

## Lecture 2

# Advanced MATLAB: Graphics

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# Outline

- 1 Graphics Handles
- 2 Advanced Plotting
  - 2D Plotting
  - Grid Data
  - Scalars over Areas
  - Vector Fields
  - Scalars over Volumes
  - Vectors over Volumes
- 3 MATLAB File Exchange
- 4 Publication-Quality Graphics
- 5 Animation

# Overview

- Graphics objects
  - Basic drawing elements used by MATLAB to display data
  - Each object *instance* has unique identifier, *handle*
    - Stored as a double
  - Objects organized in *hierarchy*

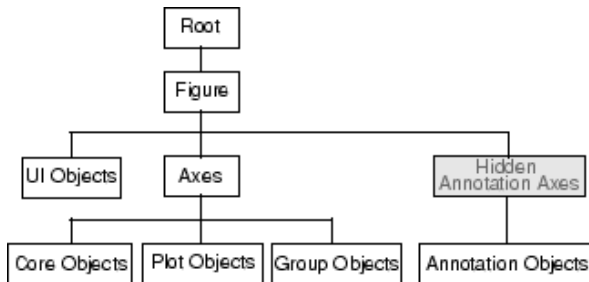


Figure: Organization of Graphics Objects (MathWorks [http://www.mathworks.com/help/matlab/creating\\_plots/organization-of-graphics-objects.html](http://www.mathworks.com/help/matlab/creating_plots/organization-of-graphics-objects.html))

# Graphics Objects

Two basic types of graphics objects

- Core graphics object
  - axes, image, light, line, patch, rectangle, surface
- Composite graphics object
  - Plot objects
    - areaseries, barseries, contourgroup, errorbarseries, lineseries, quivergroup, scattergroup, staircase, stemseries, surfaceplot
  - Annotation objects
    - arrow, doublearrow, ellipse, line, rectangle, textarrow, textbox
  - Group objects
    - hggroup, hgtransform
  - User Interface objects

## Graphics Handle

- Similar to *pointers* in that they contain a *reference* to a particular graphics object
  - `h1 = figure(2); h2 = h1;`
  - Both `h1`, `h2` point to figure 2
- Best way to obtain graphics handle is *from the call that creates the graphics object*, i.e.
  - `figH = figure('pos', [141, 258, 869, 523]);`
  - `axH = axes();`
  - `ax1H = subplot(2, 2, 3);`
  - `sinH = plot(sin(linspace(0, 2*pi, 100)));`
  - `[c, contH] = contour(peaks);`
- Alternatively, obtain graphics handle manually
  - Select figure/axes/object of interest with mouse
  - Use `gcf`, `gca`, `gco`
- Graphics handles stored as double

## Specifying Figure or Axes to Use

Handles can be used to specify which figure or axes is used when new graphics objects generated

- Specify figure in which to create new axes object
  - `for i = 1:10, fHan(i)=figure(); end`
  - `ax = axes('Parent',fHan(4))`
- Specify axes in which to create new graphics object
  - Most, if not all, plotting commands accept an axes handle as the *first* argument
  - Graphics object generated in axes object corresponding to handle passed
  - If axes handle not specified, `gca` used
  - `[C,objHan] = contourf(ax,peaks)`
- By default, MATLAB uses `gcf` (handle of current figure) or `gca` (handle of current axes)

## Exercise

- You are provided a fairly useless piece of code below (`which_plot_ex.m`)
- Your task is to alter the code below such that
  - $\sin(k \cdot x)$  is plotted vs  $x$  for  $k$  even in a single figure
  - $\sin(k \cdot x)$  is plotted vs  $x$  for  $k$  odd in a single figure (different figure from the one above)

```
figure;
axes(); hold on;

figure;
axes(); hold on;

x = linspace(0,2*pi,1000);
for k = 1:10
    plot(x,sin(k*x));
end
```

## Working with Graphics Objects

Command	Description
<code>gca</code>	Return handle of current axes
<code>gcf</code>	Return handle of current figure
<code>gco</code>	Return handle of current object
<code>get</code>	Query values of object's properties
<code>ishandle</code>	True if value is valid object handle
<code>set</code>	Set values of an object's properties



## Query/Modify Graphics Object Properties

- `get` to query properties and values for any graphics handle
  - `get(han)`
    - Display all properties and values to screen
  - `get(han, 'Property')`
    - Display Property value to screen
  - `V = get(han)`
    - Store all properties-value pairs in structure V
  - `V = get(han, 'Property')`
    - Store Property value in V
- `set` to set properties for any graphics handle
  - `set(han, 'Prop-1', Val-1, 'Prop-2', Val-2...)`
    - Set Prop-j's value to Val-j
  - `set(han, s) %s structure`
    - Set property-value pairs from s
  - `set(han, pn, pv) %pn, pv cell arrays`
    - Set value of property pn{i} to pv{i}

## Properties Common to All Objects

Command	Description
BeingDeleted	on when object's DeleteFcn called
BusyAction	Control callback routine interruption
ButtonDownFcn	Callback routine that executes when button pressed
Children	Handles of all object's child objects
Clipping	Enables/disables clipping
CreateFcn	Callback routine that executes when object created
DeleteFcn	Callback routine that executes when object deleted

## Properties Common to All Objects

Command	Description
HandleVisibility	Allows control over object handle's visibility (command line and callbacks)
HitTest	Determines if object selectable via mouse click
Interruptible	Determines whether callback can be interrupted by subsequently called callback
Parent	The object's parent
Selected	Indicates whether object is selected

## Properties Common to All Objects

Command	Description
SelectionHighlight	Specifies whether object visually indicates selection state
Tag	User-specified object label
Type	The type of object
UserData	Any data user associates with object
Visible	Determines whether object is visible

## Figure, Axes, and Plot Objects

- Figure window
  - `get(gcf)` to see all properties of Figure object and defaults
  - `Colormap`, `Position`, `PaperPositionMode`
- Axes Object
  - Axes objects contain the lines, surfaces, and other objects that represent the data visualized in a graph
  - `get(gca)` to see all properties of Axes object and defaults
  - `XLim`, `YLim`, `ZLim`, `CLim`, `XGrid`, `YGrid`, `ZGrid`, `XTick`, `XTickLabel`, `YTick`, `YTickLabel`, `ZTick`, `ZTickLabel`, `XScale`, `YScale`, `ZScale`
- Plot Objects
  - Plot objects are composite graphics objects composed of one or more core objects in a group
  - `XData`, `YData`, `ZData`, `Color`, `LineStyle`, `LineWidth`

# Legend

- Probably familiar with basic legend syntax
  - `legend('First plotted', 'Second ... plotted', 'Location', 'Northwest')`
- What if legend based on order of objects plotted is not sufficient?
  - Use handles for fine grained control
  - `legend(h, 'h(1) label', 'h(2) label')`
- Legend handle
  - Get handle by `leg = legend( )`
  - Use handle to control size/location (more control than 'Location')
  - Font size/style, interpreter, line style, etc

## Callback Routines

- Function associated with graphics handle that gets called in response to a specific action applied to the associated graphics object
  - Object creation, deletion
  - Mouse motion, mouse press, mouse release, scroll wheel
  - Key press, key release
  - [More here](#)
- All callback routines automatically passed two inputs
  - Handle of component whose callback is being executed
  - Event data
- Callback routines specified in many possible forms
  - String
    - Expression evaluated in *base* workspace
  - Function handle
  - Cell arrays to pass additional arguments to callback routine

## Demo & In-Class Assignment

`graphics_obj_han_ex.m`



# Outline

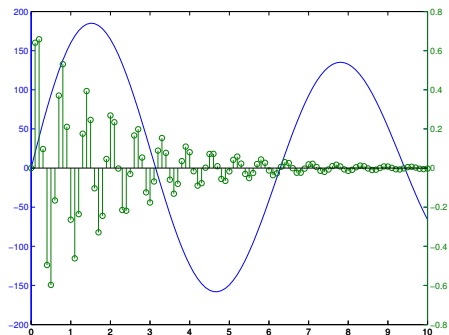
- 1 Graphics Handles
- 2 **Advanced Plotting**
  - 2D Plotting
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## Line plots

Command	Description
plot	2D line plot
plotyy	2D line plot, y-axes both sides
plot3	3D line plot
loglog	2D line plot: x- and y-axis log scale
semilogx	2D line plot, x-axis log, y-axis linear
semilogy	2D line plot, x-axis linear, y-axis log
errorbar	Error bars along 2D line plot
fplot	Plot function between specified limits
ezplot	Function plotter
ezplot3	2D parametric curve plotter

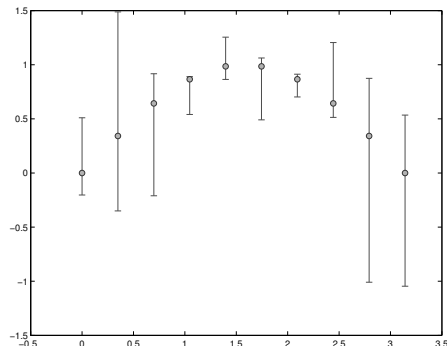
## Examples: plotyy, errorbar

Figure: plotyy Plot



• Code: `advancedplotting-ex.m`

Figure: errorbar Plot

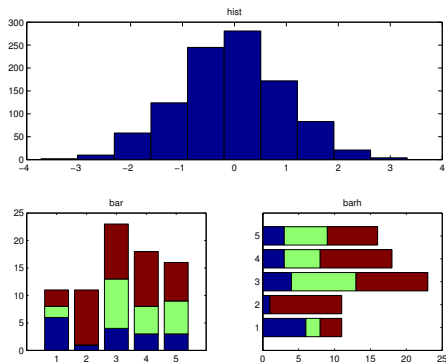


## Pie Charts, Bar Plots, and Histograms

Command	Description
bar, barh	Vertical, horizontal bar graph
bar3, bar3h	Vertical, horizontal 3D bar graph
hist	Histogram
histc	Histogram bin count (no plot)
rose	Angle histogram
pareto	Pareto chart
area	Filled area 2D plot
pie, pie3	2D, 3D pie chart

## Examples: hist, bar, barh, pie3

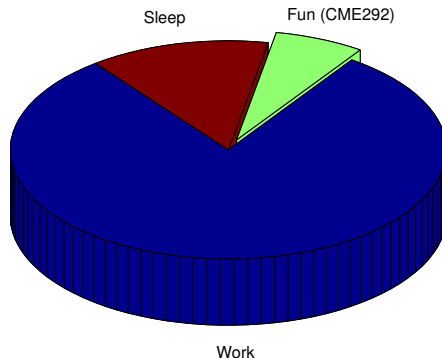
Figure: hist/bar/barh Plot



• Code: `advanced_plotting_ex.m`

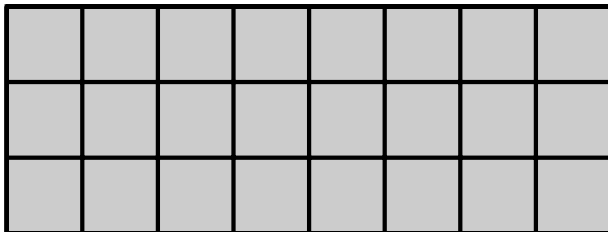
Figure: pie3 Plot

Life of a Graduate Student



## Generating Grid Data

- MATLAB graphics commands work primarily in terms of  $N$ -D grids



- Use `meshgrid` to define grid compatible with 2D, 3D MATLAB plotting commands from discretization in each dimension
  - `[X,Y] = meshgrid(x,y)`
  - `[X,Y,Z] = meshgrid(x,y,z)`

## meshgrid

- Generate 2D grid:  $[X, Y] = \text{meshgrid}(x, y)$ 
  - Relationships
    - $X(i, :) = x$  for all  $i$
    - $Y(:, j) = y$  for all  $j$
    - $X(:, i) = x(i)$  for all  $i$
    - $Y(j, :) = y(j)$  for all  $j$
- Generate 3D grid:  $[X, Y, Z] = \text{meshgrid}(x, y, z)$ 
  - Relationships
    - $X(i, :, k) = x$  for all  $i, k$
    - $Y(:, j, k) = y$  for all  $j, k$
    - $Z(i, j, :) = z$  for all  $i, j$
    - $X(:, i, :) = x(i)$  for all  $i$ ,
    - $Y(j, :, :) = y(j)$  for all  $j$
    - $Z(:, :, k) = z(k)$  for all  $k$

## meshgrid and Plotting Functions

- In MATLAB Help documentation, grid or domain data inputs/outputs usually refer to output of meshgrid or meshgrid or ndgrid

### surfnorm

Compute and display 3-D surface normals

R2014a

[expand all in page](#)

#### Syntax

```
surfnorm(Z)
surfnorm(X,Y,Z)
surfnorm(axes_handle, __)
surfnorm(__,Name,Value)
[Nx,Ny,Nz] = surfnorm(__)
```

#### Description

`surfnorm(Z)` plots a surface of the matrix `z` with `surf` and displays its surface normals as radiating vectors.

`surfnorm(X,Y,Z)` plots a surface and its surface normals from the vectors or matrices `x`, `y`, and matrix `z`. `x`, `y`, and `z` must be the same size.

`surfnorm(axes_handle, __)` plots into `axes_handle` instead of `gca` and it can include any of the input arguments in previous syntaxes.

`surfnorm(__,Name,Value)` can be used to set the value of the specified [Surface Properties](#).

`[Nx,Ny,Nz] = surfnorm(__)` returns the components of the 3-D surface normals for the surface without plotting the surface or surface normals.

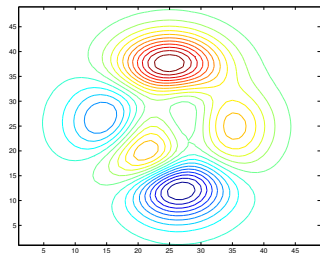


# Contour Plots

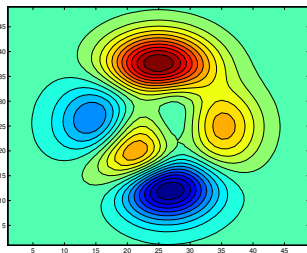
- Plot scalar-valued function of two variables as lines of constant value.
  - Visualize  $f(x, y) \in \mathbb{R}$  by displaying lines where  $f(x, y) = c$  for various values of  $c$

Command	Description
<code>contour</code>	Contour plot
<code>contourf</code>	Filled contour plot
<code>contourc</code>	Contour plot computation (no plot)
<code>contour3</code>	3D contour plot
<code>contourslice</code>	Draw contours in volume slice planes
<code>ezcontour</code>	Contour plotter
<code>ezcontourf</code>	Filled contour plotter

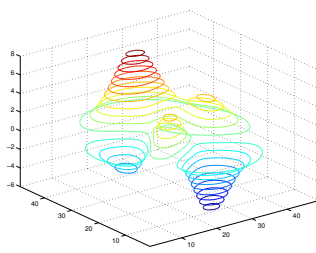
## Contour Plots



(a) contour



(b) contourf



(c) contour3

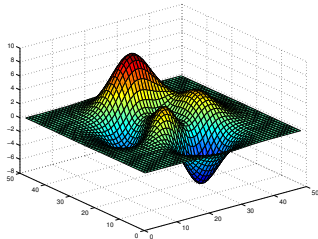
Code for plots generated in the remainder of the section:  
`advanced_plotting_ex.m` or `lec_figs.m`

## Surface and Mesh Plots

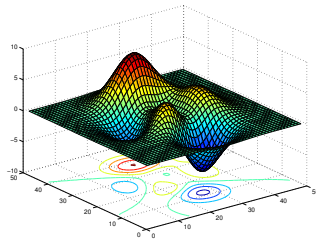
- Plot scalar-valued function of two variables  $f(x, y) \in \mathbb{R}$

Command	Description
<code>surf</code>	3D shaded surface plot
<code>surfc</code>	Contour plot under <code>surf</code> plot
<code>surf1</code>	Surface plot with colormap lighting
<code>surfnorm</code>	Compute/plot 3D surface normals
<code>mesh</code>	Mesh plot
<code>meshc</code>	Contour plot under <code>mesh</code> plot
<code>waterfall</code>	Waterfall plot
<code>ribbon</code>	Ribbon plot
<code>ezsurf</code> , <code>ezsurfc</code>	Colored surface plotters
<code>ezmesh</code> , <code>ezmeshc</code>	Mesh plotters

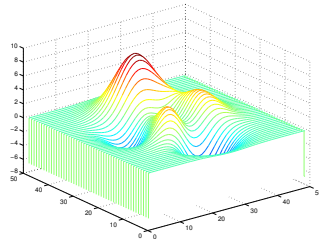
## Surface/Mesh Plots



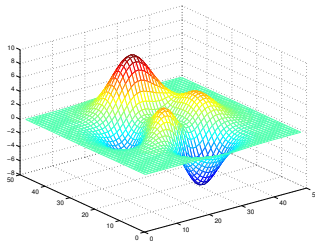
(a) surf



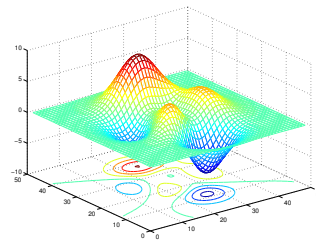
(b) surfc



(c) waterfall



(d) mesh



(e) meshc

## Contour/Surface/Mesh Plots

- `[C,h] = contour_func(Z)`
  - Contour plot of matrix `Z`
- `[C,h] = contour_func(Z,n)`
  - Contour plot of matrix `Z` with `n` contour levels
- `[C,h] = contour_func(Z,v)`
  - Contour plot of matrix `Z` with contour lines corresponding to the values in `v`
- `[C,h] = contour_func(X,Y,Z)`
  - Contour plot of matrix `Z` over domain `X, Y`
- `[C,h] = contour_func(X,Y,Z,n)`
  - Contour plot of matrix `Z` over domain `X, Y` with `n` levels
- `[C,h] = contour_func(X,Y,Z,v)`
  - Contour plot of matrix `Z` over domain `X, Y` with contour lines corresponding to the values in `v`
- Similar for surface/mesh plots

## Vector Fields

- Visualize vector-valued function of two or three variables  $\mathbf{F}(x, y) \in \mathbb{R}^2$  or  $\mathbf{F}(x, y, z) \in \mathbb{R}^3$

Command	Description
<code>feather</code>	Plot velocity vectors along horizontal
<code>quiver</code> , <code>quiver3</code>	Plot 2D, 3D velocity vectors from specified points
<code>compass</code>	Plot arrows emanating from origin
<code>streamslice</code>	Plot streamlines in slice planes
<code>streamline</code>	Plot streamlines of 2D, 3D vector data

## Vector Fields

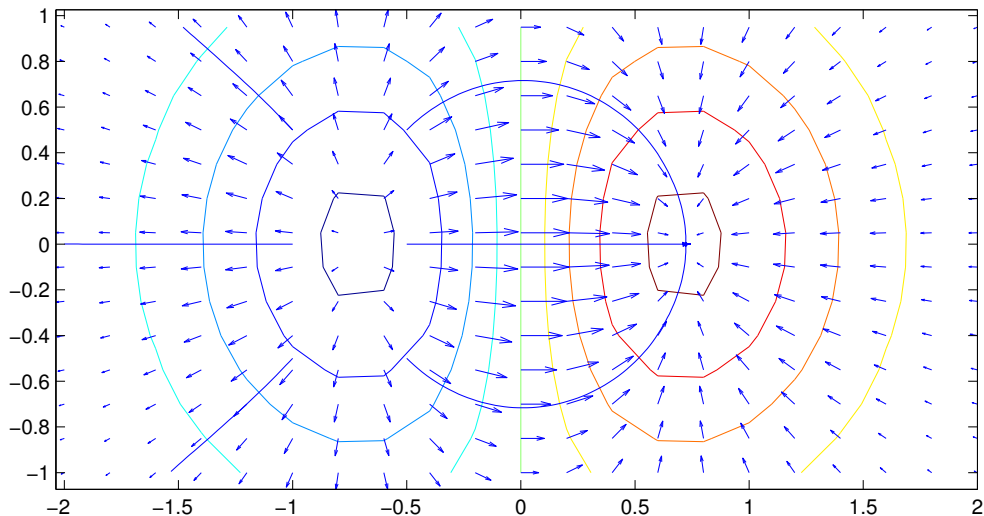


Figure: contour, quiver, streamline

## Vector fields: quiver, feather, compass

- Quiver plots
  - `h = quiver(X,Y,U,V)`
    - Displays velocity vectors as arrows with components  $(u, v)$  at the point  $(x, y)$
    - $X, Y$  generated with `meshgrid`
    - Additional call syntaxes to control display
  - `h = quiver3(X,Y,Z,U,V,W)`
    - Displays velocity vectors as arrows with components  $(u, v, w)$  at the point  $(x, y, z)$
    - $X, Y, Z$  generated with `meshgrid`
    - Additional call syntaxes to control display
  - Quivergroup Properties
- `feather`, `compass` similar, but simpler (don't require  $x, y$ )



## Streamline-type plots

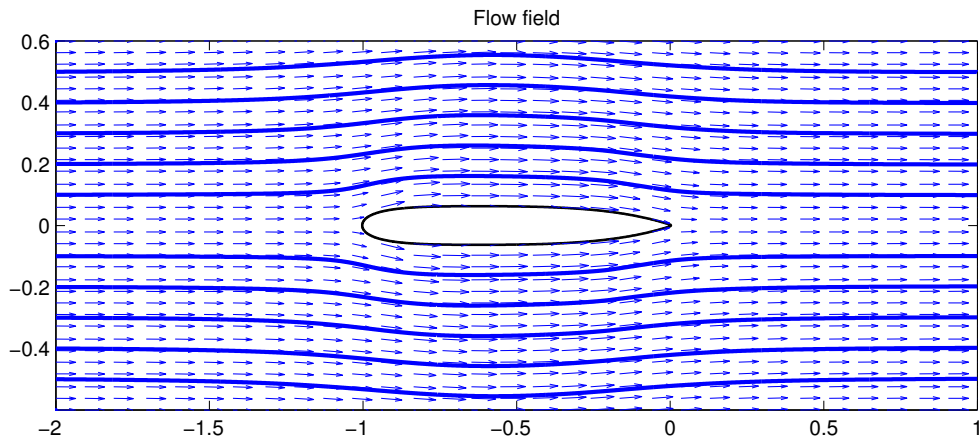


Figure: quiver, streamline, fill plots

## Streamline-type plots

- `streamline`, `stream2`, `stream3`
- Relevant for vector-valued functions of 2 or 3 variables ( $\mathbf{F}(x, y)$  or  $\mathbf{F}(x, y, z)$ )
- Requires points to initialize streamlines
- Plot the trajectory of a particle through a vector field that was placed at a given position
  - `han=streamline(X,Y,Z,F1,F2,F3,StX,StY,StZ)`
    - `X, Y, Z` - grid generated with `meshgrid`
    - `F1,F2,F3` - vector components of  $\mathbf{F}$  over grid
    - `StX, StY, StZ` - vectors (of the same size) specifying the starting location of the particles to trace

## Assignment

- Define `s = linspace(0,2*pi,100)`
- Plot  $f(x,y) = \sin(xy)$  for  $x,y \in [0, 2\pi]$  using any contour function
  - Make sure there are contour lines at  $[-1.0, -0.75, -0.5, -0.25, 0, 0.25, 0.5, 0.75, 1.0]$
  - Use any colormap except `jet` (the default)
    - `autumn`, `bone`, `colorcube`, `cool`, `copper`, `flag`, `gray`, `hot`, `hsv`, `jet`, `lines`, `pink`, `prism`, `spring`, `summer`, `white`, `winter`
  - Use a `colorbar`
- Numerically compute  $\nabla f(x,y)$  as `[Fx,Fy] = gradient(F)`
  - Make a quiver plot of  $\nabla f(x,y)$
  - Plot streamline of  $\nabla f(x,y)$  vector field, beginning at the point  $(2,2)$

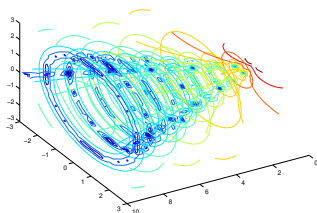
## Volume Visualization - Scalar Data

- Visualize scalar-valued function of two or three variables  $f(x, y, z) \in \mathbb{R}$

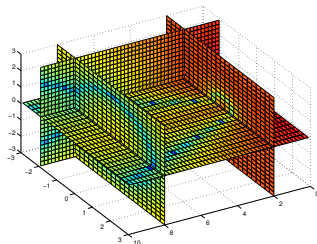
Command	Description
<code>contourslice</code>	Draw contours in volume slice planes
<code>flow</code>	Simple function of three variables
<code>isocaps</code>	Compute isosurface end-cap geometry
<code>isocolors</code>	Compute isosurface and patch colors
<code>isonormals</code>	Compute normals of isosurface vertices
<code>isosurface</code>	Extract isosurface data from volume data
<code>slice</code>	Volumetric slice plot

## Volume Visualization - Scalar Data

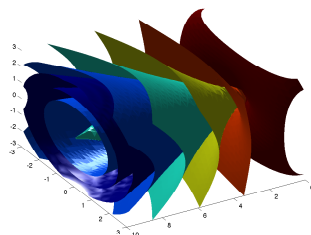
- Visualize scalar data defined over a volume.



(a) contourslice



(b) slice



(c) isosurface

## Slice-type plots

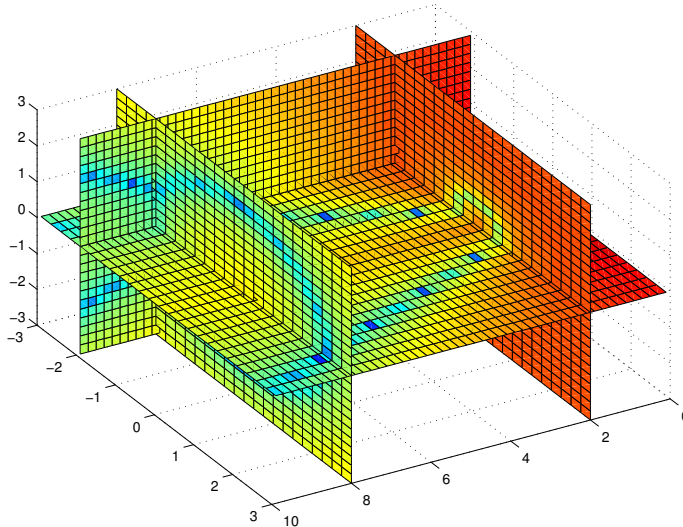


Figure: slice

## Slice-type plots

- `slice`, `contourslice`, `streamslice`
- Relevant for scalar- or vector-valued volume functions ( $f(x, y, z)$  or  $\mathbf{F}(x, y, z)$ )
- Plot information in planar slices of the volumetric domain
  - `han = slice(X, Y, Z, F, Sx, Sy, Sz)`
    - $X, Y, Z$  - grid generated by `meshgrid`
    - $F = \mathbf{F}(X, Y, Z)$
    - $Sx, Sy, Sz$  vectors specifying location of slice planes in the  $y - z$ ,  $x - z$ , and  $x - y$  planes
  - `han = slice(X, Y, Z, F, XI, YI, ZI)`
    - $XI, YI, ZI$  define *surface* (i.e. that could be plotted with `surf`) on which to plot  $F$

## Volume Visualization - Vector Data

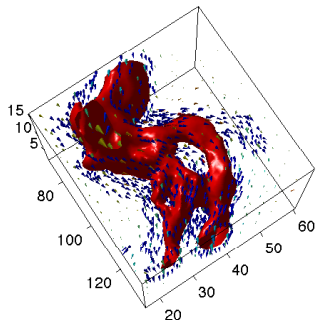
- Visualize vector-valued function of three variables  $\mathbf{F}(x, y, z) \in \mathbb{R}^3$

Command	Description
coneplot	Plot velocity vectors as cone
interpstreamspeed	Interpolate stream-line vertices from flow speed
stream2, stream3	Compute 2D, 3D streamline data
streamline	Plot streamlines of 2D, 3D vector data
streamparticles	Plot stream particles
streamribbon	3D stream ribbon plot
streamslice	Plot streamlines in slice planes
streamtube	Create 3D stream tube plot

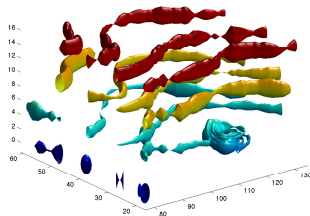


## Volume Visualization - Vector Data

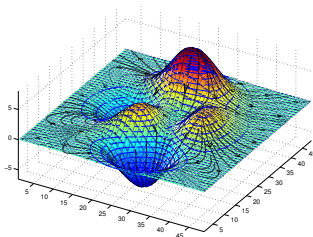
- Visualize vector data defined over a volume.



(a) coneplot



(b) streamtube



(c) streamslice

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## MATLAB File Exchange

The MATLAB File Exchange is a very useful forum for finding solutions to many MATLAB-related problems

- 3D Visualization
- Data Analysis
- Data Import/Export
- Desktop Tools and Development Environment
- External Interfaces
- GUI Development
- Graphics
- Mathematics
- Object-Oriented Programming
- Programming and Data Types

## MATLAB File Exchange

The MATLAB File Exchange is a very useful forum for sharing solutions to many MATLAB-related problems

- Clean integration of MATLAB figures in L<sup>A</sup>T<sub>E</sub>X documents
  - `matlabfrag`, `figuremaker`, `export_fig`, `mcode`, `matrix2latex`, `matlab2tikz`
- Plot formatting and manipulation
  - `xticklabel_rotate`, `tight_subplot`
- Interfacing to iPhone, iPad, Android, Kinect devices
- Interfacing to Google Earth and Maps
- Much more

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# Motivation

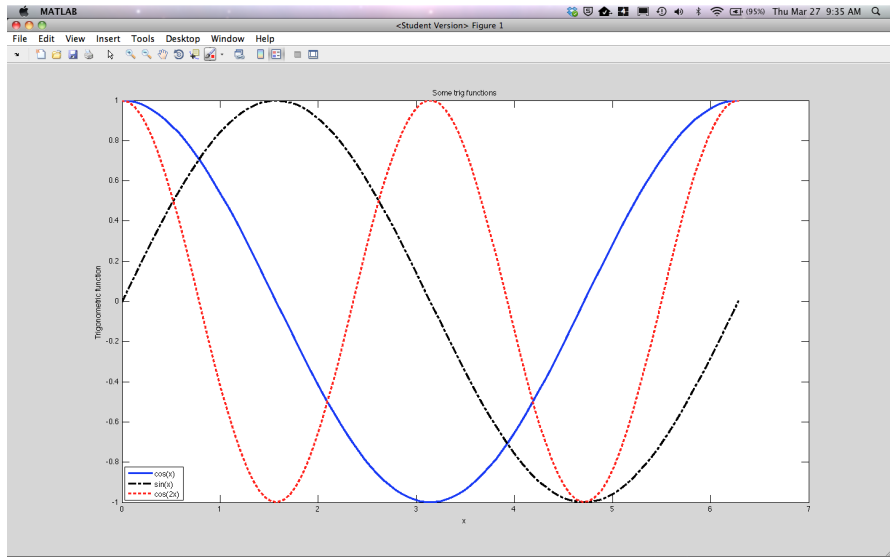
- Generating publication quality plots in MATLAB is not a trivial task
  - Plot annotation to match font size/style of document
  - Esthetic - dependent on type of publication
  - Legends can be difficult to work with
  - MATLAB figures not WYSIWYG by default
- Three fundamental approaches to generate plots for publications using MATLAB
  - Generate *plots* in MATLAB and import into document
    - Graphics handles to deal with esthetics
    - MATLAB File Exchange to integrate figures with L<sup>A</sup>T<sub>E</sub>X
  - Generate *data* in MATLAB and *plot* in document
    - TikZ/PGF popular choice for L<sup>A</sup>T<sub>E</sub>X
  - Hybrid (matlab2tikz)
- `high-quality-ex.m`

# WYSIWYG

MATLAB is not *What You See Is What You Get* (WYSIWYG) by default, when it comes to plotting

- Spend time making plot look exactly as you want
- Doesn't look the same when saved to file
  - Legend particularly annoying
  - Issues amplified when figure resized
- Very frustrating
- Force WYSIWYG
  - `set(gcf, 'PaperPositionMode', 'auto');`

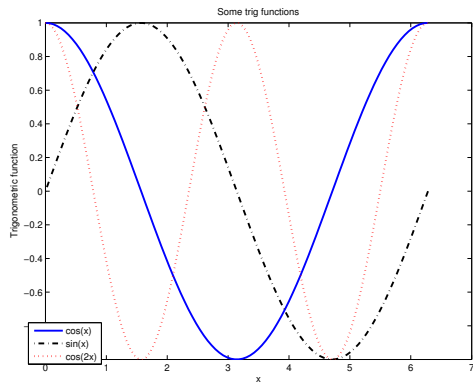
## WYSIWYG Example



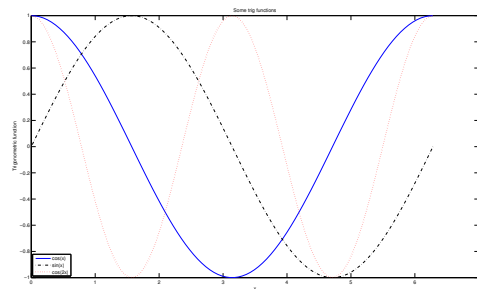


## WYSIWYG Example

(a) Without WYSIWYG



(b) With WYSIWYG



## High-Quality Graphics

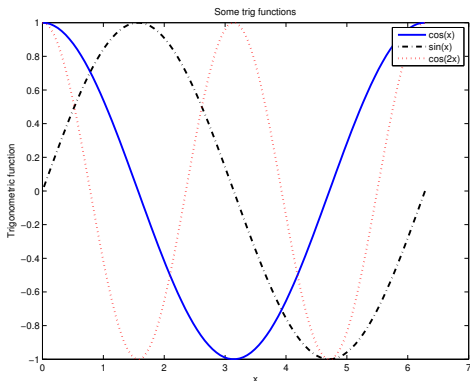
This information is based on websites [here](#) and [here](#).

- Generate plot with all lines/labels/annotations/legends/etc
- Set properties (graphics handles or interactively)
  - Figure width/height
  - Axes line width, object line width, marker size
  - Font sizes
- Save to figure to file
  - WYSIWYG
    - `set(gcf, 'PaperPositionMode', 'auto');`
  - Print to file for inclusion in document
    - `print(gcf, '-depsc2', filename)`
    - `matlabfrag(filename)`
    - `matlab2tikz(filename)`
- Fixing EPS file
  - Esthetics of dashed and dotted lines
  - `fixPSlinestyle`

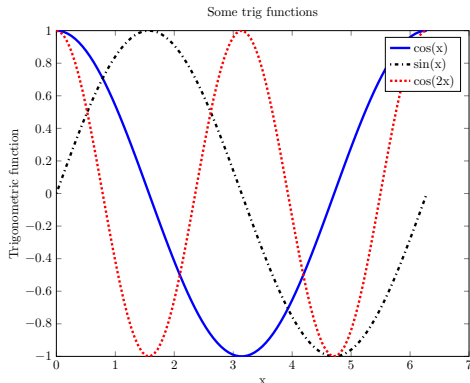
## matlab2tikz

- `matlab2tikz(FileName, ...)`
  - Save figure in native LaTeX (TikZ/Pgfplots).
  - Import file in  $\text{\LaTeX}$  (`\input` or `\includegraphics`)

(a) without matlab2tikz



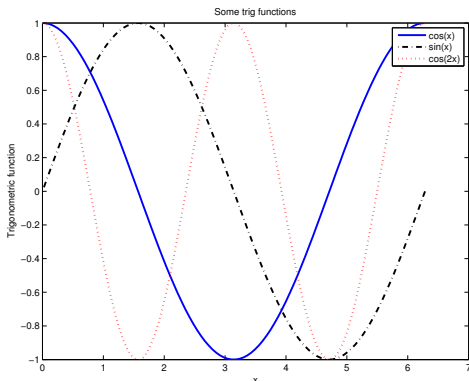
(b) with matlab2tikz



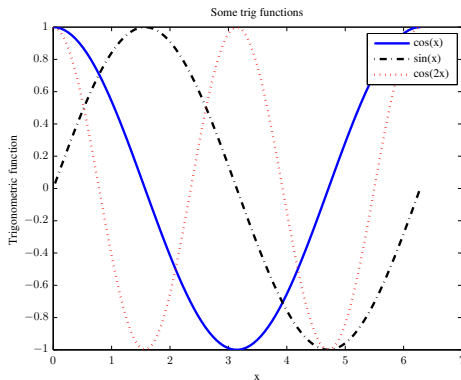
## matlabfrag

- `matlabfrag(FileName,OPTIONS)`
  - Exports a matlab figure to an .eps file and a .tex file for use with psfrag in LaTeX.
  - Doesn't seem to work well with beamer

(a) without matlabfrag

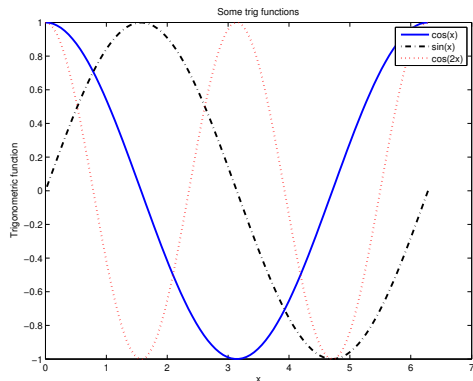


(b) with matlabfrag

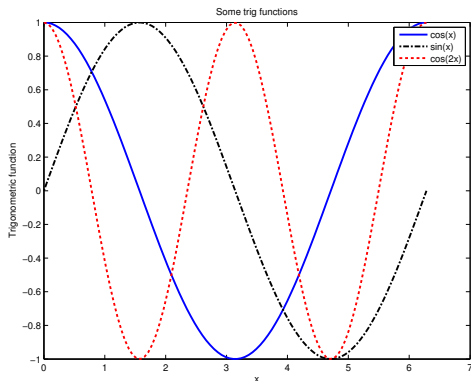


## fixPSlinestyle

(a) without fixPSlinestyle



(b) with fixPSlinestyle



### fixPSlinestyle syntax

- `fixPSlinestyle(fname)`
- `fixPSlinestyle(old_fname, new_fname)`

## Show Mcode

Two options to modify appearance of figure

- Interactively via MATLAB Figure GUI
  - Simplest and most popular
  - Not repeatable/automated
- Command line control via graphics handles
  - Less intuitive than interactive approach
  - Highly automated
  - Annoying trial/error when it comes to positioning/sizing

A hybrid approach that combines the above options is available

- Use GUI to interactively modify appearance of figure
- Show Mcode option to print underlying graphics handle operations to file
- Copy/paste into script for repeatability
- Demo: `show_mcode_ex.m`

# Outline

- 1 Graphics Handles
- 2 Advanced Plotting
  - 2D Plotting
  - Grid Data
  - Scalars over Areas
  - Vector Fields
  - Scalars over Volumes
  - Vectors over Volumes
- 3 MATLAB File Exchange
- 4 Publication-Quality Graphics
- 5 **Animation**

# Animation

Two main types of animation

- Interactive animation
  - Generate and display animation during execution of code
- Animation movies
  - Save animation in movie format



## Interactive Animation

- Generated by calling plot commands inside a loop with new data generated at each iteration
  - Before entering loop
    - Create figure and axes
    - Modify using handles to achieve desired appearance
    - Use command `set(gca, 'nextplot', 'replacechildren')` to ensure only *children* of axes object will be replaced upon next plot command (will not modify axes properties)
  - During loop
    - Plotting command to generate data on plot
    - Modify object using handle to achieve desired appearance
    - Use command `drawnow` to draw object, otherwise will not be drawn until execution is complete (MATLAB optimization as plotting is expensive)
- Alternatively, modify `XData`, `YData`, `ZData` properties of initial plot object

## Interactive Animation

- Additionally, save sequence of plotting command as frames (getframe) and play back from MATLAB window (movie)
- `animate_ex.m`

### Approach 1

```
fig=figure();
ax=axes();
obj=plot(..);
set(ax,'nextplot',...
    'replacechildren');
for j = 1:N
    obj=plot(..);
    drawnow;
end
```

### Approach 2

```
fig=figure();
ax=axes();
obj=plot(..);
set(ax,'xlim',...,'ylim',...);
for j = 1:N
    set(obj,'xdata',...);
    set(obj,'ydata',...);
    drawnow;
end
```

## Animation Movies

Saving animations as movie files can be accomplished using VideoWriter class (video\_writer\_ex.m)

- VideoWriter enables creation of video files from MATLAB figures, still images, or MATLAB movies

```
1 writerObj = VideoWriter('my_movie.avi'); %Video obj
2 set(writerObj, 'FrameRate',10); % Set the FPS
3 open(writerObj); % Open the video object
4 % Prepare the movie
5 figure; set(gca,'NextPlot','replaceChildren')
6 th = linspace(0,2*pi,100);
7 for j = th
8     plot(sin(th),cos(th),'k-'); hold on;
9     plot(sin(j),cos(j),'ro');
10    writeVideo( writerObj, getframe );
11 end
12 close(writerObj); % Close the video object
```

## VideoWriter

- List of VideoWriter properties
  - Here on MathWorks website
  - FrameRate - rate of playback (cannot change after open)
  - Quality - integer between 0, 100
- VideoWriter methods
  - open - Open file for writing video data
  - writeVideo - Write video data to file
  - close - Close file after writing video data