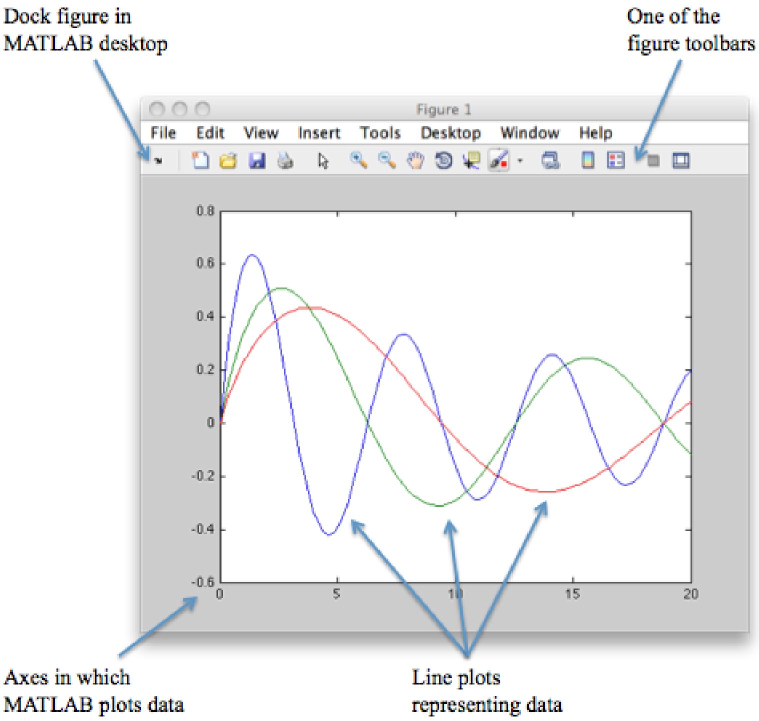
```
x = 0:.2:20;
y = sin(x)./sqrt(x+1);
y(2,:) = sin(x/2)./sqrt(x+1);
y(3,:) = sin(x/3)./sqrt(x+1);
plot(x,y)
```



The resulting figure contains a 2-D set of axes.

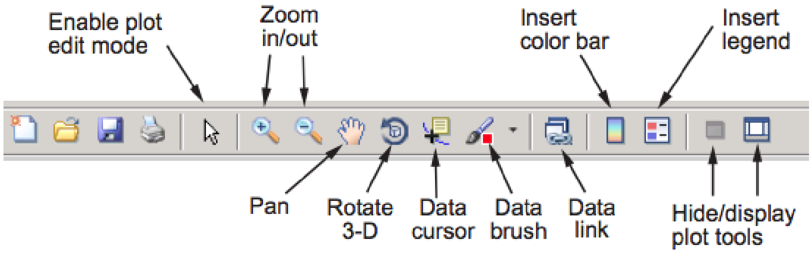
The plot function uses a default line style and color to distinguish the data sets plotted in the graph. You can change the appearance of these graphic components or add annotations to the graph to present your data in a particular way.

This graphic identifies the components and tools of a figure window.



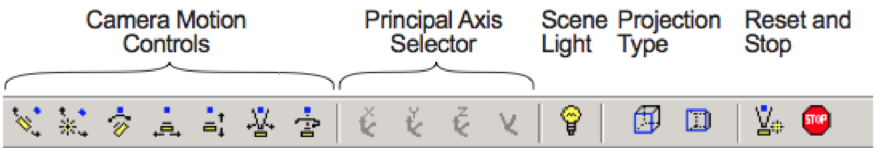
1.2 Figure toolbars

Figure toolbars provide shortcuts to access commonly used features. These include operations such as saving and printing, plus tools for interactive zooming, panning, rotating, querying, and editing plots. The following picture shows the features available from this toolbar.

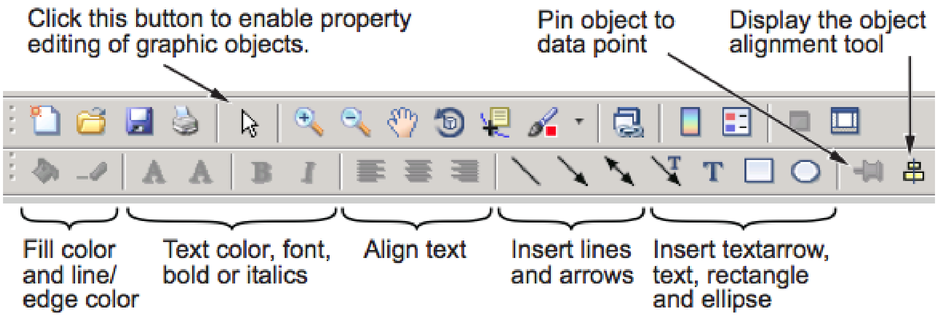


You can enable two other toolbars from the **View** menu:

- **Camera toolbar**. Use for manipulating 3-D views, with camera, light, and projection controls.



- **Plot Edit toolbar**. Use for annotation and setting plot and object properties.



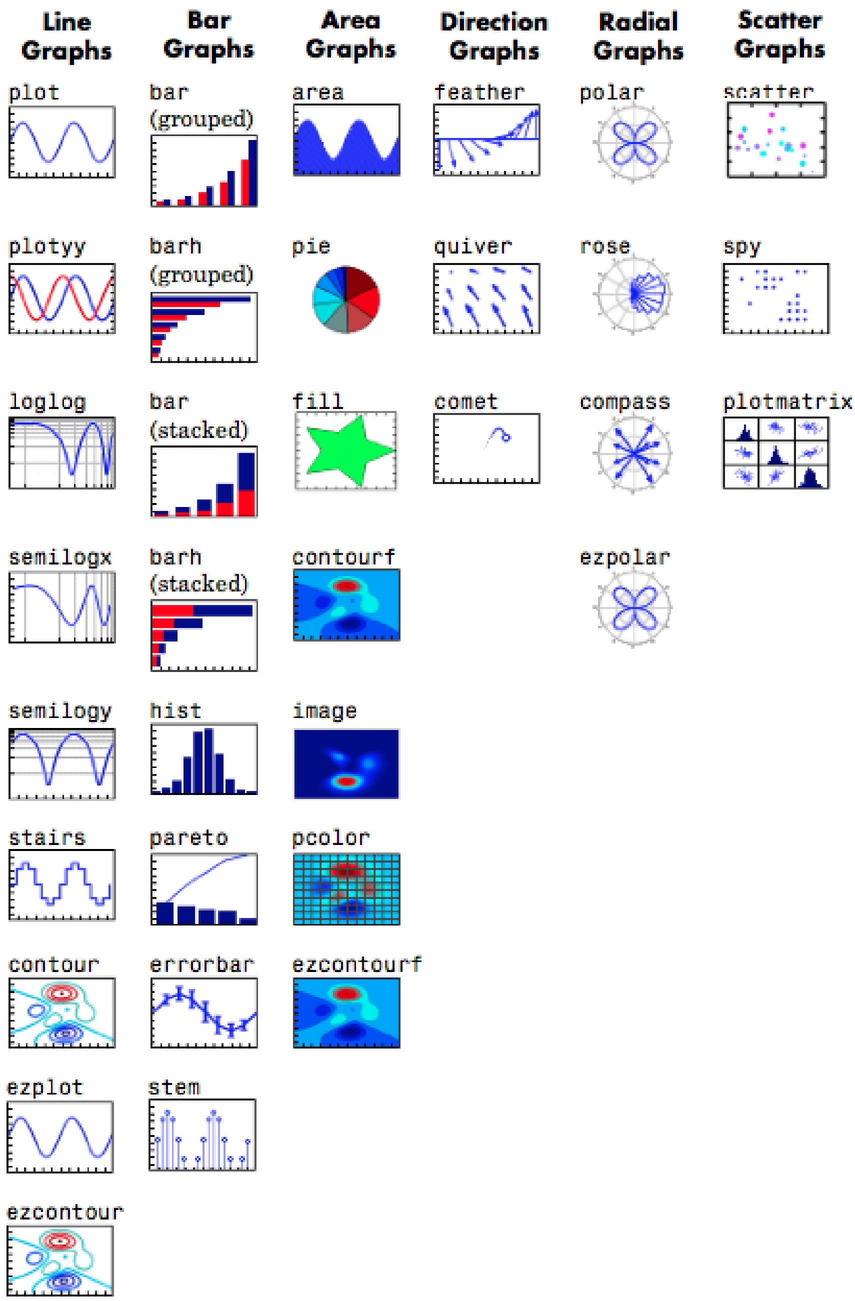
1.3 Types of plots

You can construct a wide variety of 2-D and 3-D MATLAB plots with very little, if any, programming required on your part. The following two tables classify and illustrate most of the kinds of plots you can create. They include line, bar, area, direction and vector field, radial, and scatter graphs. They also include 2-D and 3-D functions that generate and plot geometric shapes and objects. Most 2-D plots have 3-D analogs, and there are a variety of volumetric displays for 3-D solids and vector fields. Plot types that begin with "ez" (such as *ezsurf*) are convenience functions that can plot arguments given as functions.

1.3.1 Two-dimensional plotting functions

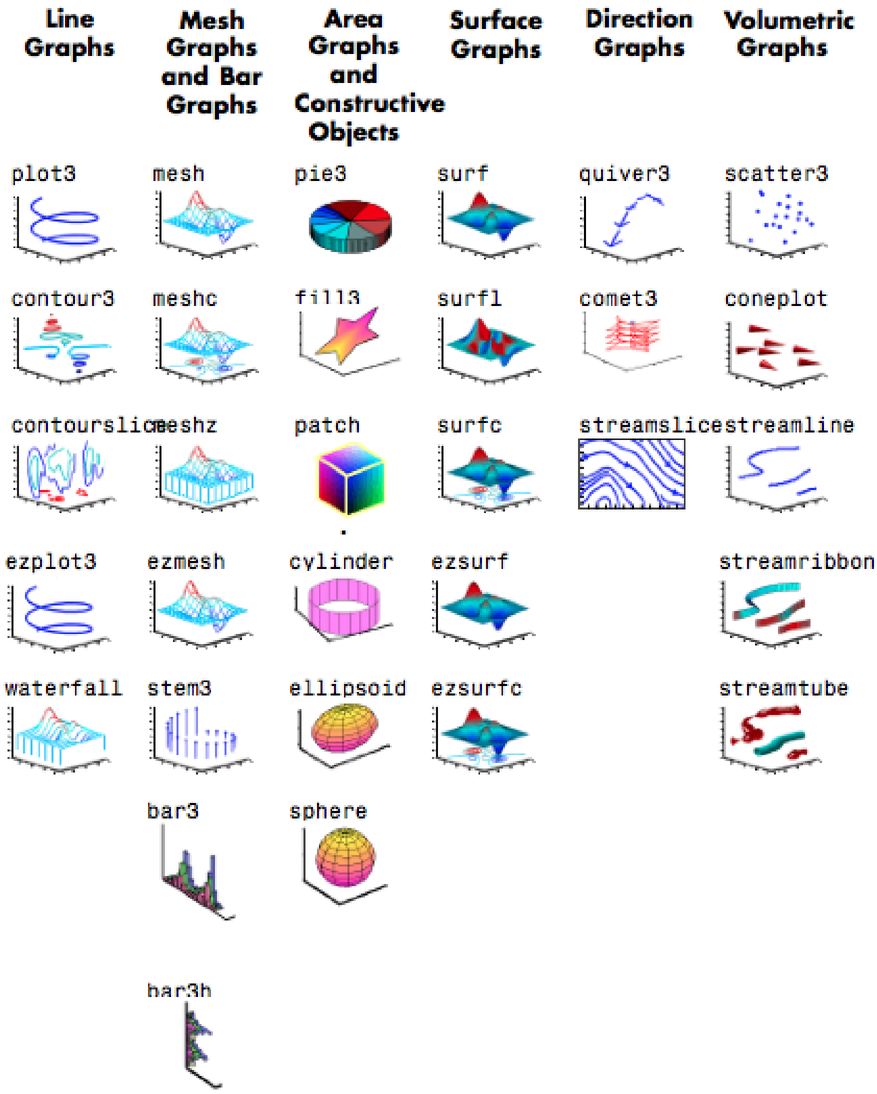
The table below shows all available MATLAB 2-D plot functions. You can get documentation for each of the functions by typing *help function_name* in the MATLAB console, for example:

```
help plotyy
```



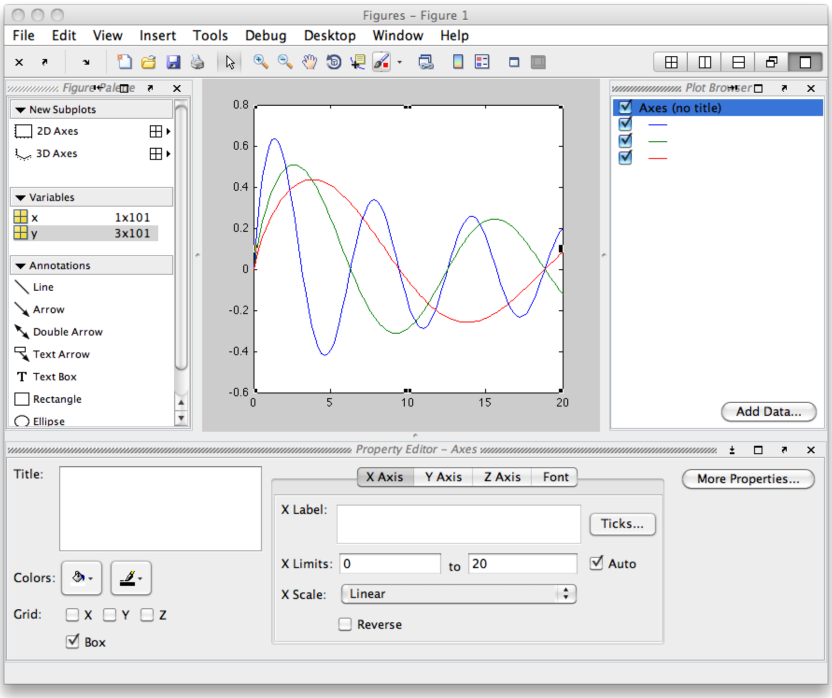
1.3.2 Three-dimensional plotting functions

The table below shows all available MATLAB 3-D and volumetric plot functions. It includes functions that generate 3-D data (*cylinder*, *ellipsoid*, *sphere*), but most plot either arrays of data or functions.



1.4 Interactive plots with the plot tools

Most of the plotting functions shown in the previous tables are accessible through the **Figure Palette**, one of the **Plot Tools** you can access via the figure window **View** menu. When the Figure Palette is active and you select one, two or more variables listed within it, you can generate a plot of any appropriate type by right-clicking and selecting a plot type from the context menu that appears. The lowest item on that menu is **More Plots**. When you select **More Plots**, the *Plot Catalog* opens for you to browse through all plot types and generate one of them, either to display the variables you selected in the Figure Palette or a MATLAB expression you can specify in the Plot Catalog window.



We won't discuss the plot tools in this course.

1.5 Basic plotting commands

1.5.1 Creating Figure Windows

MATLAB graphics are directed to a window that is separate from the Command Window. This window is referred to as a **figure**. The characteristics of this window are controlled by your computer's windowing system and MATLAB figure properties.

Graphics functions automatically create new MATLAB figure windows if none currently exist. If a figure already exists, that window is used. If multiple figures exist, one is designated as the current figure and is used (this is generally the last figure used or the last figure you clicked the mouse in). The figure function creates figure windows. For example,

```
figure
```

creates a new window and makes it the current figure. You can make an existing figure current by clicking it with the mouse or by passing its handle (the number indicated in the window title bar), as an argument to figure.

```
figure(2)
```

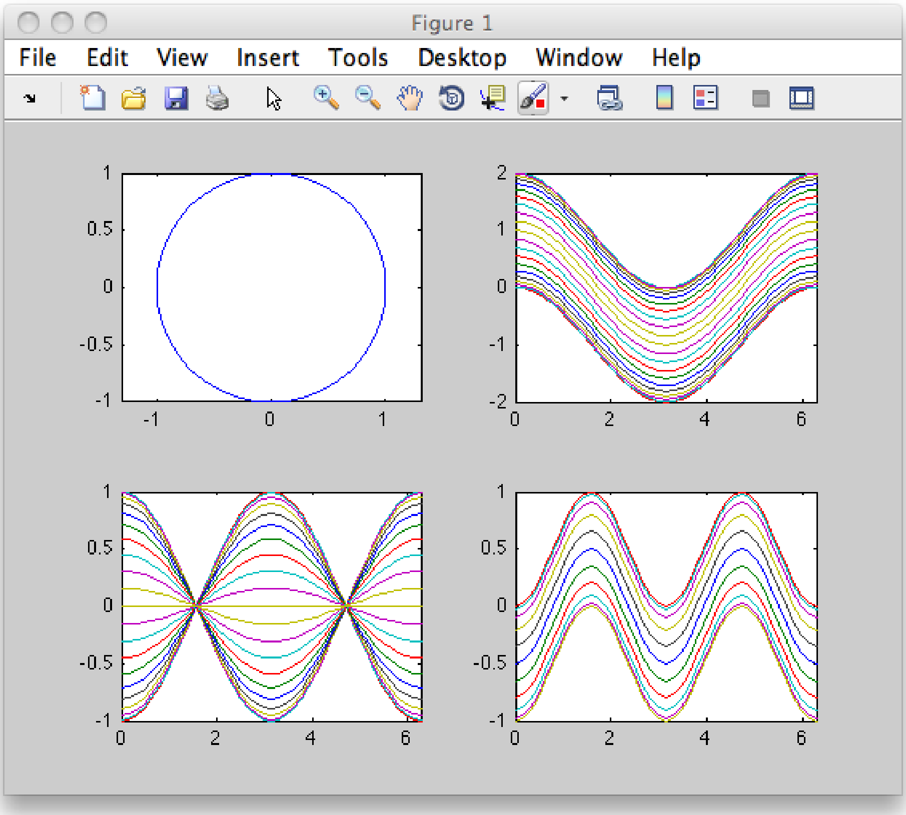
The handle is returned when the figure is created.

```
h = figure
h =
     3
```

1.5.2 Displaying Multiple Plots per Figure

You can display multiple plots in the same figure window and print them on the same piece of paper with the *subplot* function. *subplot(m,n,i)* breaks the figure window into an m-by-n matrix of small subplots and selects the *ith* subplot for the current plot. The plots are numbered along the top row of the figure window, then the second row, and so forth. For example, the following statements plot data in four different subregions of the figure window.

```
t = 0:pi/20:2*pi;
[x,y] = meshgrid(t);
subplot(2,2,1); plot(sin(t),cos(t)); axis equal;
subplot(2,2,2); z = sin(x)+cos(y); plot(t,z); axis([0 2*pi -2 2]);
subplot(2,2,3); z = sin(x).*cos(y); plot(t,z); axis([0 2*pi -1 1]);
subplot(2,2,4); z = (sin(x).^2)-(cos(y).^2); plot(t,z); axis([0 2*pi -1 1]);
```



Each subregion contains its own axes with characteristics you can control independently of the other subregions. This example uses the *axis* function to set limits and change the shape of the subplots. See the *axes*, *axis*, and *subplot* functions for more information.

1.5.3 Specifying the Target Axes

The current axes is the last one defined by *subplot*. If you want to access a previously defined subplot, for example to add a title, you must first make that axes current. You can make an axes current in three ways:

- Click on the subplot with the mouse.
- Call *subplot* with the *m*, *n*, *i* specifiers.

```
subplot(2,2,2); title('Top Right Plot');
```

- Call subplot with the handle (identifier) of the axes.

```
h = get(gcf,'Children');
subplot(h(1)); title('Most recently created axes');
subplot(gca); title('Current active axes');
```

The call

```
get(gcf,'Children');
```

returns the handles of all the axes, with the most recently created one first. The function *gca* returns the handle of the current active axes.

1.6 Using High-Level Plotting Functions

1.6.1 Functions for Plotting Line Graphs

Many types of MATLAB functions are available for displaying vector data as line plots, as well as functions for annotating and printing these graphs. The following table summarizes the functions that produce basic line plots. These functions differ in the way they scale the plot's axes. Each accepts input in the form of vectors or matrices and automatically scales the axes to accommodate the data.

Function	Description
plot	Graph 2-D data with linear scales for both axes
plot3	Graph 3-D data with linear scales for both axes
loglog	Graph with logarithmic scales for both axes
semilogx	Graph with a logarithmic scale for the x-axis and a linear scale for the y-axis
semilogy	Graph with a logarithmic scale for the y-axis and a linear scale for the x-axis
plotyy	Graph with y-tick labels on the left and right side

1.6.2 Programmatic plotting

The process of constructing a basic graph to meet your presentation graphics requirements is outlined in the following table. The table shows seven typical steps and some example code for each. If you are performing analysis only, you may want to view various graphs just to explore your data. In this case, steps 1 and 3 may be all you need. If you are creating presentation graphics, you may want to fine-tune your graph by positioning it on the page, setting line styles and colors, adding annotations, and making other such improvements.

Step	Typical code

1 Prepare your data	x = 0:0.2:12;
	y1 = besselj(1,x);
	y2 = besselj(2,x);
	y3 = besselj(3,x);

2 Select a window and position a plot region within the window	figure(1); subplot(2,2,1);
3 Call elementary plotting function	h = plot(x,y1,x,y2,x,y3);

4 Select line and marker characteristics	set(h,'LineWidth',2, ...
	{'LineStyle'},{'–';':';'-.'});
	set(h,{'Marker'},{'none';'o';'x' });
	set(h,{'Color'},{'r';'g';'b'});

5 Set axis limits, tick marks, and grid lines	axis([0 12 -0.5 1]); grid on;

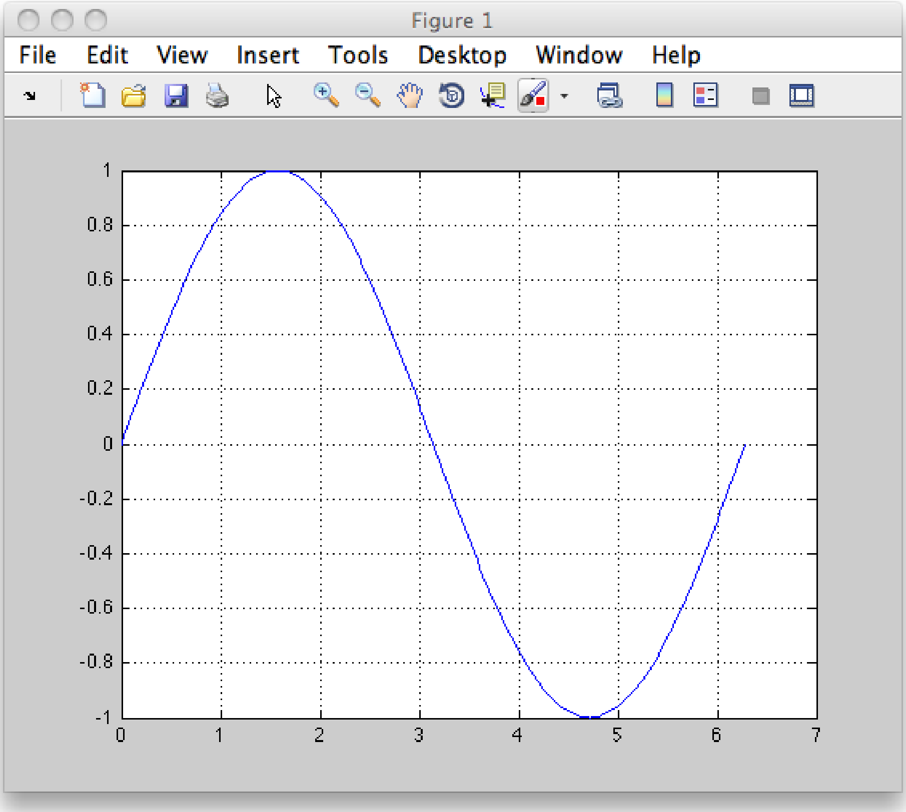
6 Annotate the graph with axis labels, legend, and text	xlabel('Time');
	ylabel('Amplitude');
	legend(h,'First','Second','Third');
	title('Bessel Functions');
	[y,ix] = min(y1);
	text(x(ix),y,'First Min \rightarrow', ...
	'HorizontalAlignment','right');

7 Export graph	print -depsc -tiff -r200 myplot

1.6.3 Creating line plots

The *plot* function has different forms depending on the input arguments. For example, if y is a vector, *plot(y)* produces a linear graph of the elements of y versus the index of the elements of y. If you specify two vectors as arguments, *plot(x,y)* produces a graph of y versus x. For example, the following statements create a vector of values in the range $[0, 2\pi]$ in increments of $\pi/100$ and then use this vector to evaluate the sine function over that range. MATLAB plots the vector on the x-axis and the value of the sine function on the y-axis.

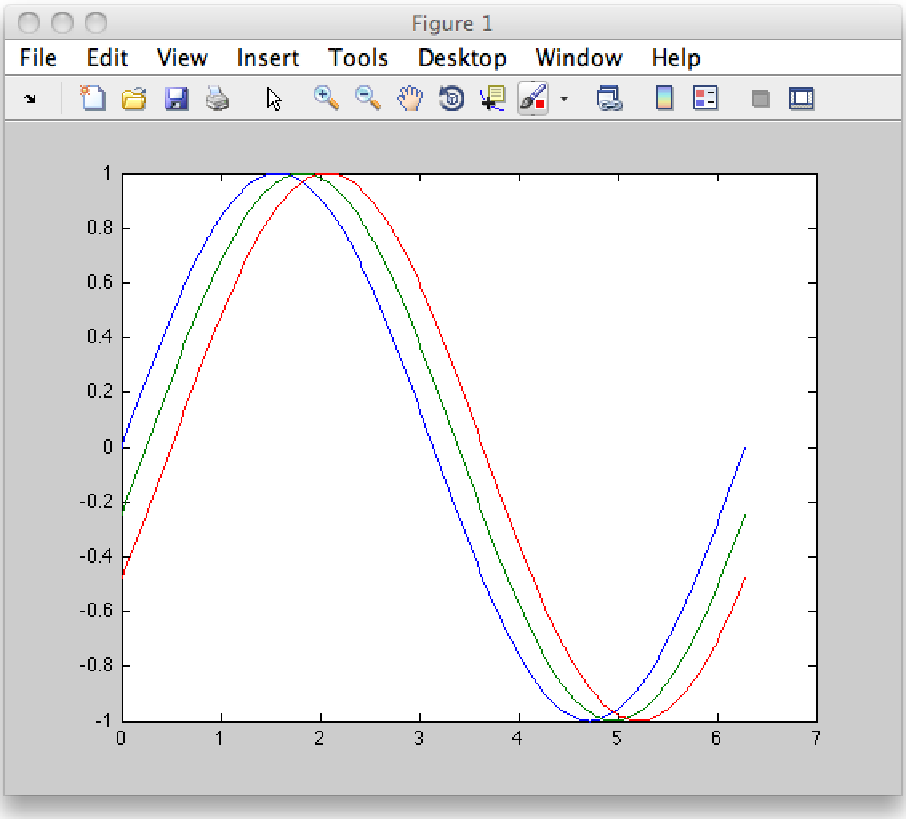
```
t = 0:pi/100:2*pi;
y = sin(t);
plot(t,y);
grid on % Turn on grid lines for this plot
```



Appropriate axis ranges and tick mark locations are automatically selected.

You can plot multiple graphs in one call to plot using *x*-*y* pairs. MATLAB automatically cycles through a predefined list of colors (determined by the axes *ColorOrder* property) to allow discrimination between sets of data. Plotting three curves as a function of *t* produces

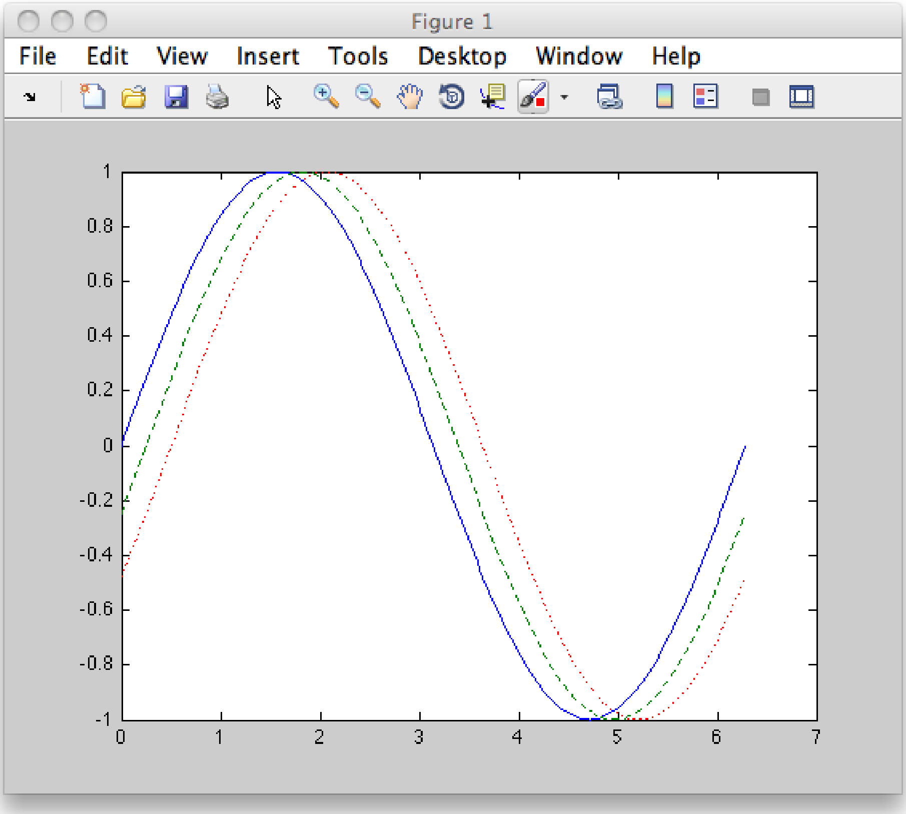
```
y = sin(t);
y2 = sin(t-0.25);
y3 = sin(t-0.5);
plot(t,y,t,y2,t,y3)
```



1.6.4 Specifying line style

You can assign different line styles to each data set by passing line style identifier strings to plot. For example,

```
plot(t,y,'-',t,y2,'--',t,y3,':')
```



The graph shows three lines of different colors and lines styles representing the value of the sine function with a small phase shift between each line, as defined by y, $y2$, and $y3$. The lines are blue solid, green dashed, and red dotted.

1.6.5 Colors, line styles, and markers

The basic plotting functions accepts character-string arguments that specify various line styles, marker symbols, and colors for each vector plotted. In the general form,

```
plot(x,y,'linestyle_marker_color')
```

linestyle_marker_color is a character string (delineated by single quotation marks) constructed from:

- A line style (e.g., dashed, dotted, etc.)
- A marker type (e.g., *x*, *, *o*, etc.)
- A predefined color specifier (*c*, *m*, *y*, *k*, *r*, *g*, *b*, *w*)

For example,

```
plot(x,y,':squarey')
```

plots a yellow dotted line and places square markers at each data point. If you specify a marker type, but not a line style, only the marker is plotted. The specification can consist of one or none of each specifier in any order. For example, the string

```
'go--'
```

defines a dashed line with circular markers, both colored green. You can also specify the size of the marker and, for markers that are closed shapes, you can specify separately the colors of the edges and the face.

1.6.6 Specifying the Color and Size of Lines

You can control a number of line style characteristics by specifying values for line properties:

- *LineWidth* — Width of the line in units of points
- *MarkerEdgeColor* — Color of the marker or the edge color for filled markers (circle, square, diamond, pentagram, hexagram, and the four triangles)
- *MarkerFaceColor* — Color of the face of filled markers
- *MarkerSize* — Size of the marker in units of points

For example, these statements,

```
x = -pi:pi/10:pi;
y = tan(sin(x)) - sin(tan(x));
plot(x,y,'--rs','LineWidth',2,...
  'MarkerEdgeColor','k',...
  'MarkerFaceColor','g',...
  'MarkerSize',10)
```

produce a graph with:

- A red dashed line with square markers
- A line width of two points
- The edge of the marker colored black
- The face of the marker colored green
- The size of the marker set to 10 points

Try!

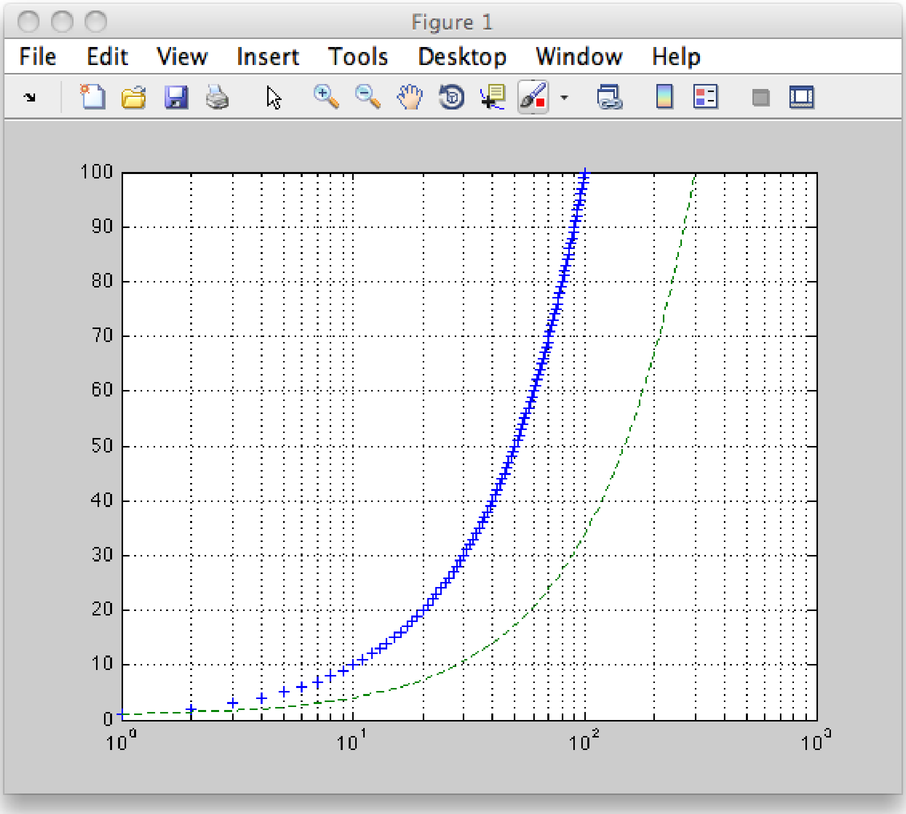
1.6.7 Adding Plots to an Existing Graph

You can add plots to an existing graph using the *hold* command. When you set *hold* to *on*, MATLAB does not remove the existing graph; it adds the new data to the current graph, rescaling if the new data falls outside the range of the previous axis limits.

For example, these statements first create a semilogarithmic plot, then add a linear plot.

```
semilogx(1:100,'+')
hold all % hold plot and cycle line colors
plot(1:3:300,1:100,'--')
hold off
grid on % Turn on grid lines for this plot
```

The x-axis limits are reset to accommodate the new data, but the scaling from logarithmic to linear does not change.



1.6.8 Line Plots of Matrix Data

When you call the *plot* function with a single matrix argument

```
plot(Y)
```

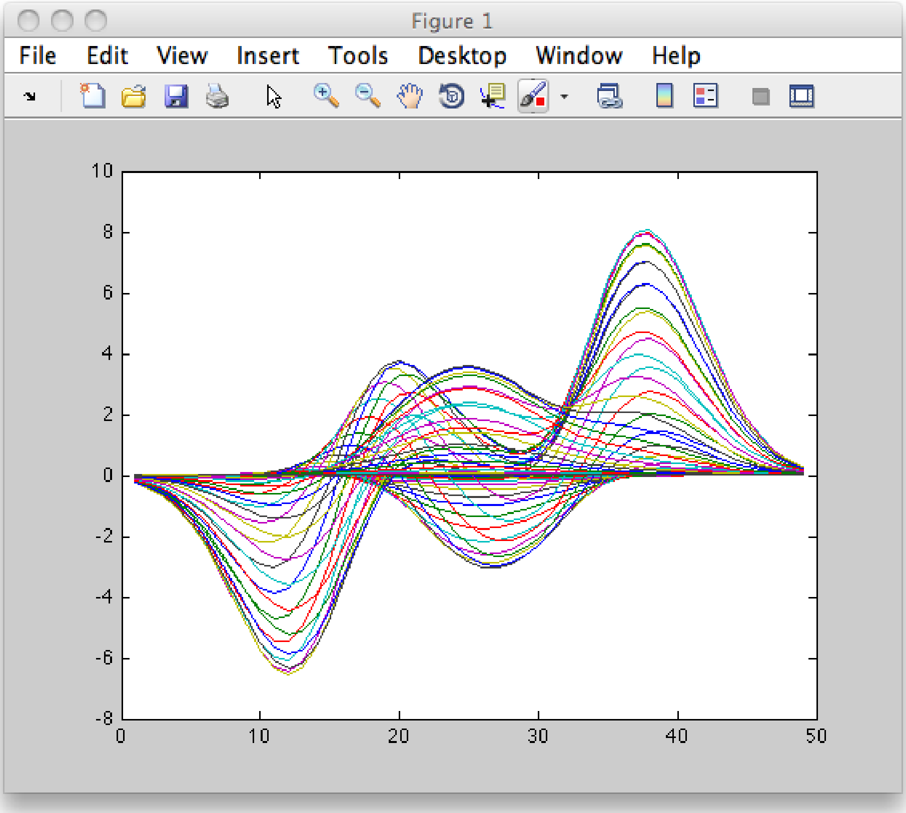
one line is plotted for each column of the matrix. The x-axis is labeled with the row index vector 1:*m*, where *m* is the number of rows in Y. For example,

```
Z = peaks;
```

returns a 49-by-49 matrix obtained by evaluating a function of two variables. Plotting this matrix

```
plot(Z)
```

produces a graph with 49 lines.



In general, if *plot* is used with two arguments and if either X or Y has more than one row or column, then:

- If Y is a matrix, and x is a vector, *plot(x,Y)* successively plots the rows or columns of Y versus vector x, using different colors or line types for each. The row or column orientation varies depending on whether the number of elements in x matches the number of rows in Y or the number of columns. If Y is square, its columns are used.

- If X is a matrix and y is a vector, *plot(X,y)* plots each row or column of X versus vector y. For example, plotting the peaks matrix versus the vector *1:length(peaks)* rotates the previous plot.

- If X and Y are both matrices of the same size, *plot(X,Y)* plots the columns of X versus the columns of Y. You can also use the plot function with multiple pairs of matrix arguments.

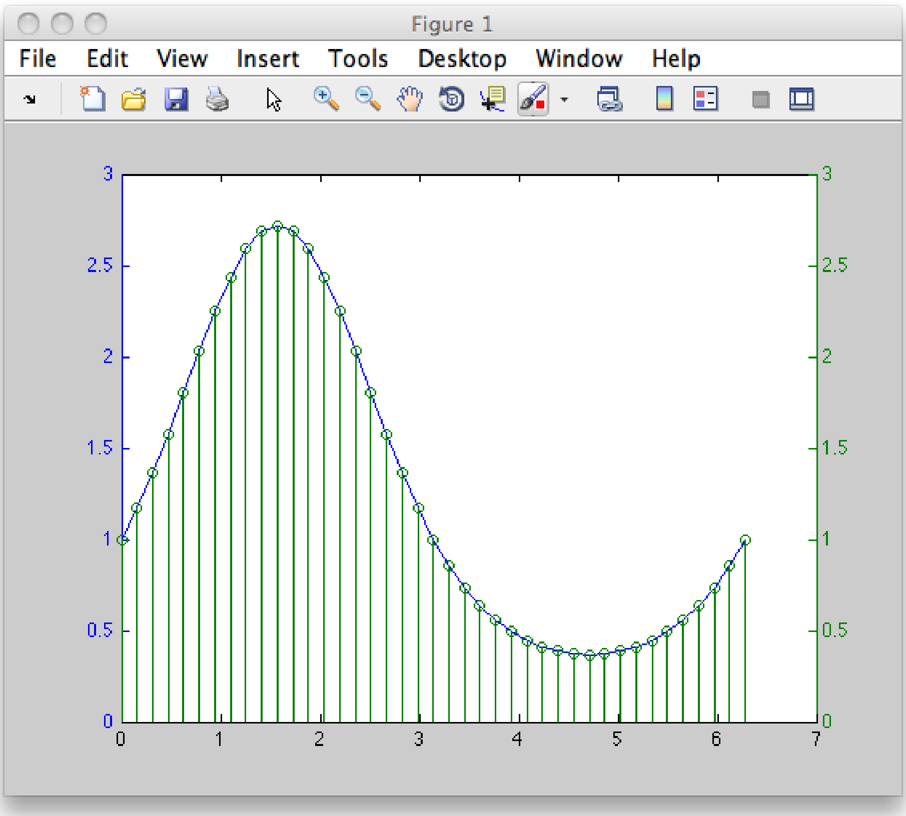
  ```
  plot(X1,Y1,X2,Y2,...)
  ```

  This statement graphs each X-Y pair, generating multiple lines. The different pairs can be of different dimensions.

1.6.9 Plotting with two y-axes

The *plotyy* function enables you to create plots of two data sets and use both left and right side y-axes. You can also apply different plotting functions to each data set. For example, you can combine a line plot with a stem plot of the same data.

```
t = 0:pi/20:2*pi;
y = exp(sin(t));
plotyy(t,y,t,y,'plot','stem')
```



1.6.10 Combining linear and logarithmic axes

You can use *plotyy* to apply linear and logarithmic scaling to compare two data sets having different ranges of values.

```
t = 0:900; A = 1000; a = 0.005; b = 0.005;
z1 = A*exp(-a*t);
z2 = sin(b*t);
[haxes,hline1,hline2] = plotyy(t,z1,t,z2,'semilogy','plot');
```

This example saves the handles of the lines and axes created to adjust and label the graph. First, label the axes whose y value ranges from 10 to 1000. This is the first handle in haxes because it was specified first in the call to plotyy. Use the axes function to make *haxes(1)* the current axes, which is then the target for the *ylabel* function.

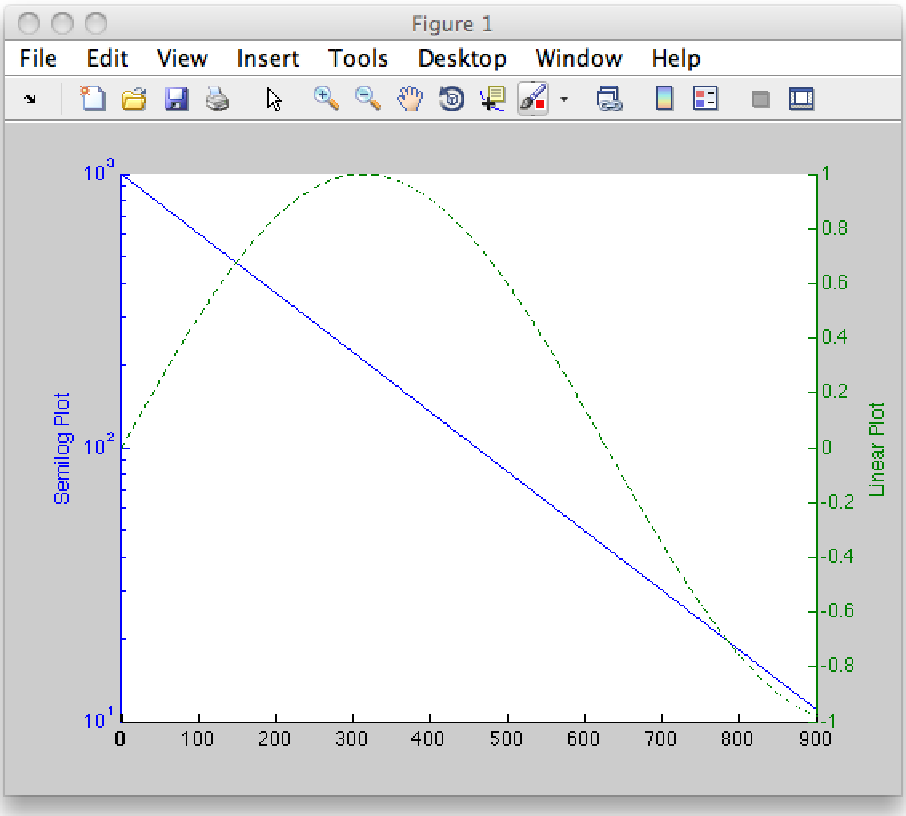
```
axes(haxes(1))
ylabel('Semilog Plot')
```

Now make the second axes current and call *ylabel* again.

```
axes(haxes(2))
ylabel('Linear Plot')
```

You can modify the characteristics of the plotted lines in a similar way. For example, to change the line style of the second line plotted to a dashed line, use the statement

```
set(hline2,'LineStyle','--')
```



1.7 Setting axis parameters

1.7.1 Axis Scaling and Ticks

When you create a MATLAB graph, the axis limits and tick-mark spacing are automatically selected based on the data plotted. However, you can also specify your own values for axis limits and tick marks with the following functions:

- *axis* — Sets values that affect the current axes object (the most recently created or the last clicked on).
- *axes* — Creates a new axes object with the specified characteristics.
- *get* and *set* — Enable you to query and set a wide variety of properties of existing axes.
- *gca* — Returns the handle (identifier) of the current axes. If there are multiple axes in the figure window, the current axes is the last graph created or the last graph you clicked on with the mouse. The following two sections provide more information and examples

1.7.2 Axis Limits and Ticks

By default, axis limits are chosen to encompass the range of the plotted data. You can specify the limits manually using the *axis* function. Call *axis* with the new limits defined as a four-element vector.

```
axis([xmin,xmax,ymin,ymax]);
```

The minimum values must be less than the maximum values.

1.7.3 Semiautomatic Limits

If you want to autoscale only one of a min/max set of axis limits, but you want to specify the other, use the MATLAB variable *Inf* or *-Inf* for the autoscaled limit.

```
axis([-Inf 5 2 2.5]);
```

1.7.4 Axis tick marks

The tick-mark locations are based on the range of data so as to produce equally spaced ticks (for linear graphs). You can specify different tick marks by setting the axes *XTick* and *YTick* properties. Define tick marks as a vector of increasing values. The values do not need to be equally spaced. For example:

```
set(gca,'YTick',[2 2.1 2.2 2.3 2.4 2.5]);
```

produces a graph with only the specified ticks on the y-axis.

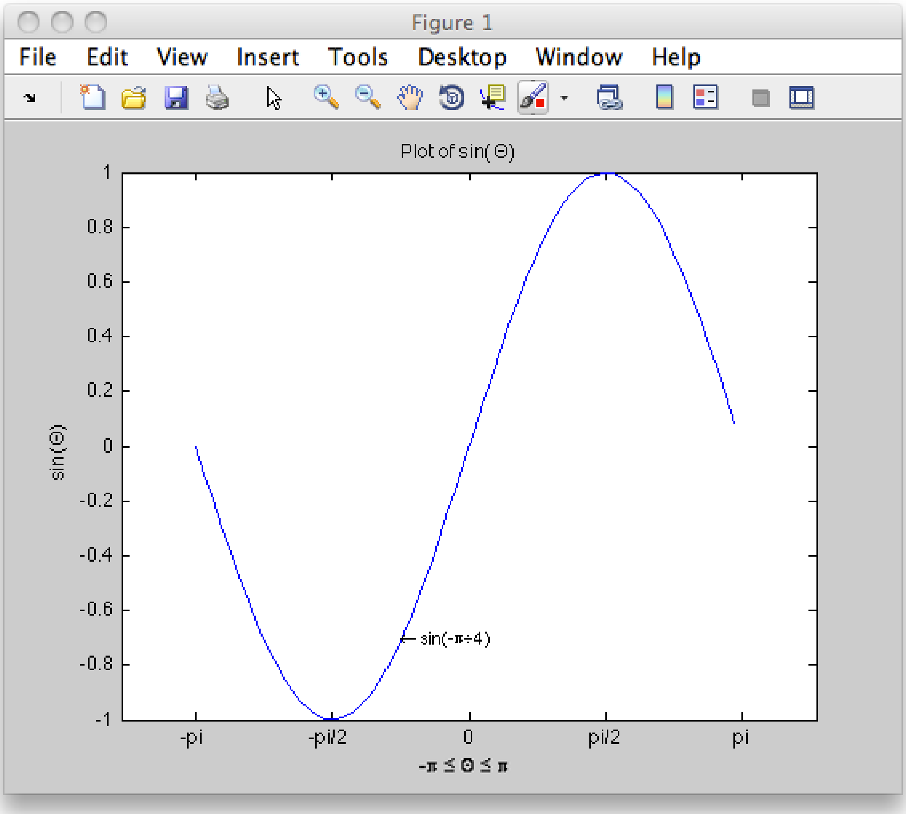
1.7.5 Example — Specifying Ticks and Tick Labels

You can adjust the axis tick-mark locations and the labels appearing at each tick mark. For example, this plot of the sine function relabels the x-axis with more meaningful values.

```
x = -pi:.1:pi;
y = sin(x);
plot(x,y);
set(gca,'XTick',-pi:pi/2:pi);
set(gca,'XTickLabel',{'-pi','-pi/2','0','pi/2','pi'})
```

These functions (*xlabel*, *ylabel*, *title*, *text*) add axis labels and draw an arrow that points to the location on the graph where $y = sin(-\pi/4)$.

```
xlabel('-\pi \leq \Theta \leq \pi');
ylabel('sin(\Theta)');
title('Plot of sin(\Theta)');
text(-pi/4,sin(-pi/4),'\leftarrow sin(-\pi\div4)',...
    'HorizontalAlignment','left');
```



The Greek symbols are created using TEX character sequences.

1.7.6 Setting aspect ratio

By default, graphs display in a rectangular axes that has the same aspect ratio as the figure window. This makes optimum use of space available for plotting. You exercise control over the aspect ratio with the axis function. For example,

```
t = 0:pi/20:2*pi;
plot(sin(t),2*cos(t));
grid on
```

produces a graph with the default aspect ratio. The command

```
axis square
```

makes the x- and y-axes equal in length.

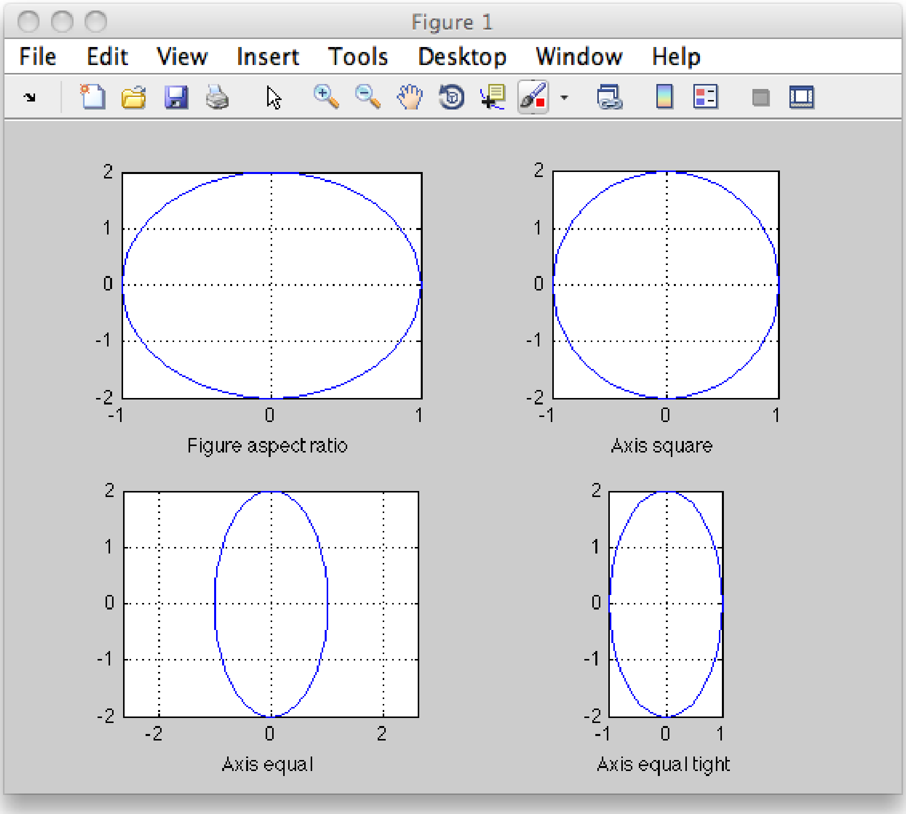
The square axes has one data unit in x to equal two data units in y. If you want the x- and y-data units to be equal, use the command

```
axis equal
```

This produces an axes that is rectangular in shape, but has equal scaling along each axis. If you want the axes shape to conform to the plotted data, use the tight option in conjunction with equal.

```
axis equal tight
```

The generated plots are displayed in the following figure.



1.8 Printing and exporting

There are four basic operations that you can perform in printing or transferring figures you've created with MATLAB graphics to specific file formats for other applications to use.

Opeation	Description
Print	Send a figure from the screen directly to the printer.
Print to File	Write a figure to a PostScript® file to be printed later.
Export to File	Export a figure in graphics format to a file, so that you can import it into an application.
Export to Clipboard	Copy a figure to the Microsoft Windows clipboard, so that you can paste it into an application.

1.8.1 Graphical user interfaces

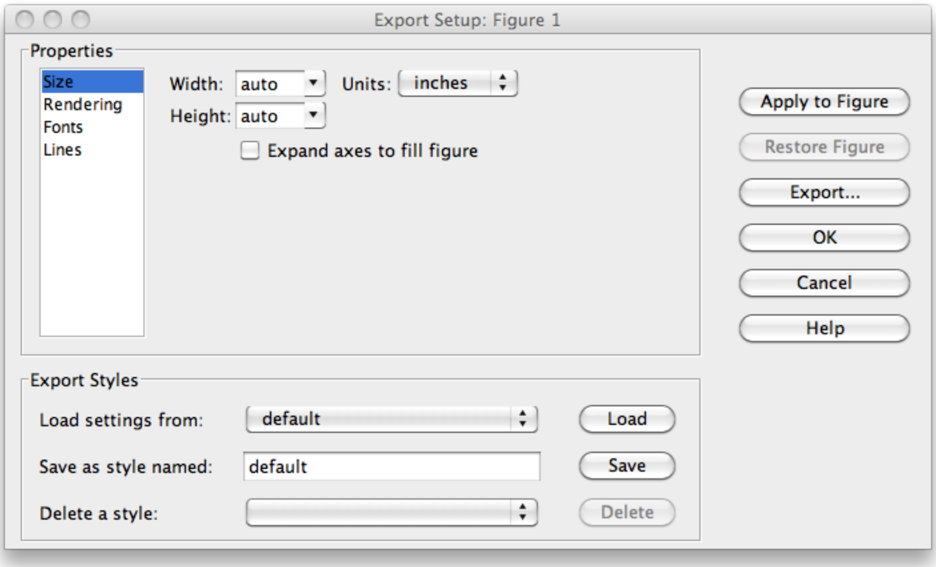
In addition to typing MATLAB commands, you can use interactive tools for either Microsoft Windows or UNIX® to print and export graphics. The table below lists the GUIs available for doing this and explains how to open them from figure windows.

Dialog Box	How to open	Description
Print (Windows and Unix)	**File > Print** or *printdlg* function	Send figure to the printer, select the printer, print to file, and several other options
Print Preview	**File > Print Preview** or *printpreview* function	View and adjust the final output
Export	**File > Export**	Export the figure in graphics format to a file
Copy Options	**Edit > Copy Options**	Set format, figure size, and background color for Copy to Clipboard
Figure Copy Template	**File > Preferences**	Change text, line, axis, and UI control properties

Before you print or export a figure, preview the image by selecting **Print Preview** from the figure window's File menu. If necessary, you can use the *set* function (see below) to adjust specific characteristics of the printed or exported figure. Adjustments that you make in the **Print Preview** dialog also set figure properties; these changes can affect the output you get should you print the figure later with the *print* command.

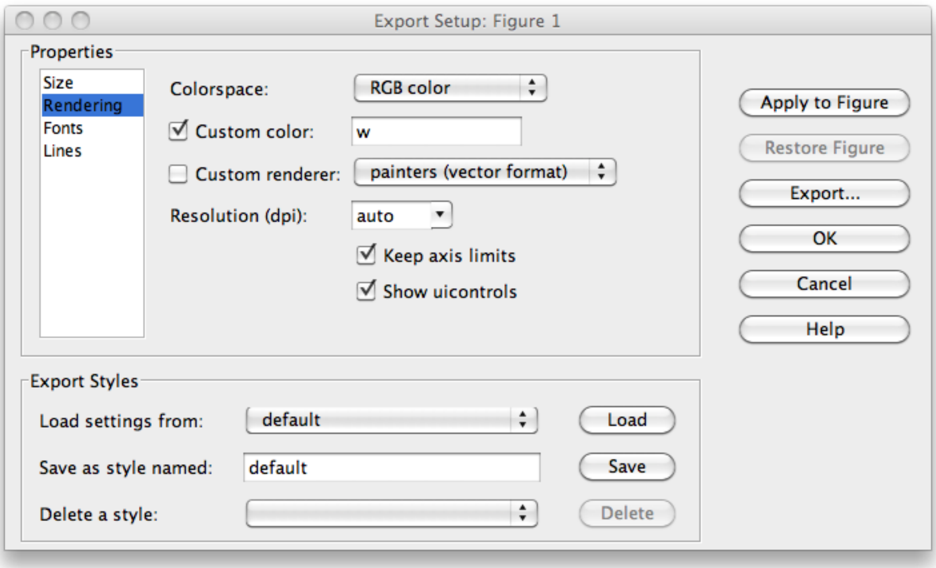
The Export Setup GUI appears when you select **Export Setup** from the **File** menu of a figure window. This GUI has four dialog boxes that enable you to adjust the size, rendering, font, and line appearance of your figure prior to exporting it. You select each of these dialog boxes by clicking **Size**, **Rendering**, **Fonts**, or **Lines** from the **Properties** list.

Adjusting the figure size Click Size in the Export Setup dialog box to display this dialog box.



The **Size** dialog box modifies the size of the figure as it will appear when imported from the export file into your application. If you leave the **Width** and **Height** settings on *auto*, the figure remains the same size as it appears on your screen. You can change the size of the figure by entering new values in the **Width** and **Height** text boxes and then clicking **Apply to Figure**. To go back to the original settings, click **Restore Figure**.

Adjusting the rendering Click **Rendering** in the Export Setup dialog box to display this dialog box.



You can change the settings in this dialog box as follows.

- **Colorspace**. Use the drop-down list to select a colorspace. Your choices are:

  - Black and white
  - Grayscale
  - RGB color
  - CMYK color

- **Custom Color**. Click the check box and enter a color to be used for the figure background. Valid entries are:

  - white, yellow, magenta, red, cyan, green, blue, or black
  - Abbreviated name for the same colors — w, y, m, r, c, g, b, k
  - Three-element RGB value — examples: [1 0 1] is magenta. [0 .5 .4] is a dark shade of green.

- **Custom Renderer**. Click the check box and select a renderer from the drop-down list:

  - painters (vector format)
  - OpenGL (bitmap format)
  - Z-buffer (bitmap format)

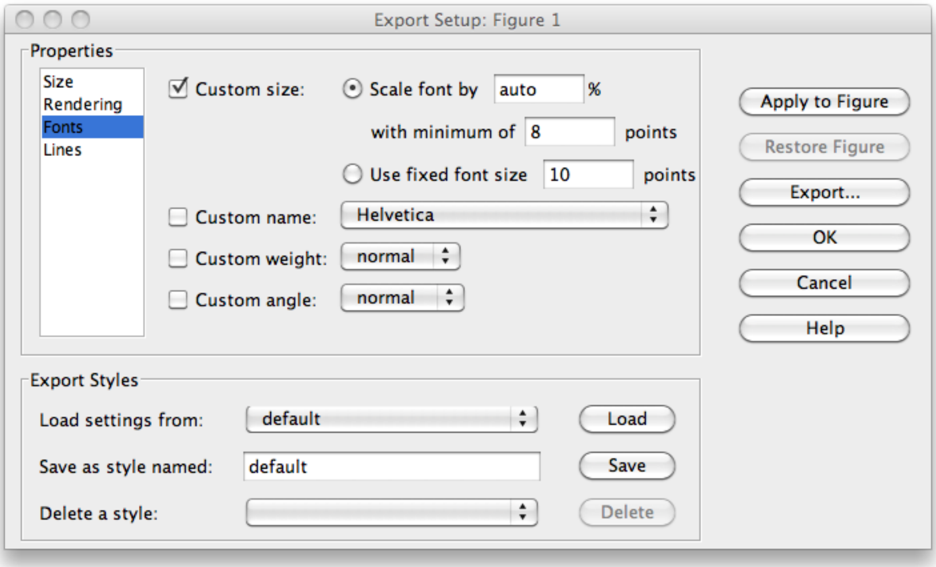
- **Resolution**. You can select one of the following from the drop-down list:

  - Screen — The same resolution as used on your screen display
  - A specific numeric setting — 150, 300, or 600 dpi
  - auto — automatic selection of a suitable setting

- **Keep axis limits**. Click the check box to keep axis tick marks and limits as shown. If unchecked, automatically adjust depending on figure size.

- **Show uicontrols**. Click the check box to show all user interface controls in the figure. If unchecked, hide user interface controls.

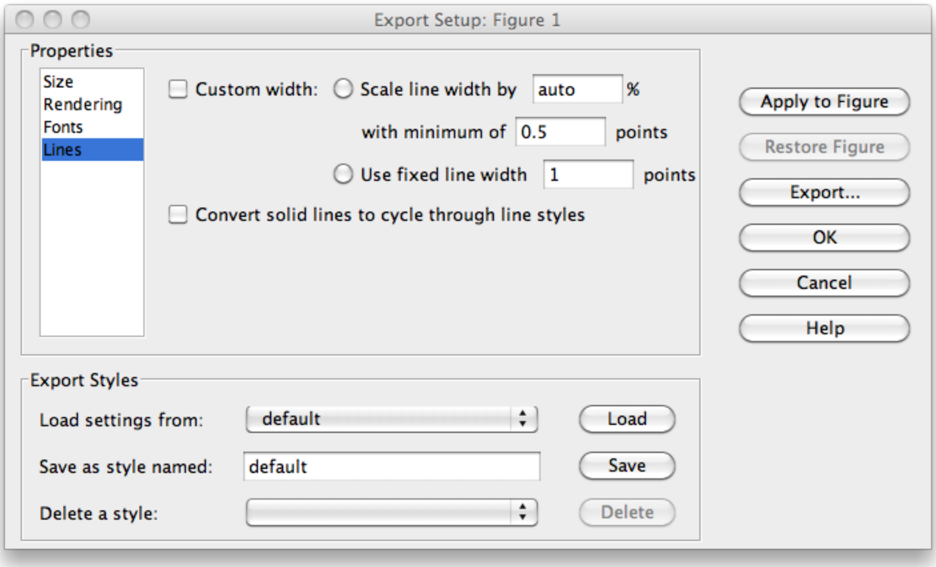
Changing font characteristics Click **Fonts** in the Export Setup dialog box to display this dialog box.



You can change the settings in this dialog box as follows.

- **Custom Size**. Click the check box and use the radio buttons to select a relative or absolute font size for text in the figure.
  - Scale font by N % — Increases or decreases the size of all fonts by a relative amount, N percent. Enter the word *auto* to automatically select the appropriate font size.
  - With minimum of N points — You can specify a minimum font size when scaling the font by a percentage.
  - Use fixed font size N points — Sets the size of all fonts to an absolute value, N points.
- **Custom Name**. Click the check box and use the drop-down list to select a font name from those offered in the drop-down list.
- **Custom Weight**. Click the check box and use the drop-down list to select the weight or thickness to be applied to text in the figure. Choose from *normal*, *light*, *demi*, or *bold*.
- **Custom Angle**. Click the check box and use the drop-down list to select the angle to be applied to text in the figure. Choose from *normal*, *italic*, or *oblique*.

Changing line characteristics Click **Lines** in the Export Setup dialog box to display this dialog box.



You can change the settings in this dialog box as follows.

- **Custom width**. Click the check box and use the radio buttons to select a relative or absolute line size for the figure.
  - Scale line width by N % — Increases or decreases the width of all lines by a relative amount, N percent. Enter the word *auto* to automatically select the appropriate line width.
  - With minimum of N points — Specify a minimum line width when scaling the font by a percentage.
  - Use fixed line width N points — Sets the width of all lines to an absolute value, N points.

Convert solid lines to cycle through line styles. When colored graphics are imported into an application that does not support color, lines that could formerly be distinguished by unique color are likely to appear the same. For example, a red line that shows an input level and a blue line showing output both appear as black when imported into an application that does not support colored graphics. Clicking this check box causes exported lines to have different line styles, such as solid, dotted, or dashed lines rather than differentiating between lines based on color.

Saving and Loading Settings If you think you might use these export settings at another time, you can save them now and reload them later. At the bottom of each Export Setup dialog box, there is a panel labeled **Export Styles**. To save your current export styles, type a name into the **Save as style named** text box, and then click **Save**. If you then click the **Load** settings from drop-down list, the name of the style you just saved appears among the choices of export styles you can load. To load a style, select one of the choices from this list and then click **Load**. To delete any style you no longer have use for, select that style name from the **Delete a style** drop-down list and click **Delete**.

Exporting the figure When you finish setting the export style for your figure, you can export the figure to a file by clicking the **Export** button on the right side of any of the four Export Setup dialog boxes. As new window labeled **Save As** opens. Select a folder to save the file in from the Save in list at the top. Select a file type for your file from the **Save as type** drop-down list at the bottom, and then enter a file name in the **File name** text box. Click the **Save** button to export the file.

1.8.2 Command line interface

You can print a MATLAB figure from the command line or from a MATLAB file. Use the *set* function to set the properties that control how the printed figure looks. Use the *print* function to specify the output format and start the print or export operation.

The *set* function changes the values of properties that control the look of a figure and objects within it. These properties are stored with the figure; some are also properties of children such as axes or annotations. When you change one of the properties, the new value is saved with the figure and affects the look of the figure each time you print it until you change the setting again.

To change the print properties of the current figure, the *set* command has the form

```
set(gcf, 'Property1', value1, 'Property2', value2, ...)
```

where *gcf* is a function call that returns the handle of the current figure, and each property value pair consists of a named property followed by the value to which the property is set. For example,

```
set(gcf, 'PaperUnits', 'centimeters', 'PaperType', 'A4', ...)
```

sets the units of measure and the paper size.

The *print* function performs any of the four actions shown in the table below. You control what action is taken, depending on the presence or absence of certain arguments.

Action	Print command
Print a figure to a printer	print
Print a figure to a file for later printing	print filename
Copy a figure in graphics format to the clipboard	print -dfileformat
Export a figure to a graphics format file that you can later import into an application	print -dfileformat filename

You can also include optional arguments with the *print* command. For example, to export Figure No. 2 to file spline2d.eps, with 600 dpi resolution, and using the EPS color graphics format, use

```
print -f2 -r600 -depsc spline2d
```

The functional form of this command is

```
print('-f2', '-r600', '-depsc', 'spline2d');
```

Changing figure proprieties for printing or exporting The table below shows parameters that you can set before submitting your figure to the printer. The print Command or set Property column shows how to set the parameter using the MATLAB *print* or *set* function. When using *print*, the table shows the appropriate command option (for example, *print -loose*). When using *set*, it shows the property name to set along with the type of object (for example, (Line) for line objects).

Parameter	*Default*	*print* Command or *set* Property
Select figure	Last active window	print -f*handle*
Select printer	System default	print -p*printer*
Figure size	8-by-6 inches	PaperSize (Figure), PaperUnits (Figure)
Position on page	0.25 in. from left, 2.5 in. from bottom	PaperPosition (Figure), PaperUnits (Figure)
Position mode	Manual	PaperPositionMode (Figure)
Paper type	Letter	PaperType (Figure)
Paper orientation	Portrait	PaperOrientation (Figure)
Renderer	Selected automatically	print -zbuffer | -painters | -opengl
Renderer mode	Auto	RendererMode (Figure)
Resolution	Depends on driver or graphics format	print -r*resolution*
Axes tick marks	Recompute	XTickMode, etc. (Axes)
Background color	Force to white	Color (Figure), InvertHardCopy (Figure)
Font size	As in the figure	FontSize (Text)
Bold font	Regular font	FontWeight (Text)
Line width	As in the figure	LineWidth (Line)
Line style	Black or white	LineStyle (Line)
Line and text color	Black and white	Color (Line, Text)
CMYK color	RGB color	print -cmyk
UI controls	Printed	print -noui
Bounding box	Tight	print -loose
Copy background	Transparent	See "Background color"
Copy size	Same as screen size	See "Figure Size"

1.9 References

- http://www.mathworks.com/access/helpdesk/help/techdoc/creating_plots/bqrw9tj.html
- http://www.mathworks.com/access/helpdesk/help/pdf_doc/matlab/graphg.pdf

2 Creating Graphical User Interfaces

2.1 What is a GUI?

A graphical user interface (GUI) is a graphical display in one or more windows containing controls, called components, that enable a user to perform interactive tasks. The user of the GUI does not have to create a script or type commands at the command line to accomplish the tasks. Unlike coding programs to accomplish tasks, the user of a GUI need not understand the details of how the tasks are performed. GUI components can include menus, toolbars, push buttons, radio buttons, list boxes, and sliders—just to name a few. GUIs created using MATLAB tools can also perform any type of computation, read and write data files, communicate with other GUIs, and display data as tables or as plots.

Most GUIs wait for their user to manipulate a control, and then respond to each action in turn. Each control, and the GUI itself, has one or more user-written routines (executable MATLAB code) known as *callbacks*, named for the fact that they "call back" to MATLAB to ask it to do things. The execution of each callback is triggered by a particular user action such as pressing a screen button, clicking a mouse button, selecting a menu item, typing a string or a numeric value, or passing the cursor over a component. The GUI then responds to these events. You, as the creator of the GUI, provide callbacks which define what the components do to handle events. This kind of programming is often referred to as *event-driven programming*. In the example, a button click is one such event. In event-driven programming, callback execution is *asynchronous*, that is, it is triggered by events external to the software. In the case of MATLAB GUIs, most events are user interactions with the GUI, but the GUI can respond to other kinds of events as well, for example, the creation of a file or connecting a device to the computer.

2.2 Ways to build MATLAB GUIs

A MATLAB GUI is a figure window to which you add user-operated controls. You can select, size, and position these components as you like. Using callbacks you can make the components do what you want when the user clicks or manipulates them with keystrokes. You can build MATLAB GUIs in two ways:

- Use GUIDE (GUI Development Environment), an interactive GUI construction kit.
- Create code files that generate GUIs as functions or scripts (programmatic GUI construction).

The first approach starts with a figure that you populate with components from within a graphic layout editor. GUIDE creates an associated code file containing callbacks for the GUI and its components. GUIDE saves both the figure (as a FIG-file) and the code file. Opening either one also opens the other to run the GUI.

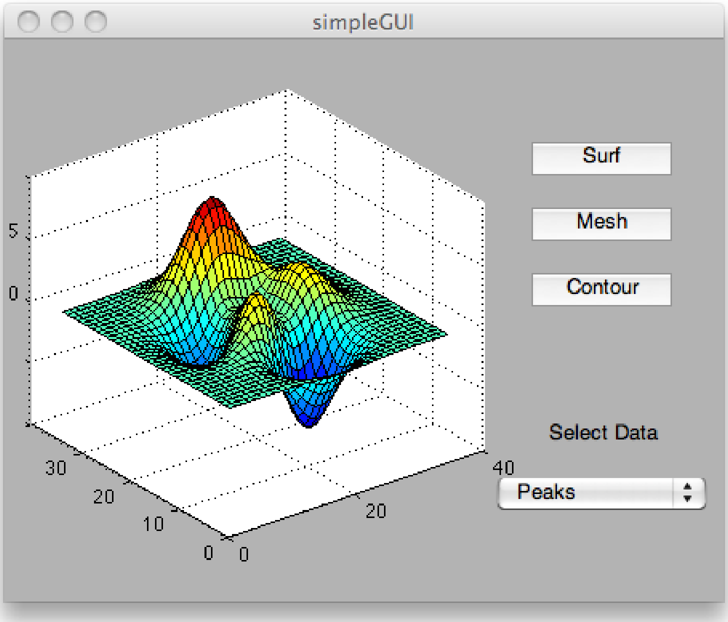
In the second, *programmatic*, GUI-building approach, you create a code file that defines all component properties and behaviors; when a user executes the file, it creates a figure, populates it with components, and handles user interactions. The figure is not normally saved between sessions because the code in the file creates a new one each time it runs. As a result, the code files of the two approaches look different.

Programmatic GUI files are generally longer, because they explicitly define every property of the figure and its controls, as well as the callbacks. GUIDE

GUIs define most of the properties within the figure itself. They store the definitions in its FIG-file rather than in its code file. The code file contains callbacks and other functions that initialize the GUI when it opens.

2.3 Creating a simple GUI with GUIDE

This section shows you how to create the graphical user interface (GUI) shown in the following figure. using GUIDE.



The GUI contains:

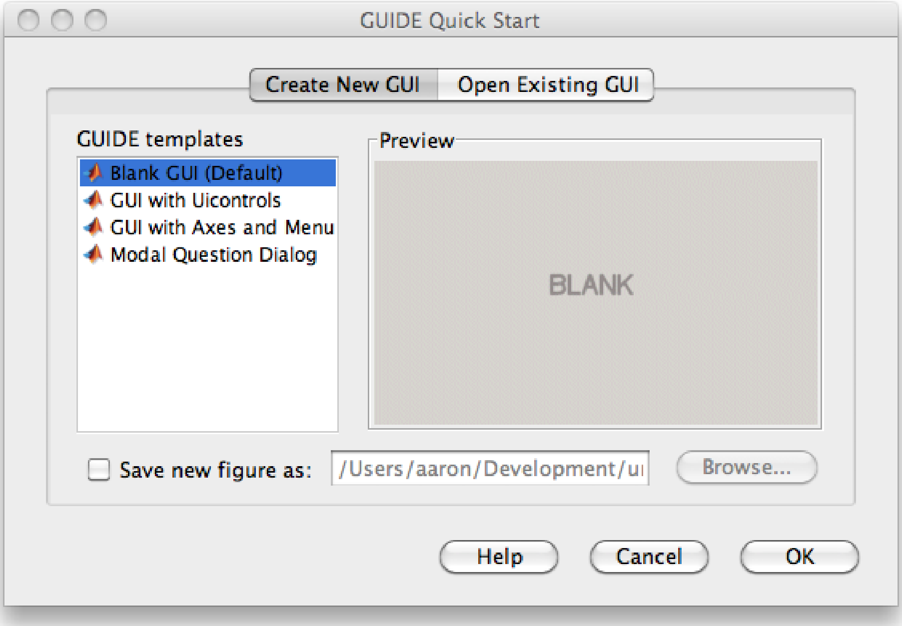
- An axes component
- A pop-up menu listing three different data sets that correspond to MATLAB functions: *peaks*, *membrane*, and *sinc*
- A static text component to label the pop-up menu
- Three push buttons, each of which displays a different type of plot: *surface*, *mesh*, and *contour*

2.3.1 Laying out the GUI with GUIDE

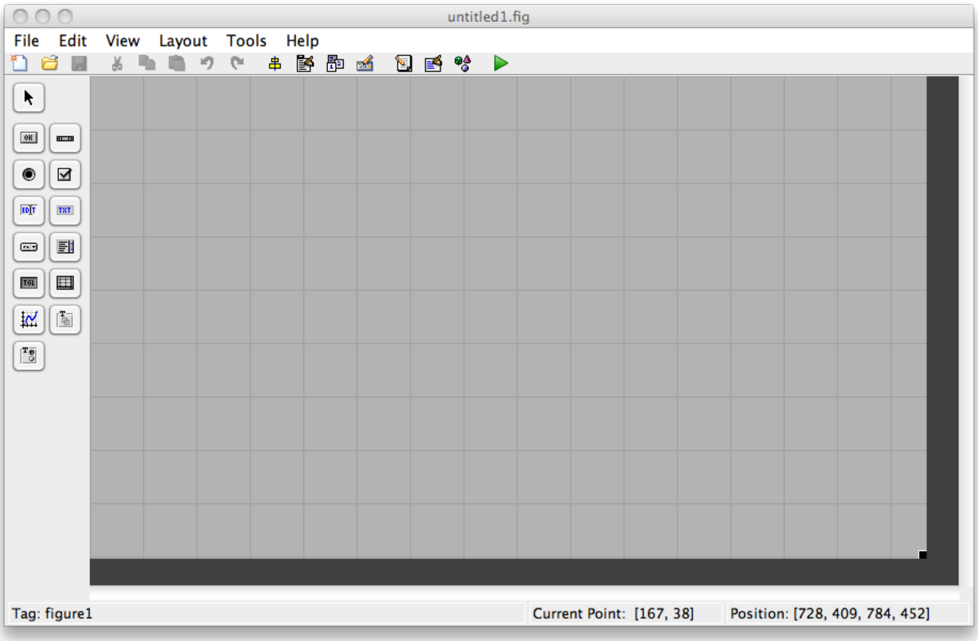
- Start GUIDE by typing:

```
>> guide
```

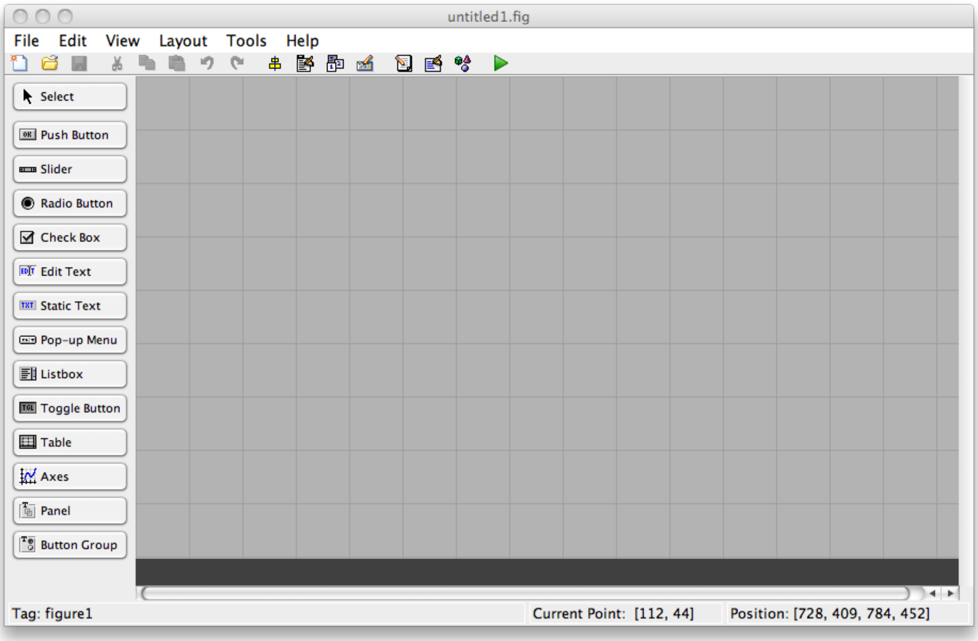
  at the MATLAB prompt. The GUIDE Quick Start dialog displays, as shown in the following figure.



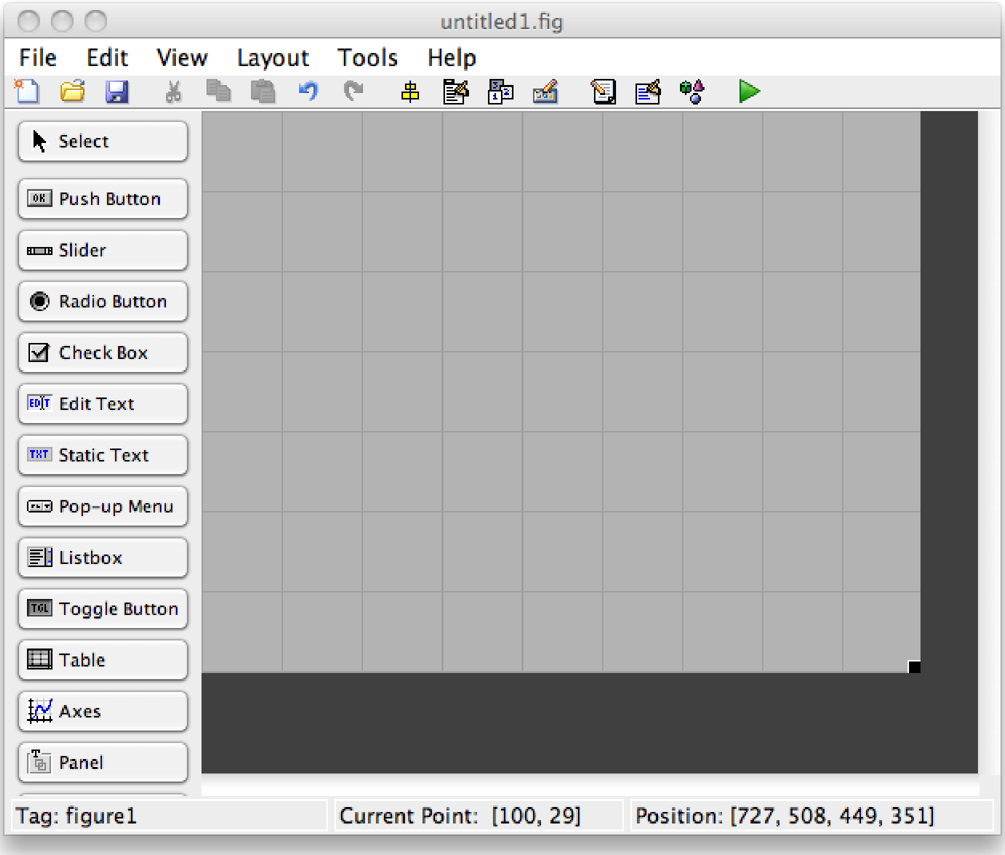
- In the Quick Start dialog, select the *Blank GUI (Default)* template. Click OK to display the blank GUI in the Layout Editor, as shown in the following figure.



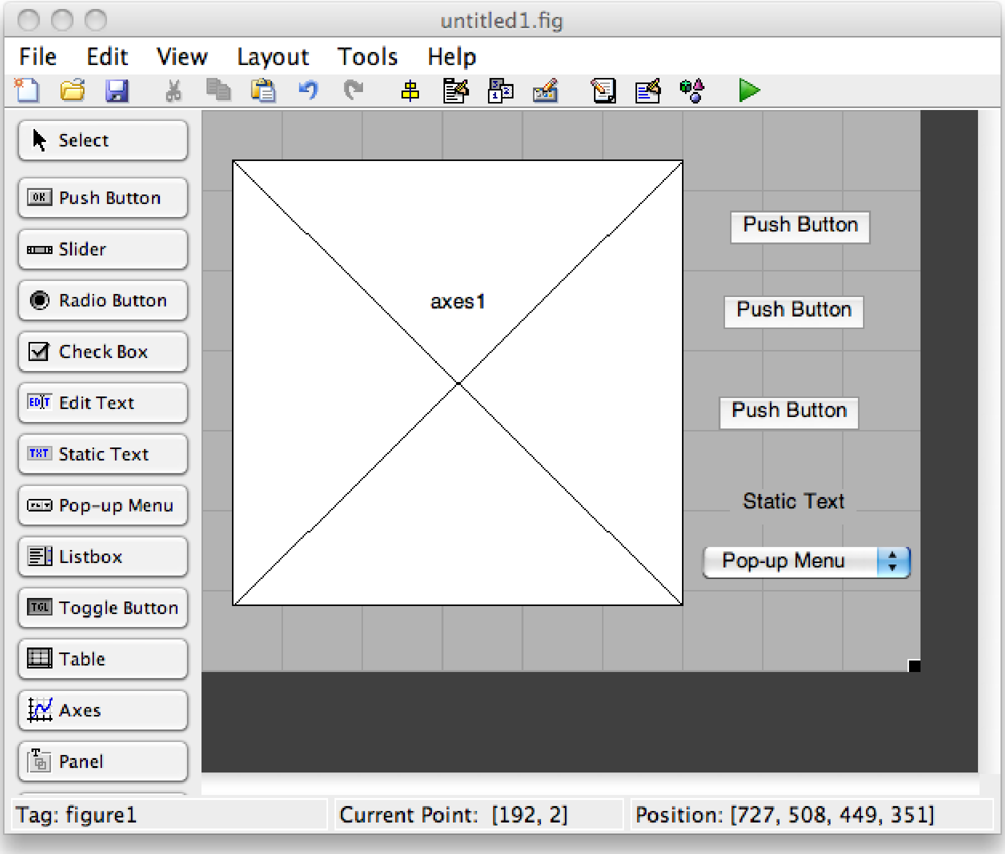
- Display the names of the GUI components in the component palette. Select **Preferences** from the MATLAB File menu. Then select **GUIDE > Show names in component palette**, and click OK. The Layout Editor then appears as shown in the following figure.



- Set the size of the GUI by resizing the grid area in the Layout Editor. Click the lower-right corner and drag it until the GUI is approximately 3 inches high and 4 inches wide. If necessary, make the window larger.

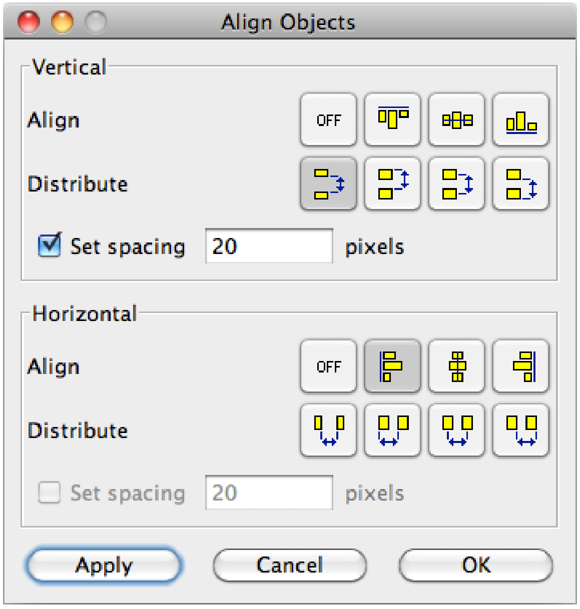


- Add **three push buttons**, a **static text area**, a **pop-up menu**, and an **axes** to the GUI. Select the corresponding entries from the component palette at the left side of the Layout Editor and drag them into the layout area. Position all controls approximately as shown in the following figure.

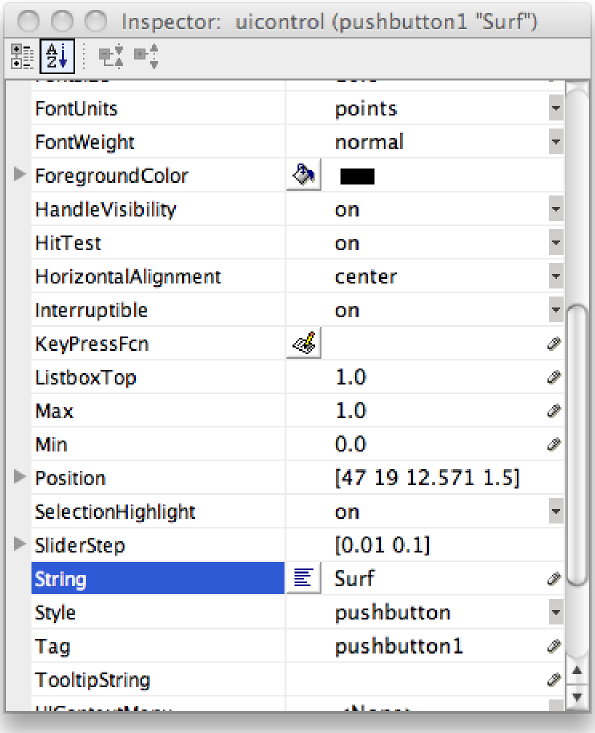


- If several components have the same parent, you can use the **Alignment Tool** to align them to one another. To align the three push buttons:

  1. Select all three push buttons by pressing **Ctrl** and clicking them.
  2. Select **Align Objects** from the **Tools** menu to display the **Alignment Tool**.
  3. Make these settings in the Alignment Tool, as shown in the following figure:
     - 20 pixels spacing between push buttons in the vertical direction.
     - Left-aligned in the horizontal direction.

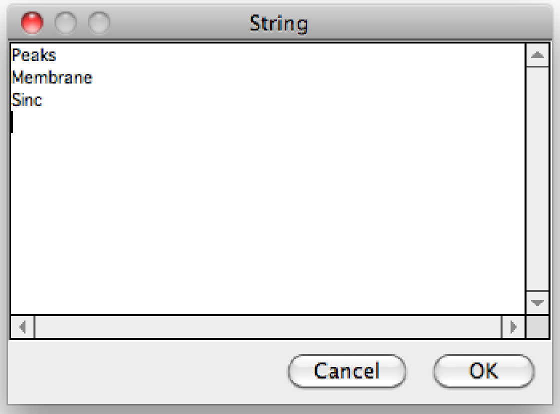


- Use the Alignment Tool to align and distribute all controls in the figure.
- The push buttons, pop-up menu, and static text have default labels when you create them. Their text is generic, for example **Push Button 1**. Change the text to be specific to your GUI, so that it explains what the component is for.
- To change the text of the first Push Button:
  1. Select **Property Inspector** from the **View** menu.
  2. In the layout area, click the Push Button you want to modify.
  3. In the Property Inspector, select the *String* property and then replace the existing value with the word *Surf*.
  4. Select each of the remaining push buttons in turn and repeat steps 2 and 3. Label the middle push button *Mesh*, and the bottom button *Contour*.



- The pop-up menu provides a choice of three data sets: *peaks*, *membrane*, and *sinc*. These data sets correspond to MATLAB functions of the same name. To list those data sets as choices in the pop-menu:

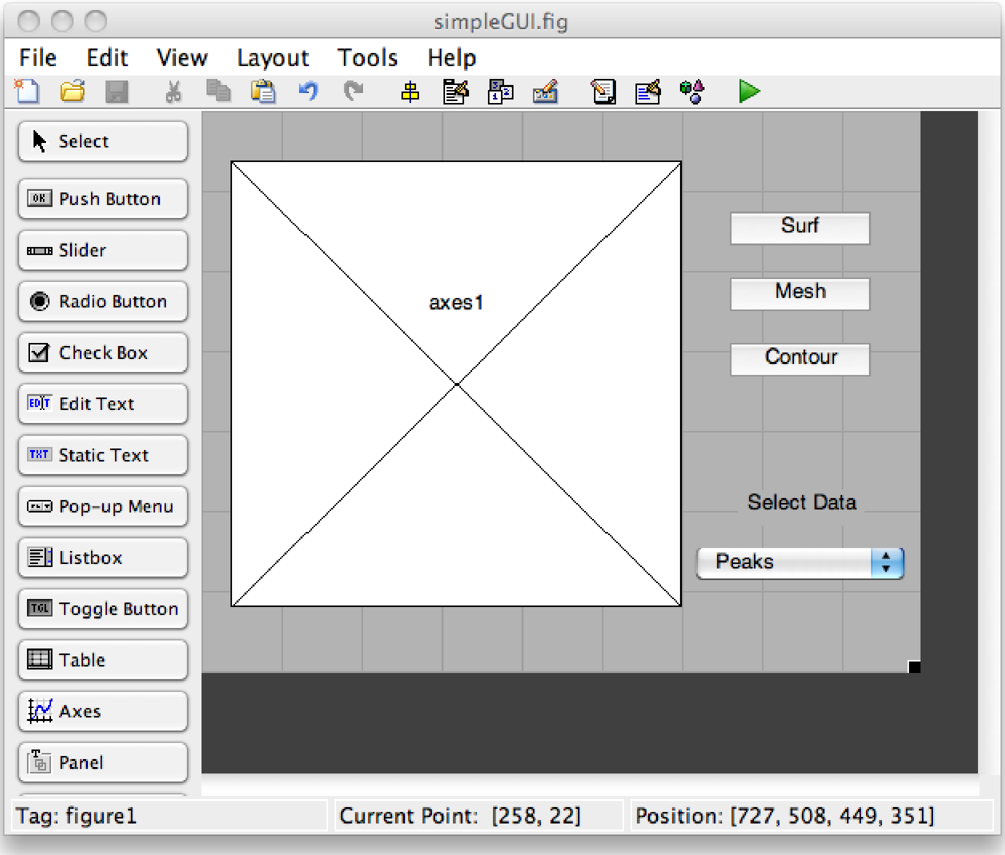
  1. In the layout area, select the pop-up menu by clicking it.
  2. In the Property Inspector, click the button next to String. The String dialog box displays.
  3. Replace the existing text with the names of the three data sets: *Peaks*, *Membrane*, and *Sinc*. Press Enter to move to the next line.
  4. When you have finished editing the items, click OK. The first item in your list, Peaks, appears in the pop-up menu in the layout area.



- In this GUI, the static text serves as a label for the pop-up menu. The user cannot change this text. This topic shows you how to change the static text to read *Select Data*.

  1. In the layout area, select the static text by clicking it.
  2. In the Property Inspector, click the button next to String. In the String dialog box that displays, replace the existing text with the phrase *Select Data*.
  3. Click OK. The phrase *Select Data* appears in the static text component above the pop-up menu.

- In the Layout Editor, your GUI now looks like in the following figure, and the next step is to save the layout.



- When you save a GUI, GUIDE creates two files, a FIG-file and a code file. The FIG-file, with extension .fig, is a binary file that contains a description of the layout. The code file, with extension .m, contains MATLAB functions that control the GUI.

- To save a GUI you can either choose **Save as...** from the **File** menu or **Run** it (from the **Tools** menu). If you try to run an unsaved Figure, GUIDE will ask you to save it first. Save the Figure as **simpleGUI.fig** (in the current path): GUIDE saves the files simpleGUI.fig and simpleGUI.m. The latter file is opened in the Editor.

- Run the figure by choosing Tools > Run or from the MATLAB console, by typing:

```
>> simpleGUI
```

- Now the GUI is designed, but it does not do anything!

2.3.2 Adding code to the GUI

When you saved your GUI in the previous section, GUIDE created two files: a FIG-file simpleGUI.fig that contains the GUI layout and a file, simpleGUI.m, that contains the code that controls how the GUI behaves. The code consists of a set of MATLAB functions (that is, it is not a script). But the GUI did not respond because the functions contain no statements that perform actions yet.

Here we will see how to add code to the file to make the GUI do things.

Generating data to plot In this section we will learn how to generate the data to be plotted when the GUI user clicks a button. The opening function generates this data by calling MATLAB functions. The **opening function**, which initializes a GUI when it opens, is the first callback in every GUIDE-generated GUI code file. In this example, you add code that creates three data sets to the opening function. The code uses the MATLAB functions peaks, membrane, and sinc. Open simpleGUI.m in the Editor:

```
>> edit simpleGUI
```

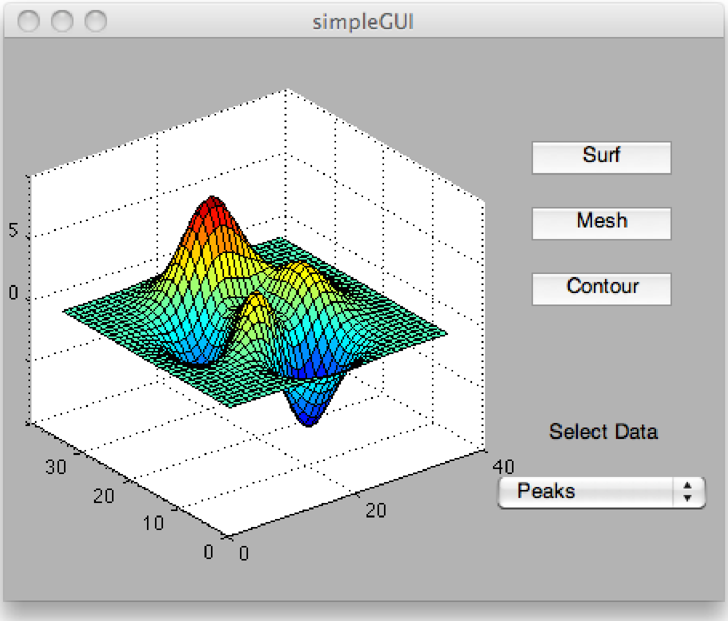
Scroll to the **simpleGUI_OpeningFcn** function (or choose it in the Show functions $f()$ tool in the editor and add this code to create data for the GUI immediately after the comment that begins with

```
% varargin   command line arguments to simpleGUI (see VARARGIN)

% Create the data to plot.
handles.peaks=peaks(35);
handles.membrane=membrane;
[x,y] = meshgrid(-8:.5:8);
r = sqrt(x.^2+y.^2) + eps;
sinc = sin(r)./r;
handles.sinc = sinc;
% Set the current data value.
handles.current_data = handles.peaks;
surf(handles.current_data)
```

Make sure to leave the already esisting code after the lines you added.

The first six executable lines create the data using the MATLAB functions *peaks*, *membrane*, and *sinc*. They store the data in the *handles* structure, an argument provided to all callbacks. Callbacks for the push buttons can retrieve the data from the handles structure.

The last two lines create a current data value and set it to peaks, and then display the surf plot for peaks. The following figure shows how the GUI now looks when it first displays.



Programming the popup menu The pop-up menu enables the user to select the data to plot. When the GUI user selects one of the three plots, MATLAB sets the pop-up menu *Value* property to the index of the selected string. The pop-up menu callback reads the pop-up menu *Value* property to determine the item that the menu currently displays, and sets *handles.current_data* accordingly.

- To program the pop-up menu callback, right-click on the pop-up menu in GUIDE and select **View Callbacks > Callback**.
- This will display the *popupmenu1_Callback()* function in the Editor.
- Add the following code to the *popupmenu1_Callback()* after the comments. This code first retrieves two pop-up menu properties:
  - String — a cell array that contains the menu contents
  - Value — the index into the menu contents of the selected data set

  It then uses a switch statement to make the selected data set the current data. The last statement saves the changes to the handles structure.

```
% Determine the selected data set.
str = get(hObject, 'String');
val = get(hObject,'Value');
% Set current data to the selected data set.
switch str{val}
  case 'Peaks' % User selects peaks.
    handles.current_data = handles.peaks;
  case 'Membrane' % User selects membrane.
    handles.current_data = handles.membrane;
  case 'Sinc' % User selects sinc.
    handles.current_data = handles.sinc;
```

```
end
% Save the handles structure.
guidata(hObject,handles)
```

Programming the push buttons Each of the push buttons creates a different type of plot using the data specified by the current selection in the pop-up menu. The push button callbacks get data from the handles structure and then plot it.

- Right-click the *Surf* push button in the Layout Editor to display a context menu. From that menu, select **View Callbacks > Callback**.
- This will display the *pushbutton1_Callback()* function in the Editor.
- Add the following code to the *pushbutton1_Callback()* after the comments:

```
% Display surf plot of the currently selected data.
surf(handles.current_data);
```

- Repeat previous steps for the *Mesh* push button and add this code to the *pushbutton2_Callback()*:

```
% Display mesh plot of the currently selected data.
mesh(handles.current_data);
```

- Repeat previous steps for the *Contour* push button and add this code to the *pushbutton3_Callback()*:

```
% Display contour plot of the currently selected data.
contour(handles.current_data);
```

- Save the simpleGUI.m file.

Running the GUI Run the GUI from the MATLAB console.

```
>> simpleGUI;
```

2.4 Creating a simple GUI programmatically

In this section we will create the same GUI as in the previous one, but without using GUIDE.

2.4.1 Creating a GUI code file

We will start by creating the backbone of our M-file. In the MATLAB console type:

```
>> edit simpleGUI2
```

and add the following code in the file:

```
function simpleGUI2
% SIMPLEGUI2 Select a data set from the pop-up menu, then
% click one of the plot-type push buttons. Clicking the button
% plots the selected data in the axes.
end
```

Save the file in the current path.

2.4.2 Laying out a simple GUI

Creating the figure In MATLAB, a GUI is a figure. This first step creates the figure and positions it on the screen. It also makes the GUI invisible so that the GUI user cannot see the components being added or initialized. When the GUI has all its components and is initialized, the example makes it visible.

```
% Initialize and hide the GUI as it is being constructed.
f = figure('Visible','off','MenuBar','None','Position',[360,500,450,285]);
```

The call to the figure function uses two *property/value* pairs. The *Position* property is a four-element vector that specifies the location of the GUI on the screen and its size: *[distance from left, distance from bottom, width, height]*. Add the previous code right after the initial comments in simpleGUI2.m.

Adding the components The example GUI has six components: three push buttons, one static text, one pop-up menu, and one axes. Start by writing statements that add these components to the GUI. Create the push buttons, static text, and pop-up menu with the uicontrol function. Use the axes function to create the axes.

- Add the three push buttons to your GUI by adding these statements to your code file following the call to figure.

  ```
  % Construct the components.
  hsurf = uicontrol('Style','pushbutton',...
      'String','Surf','Position',[315,220,70,25]);
  hmesh = uicontrol('Style','pushbutton',...
      'String','Mesh','Position',[315,180,70,25]);
  hcontour = uicontrol('Style','pushbutton',...
      'String','Countour','Position',[315,135,70,25]);
  ```

  These statements use the *uicontrol* function to create the push buttons. Each statement uses a series of *property/value* pairs to define a push button:

  - Style — In the example, pushbutton specifies the component as a push button.
  - String — Specifies the label that appears on each push button. Here, there are three types of plots: *Surf, Mesh, Contour.*
  - Position — Uses a four-element vector to specify the location of each push button within the GUI and its size: *[distance from left, distance from bottom, width, height]*. Default units for push buttons are pixels.

  Each call returns the handle of the component that is created (*hsurf, hmesh, hcontour*).

- Add the pop-up menu and its label to your GUI by adding these statements to the code file following the push button definitions.

  ```
  hpopup = uicontrol('Style','popupmenu',...
      'String',{'Peaks','Membrane','Sinc'},...
      'Position',[300,50,100,25]);
  htext = uicontrol('Style','text','String','Select Data',...
      'Position',[325,90,60,15]);
  ```

For the pop-up menu, the *String* property uses a cell array to specify the three items in the pop-up menu: *Peaks, Membrane, Sinc*. The static text component serves as a label for the pop-up menu. Its *String* property tells the GUI user to *Select Data*. Default units for these components are pixels.

- Add the axes to the GUI by adding this statement to the code file. Set the Units property to pixels so that it has the same units as the other components.

```
ha = axes('Units','pixels','Position',[50,60,200,185]);
```

- Align all components except the axes along their centers with the following statement. Add it to the code file following all the component definitions.

```
align([hsurf,hmesh,hcontour,htext,hpopup],'Center','None');
```

- Make your GUI visible by adding this command following the align command.

```
set(f,'Visible','on')
```

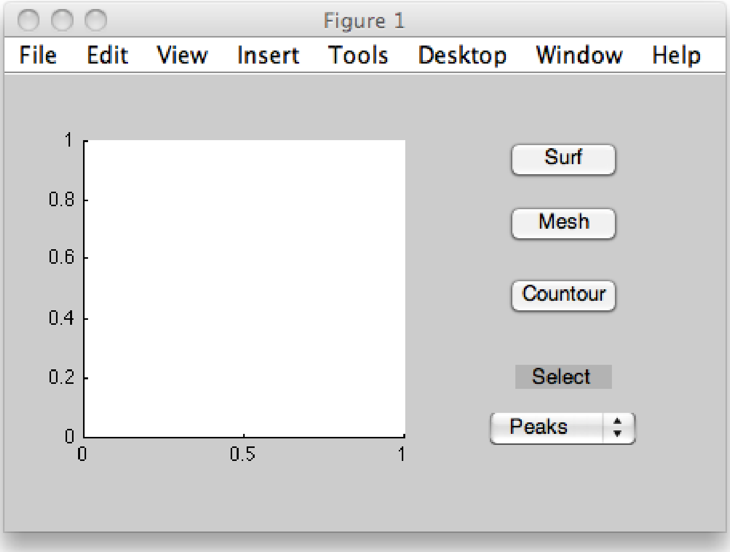
- This is what your code file should now look like:

```
function simpleGUI2
% SIMPLEGUI2 Select a data set from the pop-up menu, then
% click one of the plot-type push buttons. Clicking the button
% plots the selected data in the axes.

% Create and hide the GUI as it is being constructed.
f = figure('Visible','off','MenuBar','None','Position',[360,500,450,285]);

% Construct the components.
hsurf = uicontrol('Style','pushbutton','String','Surf',...
    'Position',[315,220,70,25]);
hmesh = uicontrol('Style','pushbutton','String','Mesh',...
    'Position',[315,180,70,25]);
hcontour = uicontrol('Style','pushbutton',...
    'String','Countour',...
    'Position',[315,135,70,25]);
htext = uicontrol('Style','text','String','Select Data',...
    'Position',[325,90,60,15]);
hpopup = uicontrol('Style','popupmenu',...
    'String',{'Peaks','Membrane','Sinc'},...
    'Position',[300,50,100,25]);
ha = axes('Units','Pixels','Position',[50,60,200,185]);
align([hsurf,hmesh,hcontour,htext,hpopup],'Center','None');

% Make the GUI visible.
set(f,'Visible','on')

end
```

- Run your code by typing

```
>> simpleGUI2
```

at the command line. This is what your GUI now looks like. Note that you can select a data set in the pop-up menu and click the push buttons. But nothing happens. This is because there is no code in the file to service the pop-up menu or the buttons.



Initializing the GUI When you make the GUI visible, it should be initialized so that it is ready for the user. This section shows you how to

1. Make the GUI behave properly when it is resized by changing the component and figure units to normalized. This causes the components to resize when the GUI is resized. Normalized units map the lower-left corner of the figure window to (0,0) and the upper-right corner to (1.0, 1.0).

2. Generate the data to plot. The example needs three sets of data: peaks_data, membrane_data, and sinc_data. Each set corresponds to one of the items in the pop-up menu.

3. Create an initial plot in the axes

4. Assign the GUI a name that appears in the window title

5. Move the GUI to the center of the screen

6. Make the GUI visible

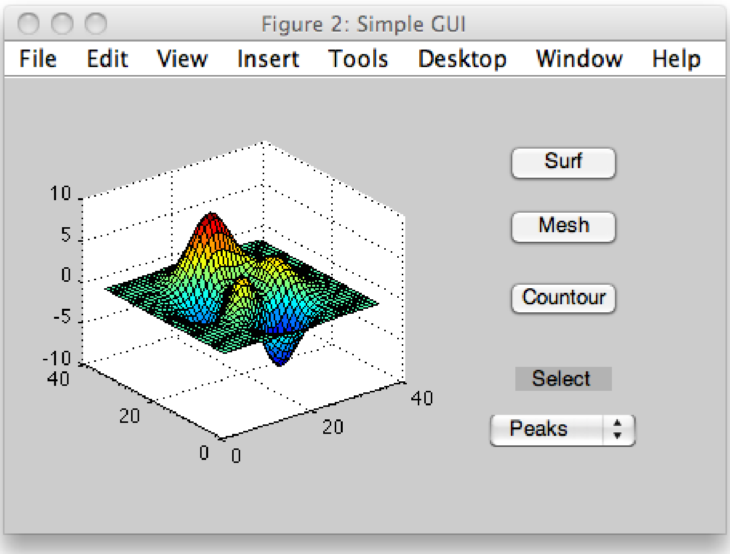
Replace this code in editor:

```
% Make the GUI visible.
set(f,'Visible','on')
```

with this code:

```
% Initialize the GUI.

% Change units to normalized so components resize automatically.
set([f,ha,hsurf,hmesh,hcontour,htext,hpopup],'Units','normalized');

% Generate the data to plot.
peaks_data = peaks(35);
membrane_data = membrane;
[x,y] = meshgrid(-8:.5:8);
r = sqrt(x.^2+y.^2) + eps;
sinc_data = sin(r)./r;

% Create a plot in the axes.
current_data = peaks_data;
surf(current_data);

% Assign the GUI a name to appear in the window title.
set(f,'Name','Simple GUI')

% Move the GUI to the center of the screen.
movegui(f,'center')

% Make the GUI visible.
set(f,'Visible','on');
```

- Run your code by typing simpleGUI2 at the command line. The initialization above cause it to display the default peaks data with the surf function, making the GUI look like this.



Programming the pop-up menu The pop-up menu enables users to select the data to plot. When a GUI user selects one of the three data sets, MATLAB sets the pop-up menu *Value* property to the index of the selected string. The pop-up menu callback reads the pop-up menu *Value* property to determine which item is currently displayed and sets *current*_data accordingly. Add the following callback to your file following the initialization code and before the final end statement.

```
% Pop-up menu callback. Read the pop-up menu Value property to
% determine which item is currently displayed and make it the
% current data. This callback automatically has access to
% current_data because this function is nested at a lower level.
function popup_menu_Callback(source,eventdata)
  % Determine the selected data set.
  str = get(source, 'String');
  val = get(source,'Value');
  % Set current data to the selected data set.
  switch str{val}
    case 'Peaks' % User selects Peaks.
      current_data = peaks_data;
    case 'Membrane' % User selects Membrane.
      current_data = membrane_data;
    case 'Sinc' % User selects Sinc.
      current_data = sinc_data;
   end
end
```

Programming the push buttons Each of the three push buttons creates a different type of plot using the data specified by the current selection in the pop-up menu. The push button callbacks plot the data in *current*_data. They automatically have access to *current*_data because they are nested at a lower level. Add the following callbacks to your file following the pop-up menu callback and before the final end statement.

```
% Push button callbacks. Each callback plots current_data in the
% specified plot type.
function surfbutton_Callback(source,eventdata)
  % Display surf plot of the currently selected data.
  surf(current_data);
end
function meshbutton_Callback(source,eventdata)
  % Display mesh plot of the currently selected data.
  mesh(current_data);
end
function contourbutton_Callback(source,eventdata)
  % Display contour plot of the currently selected data.
  contour(current_data);
end
```

Associating callbacks to their components When the GUI user selects a data set from the pop-up menu or clicks one of the push buttons, MATLAB software executes the callback associated with that particular event. But how does the software know which callback to execute? You must use each component's *Callback* property to specify the name of the callback with which it is associated.

- To the *uicontrol* statement that defines the *Surf* push button, add the *property/value* pair

  ```
  'Callback',{@surfbutton_Callback}
  ```

  so that the statement looks like this:

  ```
  hsurf = uicontrol('Style','pushbutton','String','Surf',...
  ```

```
'Position',[315,220,70,25],...
'Callback',{@surfbutton_Callback});
```

Callback is the name of the *property*. *surfbutton_Callback* is the name of the callback that services the Surf push button.

- Similarly, to the *uicontrol* statement that defines the *Mesh* push button, add the *property/value* pair

```
'Callback',{@meshbutton_Callback}
```

- To the *uicontrol* statement that defines the *Contour* push button, add the *property/value* pair

```
'Callback',{@contourbutton_Callback}
```

- To the *uicontrol* statement that defines the pop-up menu, add the *property/value* pair

```
'Callback',{@popup_menu_Callback}
```

Running the GUI Run the GUI by typing the name of the code file at the command line.

```
>> simpleGUI2
```

2.5 References

- http://www.mathworks.com/access/helpdesk/help/techdoc/creating_guis/bqz79mu.html
- http://www.mathworks.com/access/helpdesk/help/pdf_doc/matlab/buildgui.pdf