6.094

Introduction to programming in MATLAB

Lecture 2: Visualization and Programming

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Homework 1 Recap

- How long did it take to do required problems?
- Did anyone do optional problems?
- Was level of guidance appropriate?
- Unanswered Questions?

- Some things that came up:
- Use of semicolon – never required if one command per line. You can also put multiple commands on one line; in this case a semicolon is necessary to separate commands:

```
» x=1:10; y=(x-5).^2; plot(x,y);
```

- Assignment using indices – remember that you can index into matrices to either **look up** values or to **assign** value:

```
» x=rand(50,1); inds=find(x<0.1); y=x(inds);
  x(inds)=-x(inds); x(inds)=3;
```

Outline

(1) Functions

(2) Flow Control

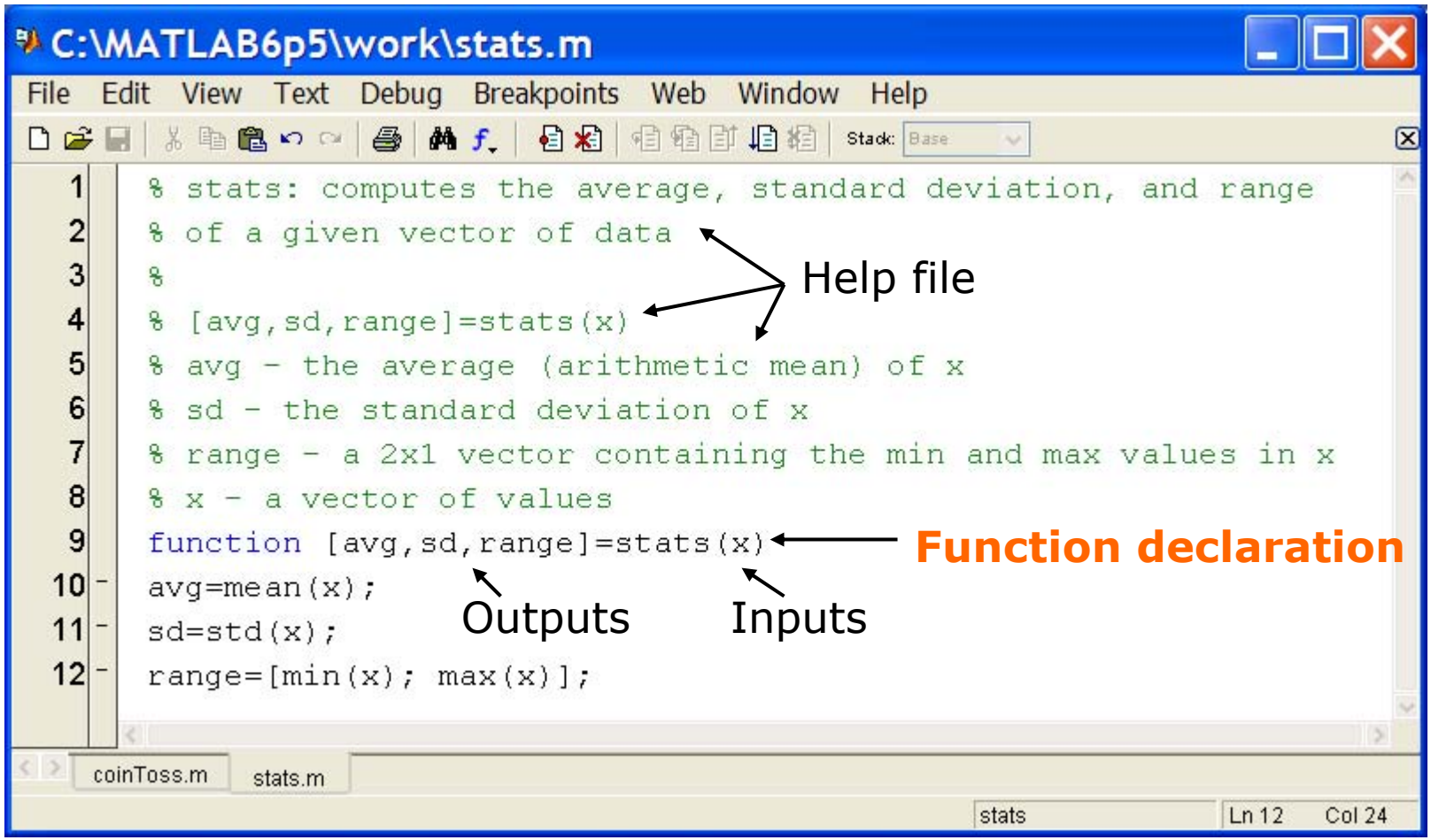
(3) Line Plots

(4) Image/Surface Plots

(5) Vectorization

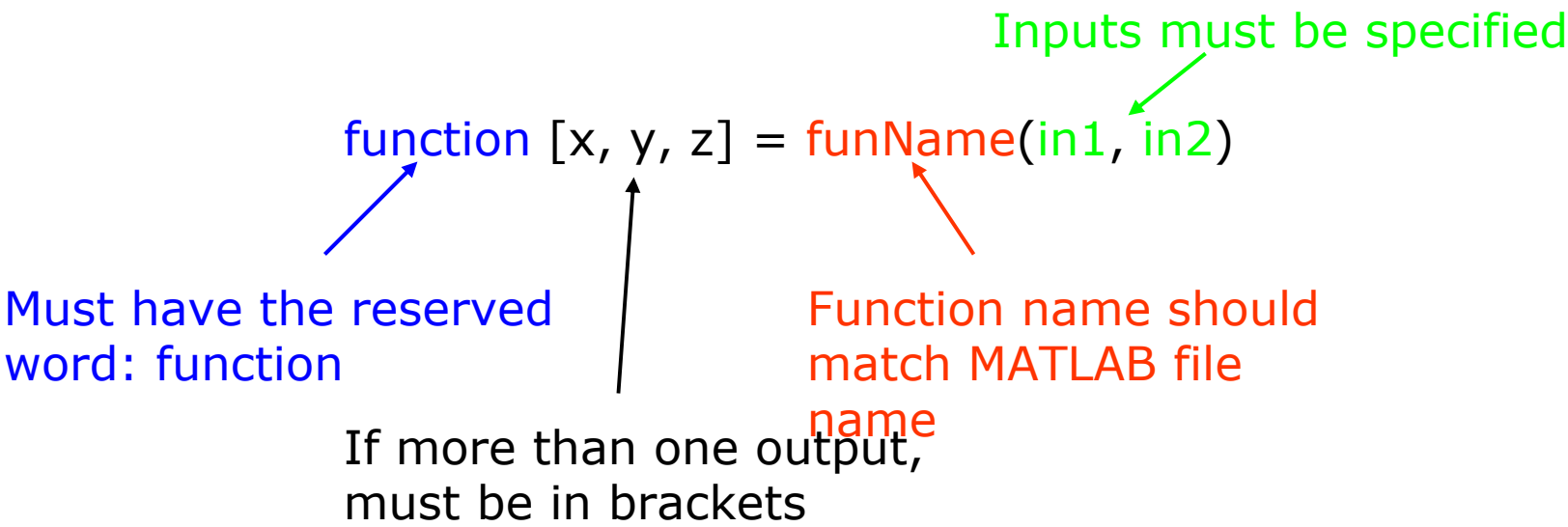
User-defined Functions

- Functions look exactly like scripts, but for **ONE** difference
  - Functions must have a function declaration



User-defined Functions

- Some comments about the function declaration



- No need for return: MATLAB 'returns' the variables whose names match those in the function declaration
- Variable scope: Any variables created within the function but not returned disappear after the function stops running

Functions: overloading

- We're familiar with
  - `» zeros`
  - `» size`
  - `» length`
  - `» sum`

- Look at the help file for size by typing
  - `» help size`

- The help file describes several ways to invoke the function
  - D = SIZE(X)
  - [M,N] = SIZE(X)
  - [M1,M2,M3,...,MN] = SIZE(X)
  - M = SIZE(X,DIM)

Functions: overloading

- MATLAB functions are generally overloaded
  - Can take a variable number of inputs
  - Can return a variable number of outputs

- What would the following commands return:

```
» a=zeros(2,4,8); %n-dimensional matrices are OK
» D=size(a)
» [m,n]=size(a)
» [x,y,z]=size(a)
» m2=size(a,2)
```

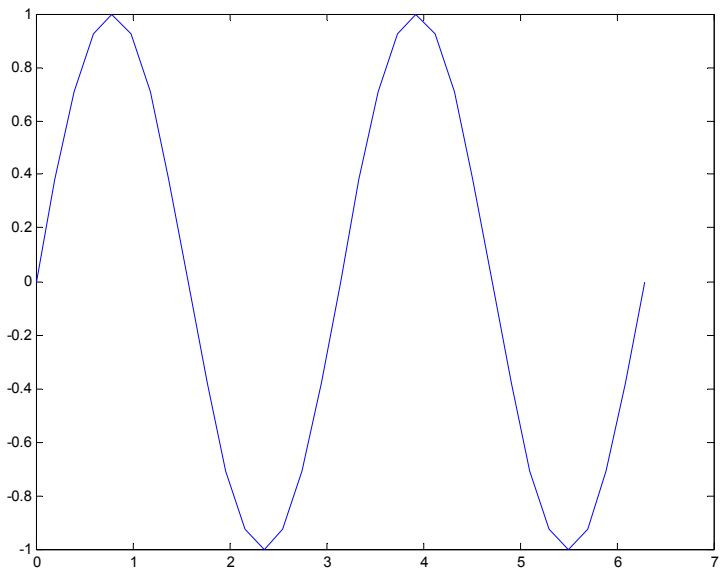
- You can overload your own functions by having variable input and output arguments (see **varargin**, **nargin**, **varargout**, **nargout**)

Functions: Excercise

- Write a function with the following declaration:
  `function plotSin(f1)`

- In the function, plot a sin wave with frequency f1, on the range [0,2π]: $\sin(f_1 x)$

- To get good sampling, use 16 points per period.



Functions: Excercise

- Write a function with the following declaration:
  ```
  function plotSin(f1)
  ```

- In the function, plot a sin wave with frequency f1, on the range [0,2π]: $\sin(f_1 x)$

- To get good sampling, use 16 points per period.

- In an MATLAB file saved as plotSin.m, write the following:

```
» function plotSin(f1)

  x=linspace(0,2*pi,f1*16+1);
  figure
  plot(x,sin(f1*x))
```

Outline

(1) Functions

(2) Flow Control

(3) Line Plots

(4) Image/Surface Plots

(5) Vectorization

Relational Operators

- MATLAB uses *mostly* standard relational operators
  - equal ==
  - **not** equal ~=
  - greater than >
  - less than <
  - greater or equal >=
  - less or equal <=
- Logical operators — elementwise — short-circuit (scalars)
  - And — & — &&
  - Or — | — ||
  - **Not** — ~
  - Xor — xor
  - All true — all
  - Any true — any

- Boolean values: zero is false, nonzero is true
- See **help .** for a detailed list of operators

if/else/elseif

- Basic flow-control, common to all languages
- MATLAB syntax is somewhat unique

IF

```
if cond
    commands
end
```

Conditional statement: evaluates to true or false

ELSE

```
if cond
    commands1
else
    commands2
end
```

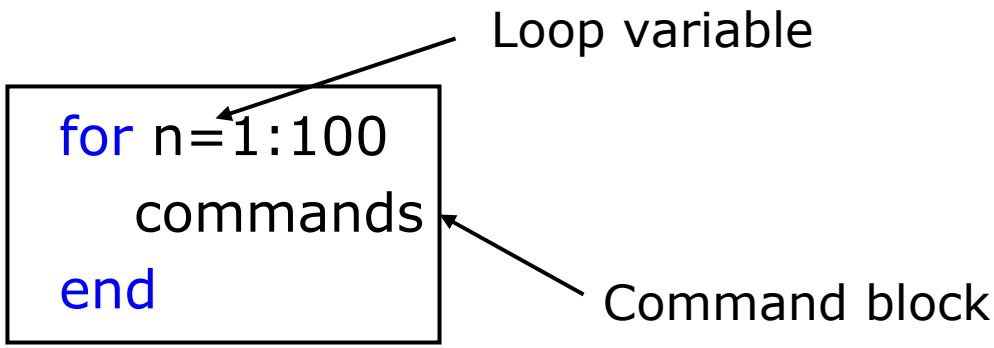
ELSEIF

```
if cond1
    commands1
elseif cond2
    commands2
else
    commands3
end
```

- No need for parentheses: command blocks are between reserved words

for

- **for** loops: use for a known number of iterations
- MATLAB syntax:



- The loop variable
  - Is defined as a vector
  - Is a scalar within the command block
  - Does not have to have consecutive values (but it's usually cleaner if they're consecutive)
- The command block
  - Anything between the **for** line and the **end**

while

- The while is like a more general for loop:
  - Don't need to know number of iterations

WHILE

```
while cond
    commands
end
```

- The command block will execute while the conditional expression is true
- Beware of infinite loops!

Exercise: Conditionals

- Modify your plotSin(f1) function to take two inputs: plotSin(f1,f2)
- If the number of input arguments is 1, execute the plot command you wrote before. Otherwise, display the line `'Two inputs were given'`
- Hint: the number of input arguments are in the built-in variable `nargin`

Exercise: Conditionals

- Modify your `plotSin(f1)` function to take two inputs: `plotSin(f1,f2)`

- If the number of input arguments is 1, execute the plot command you wrote before. Otherwise, display the line `'Two inputs were given'`
- Hint: the number of input arguments are in the built-in variable `nargin`

```
» function plotSin(f1,f2)

  x=linspace(0,2*pi,f1*16+1);
  figure

  if nargin == 1
      plot(x,sin(f1*x));
  elseif nargin == 2
      disp('Two inputs were given');
  end
```

Outline

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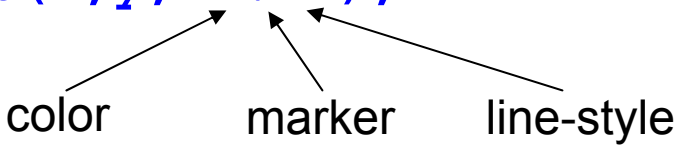
Plot Options

- Can change the line color, marker style, and line style by adding a string argument

```
» plot(x,y,'k.-');
```

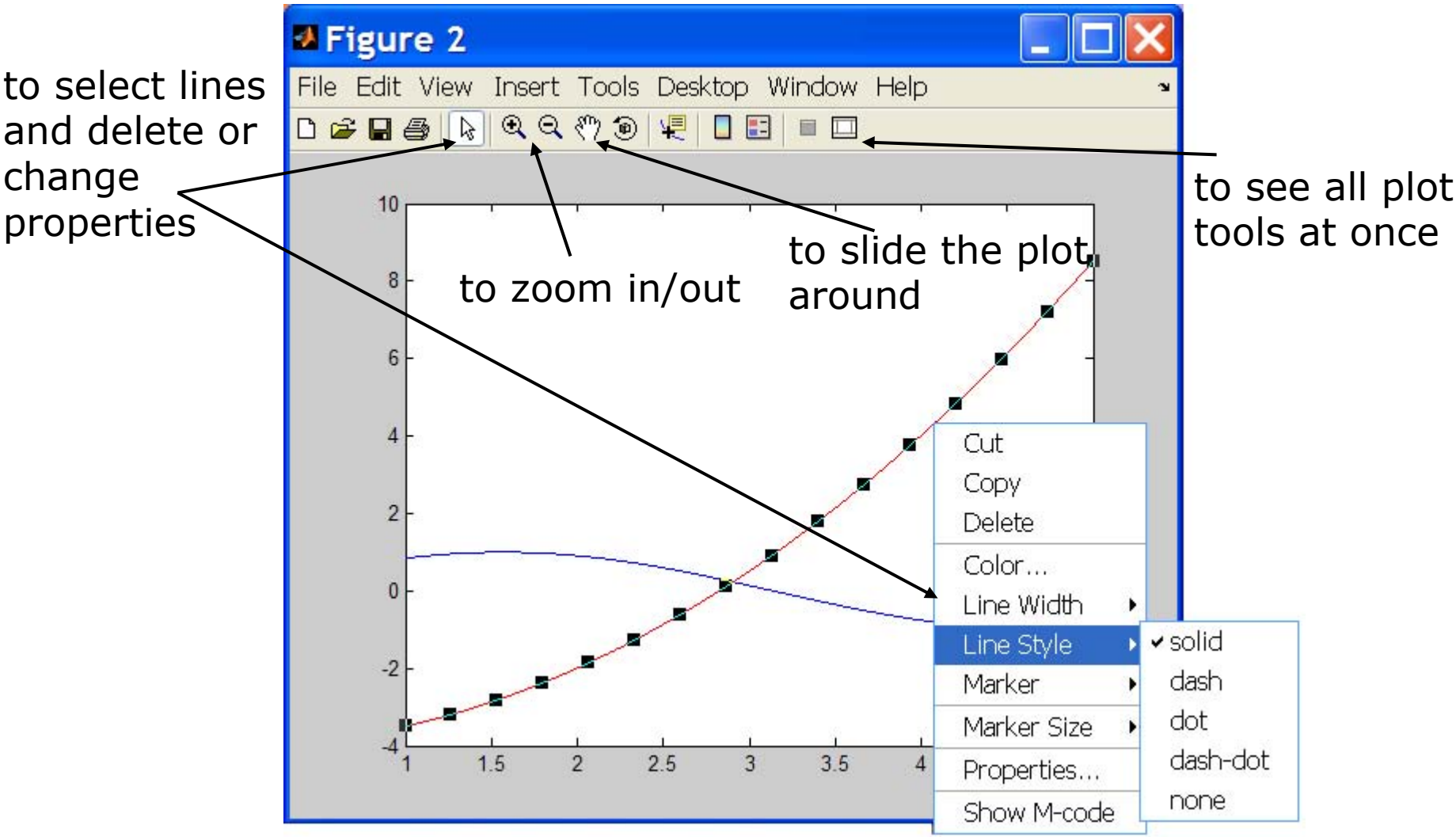


- Can plot without connecting the dots by omitting line style argument

```
» plot(x,y,'.')
```

- Look at **help plot** for a full list of colors, markers, and linestyles

Playing with the Plot

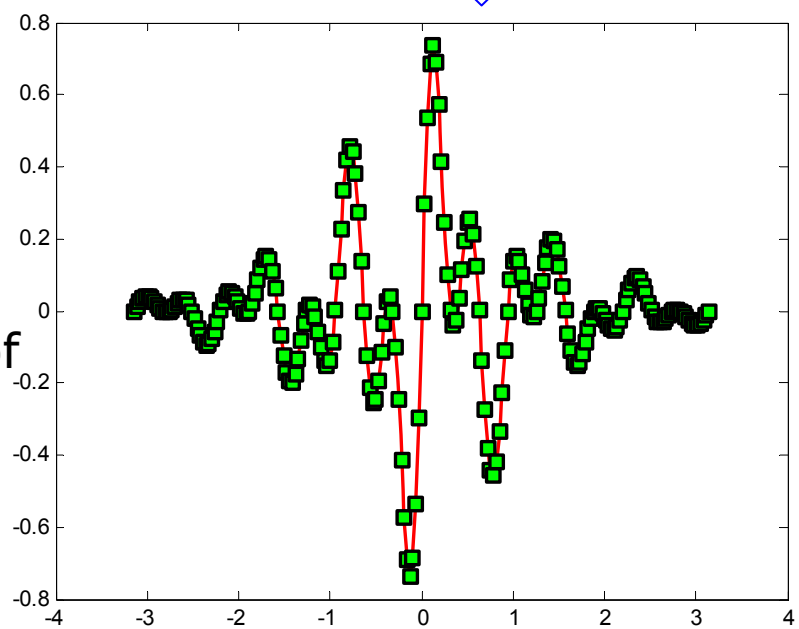


Line and Marker Options

- Everything on a line can be customized

```
» plot(x,y,'--s','LineWidth',2,...
           'Color', [1 0 0], ...
           'MarkerEdgeColor','k',...
           'MarkerFaceColor','g',...
           'MarkerSize',10)
```

You can set colors by using a vector of [R G B] values or a predefined color character like 'g', 'k', etc.



- See **doc line_props** for a full list of properties that can be specified

Cartesian Plots

- We have already seen the plot function

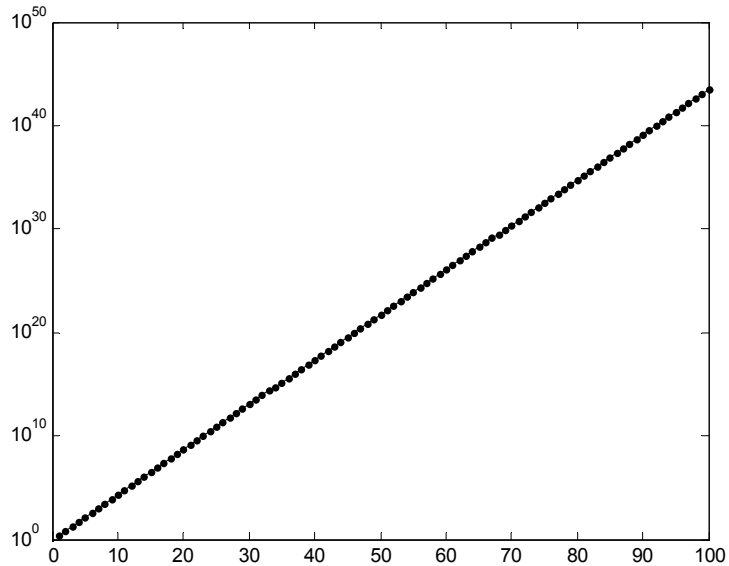
```
» x=-pi:pi/100:pi;
» y=cos(4*x).*sin(10*x).*exp(-abs(x));
» plot(x,y,'k-');
```

- The same syntax applies for semilog and loglog plots

```
» semilogx(x,y,'k');
» semilogy(y,'r.-');
» loglog(x,y);
```

- For example:

```
» x=0:100;
» semilogy(x,exp(x),'k.-');
```



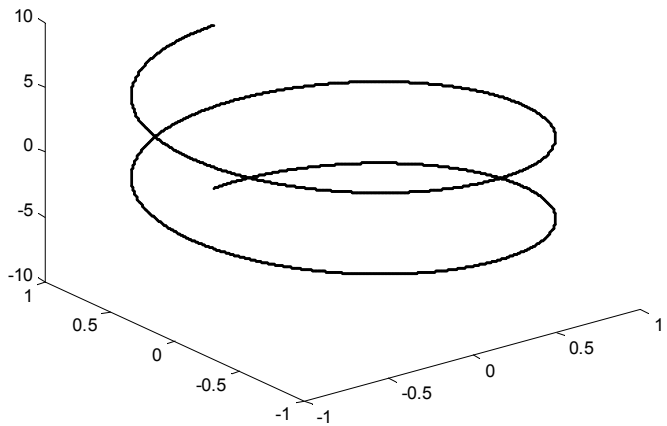
3D Line Plots

- We can plot in 3 dimensions just as easily as in 2

```
» time=0:0.001:4*pi;
» x=sin(time);
» y=cos(time);
» z=time;
» plot3(x,y,z,'k','LineWidth',2);
» zlabel('Time');
```

- Use tools on figure to rotate it
- Can set limits on all 3 axes

```
» xlim, ylim, zlim
```



Axis Modes

- Built-in axis modes

  - `» axis square`
    - makes the current axis look like a box
  - `» axis tight`
    - fits axes to data
  - `» axis equal`
    - makes x and y scales the same
  - `» axis xy`
    - puts the origin in the bottom left corner (default for plots)
  - `» axis ij`
    - puts the origin in the top left corner (default for matrices/images)

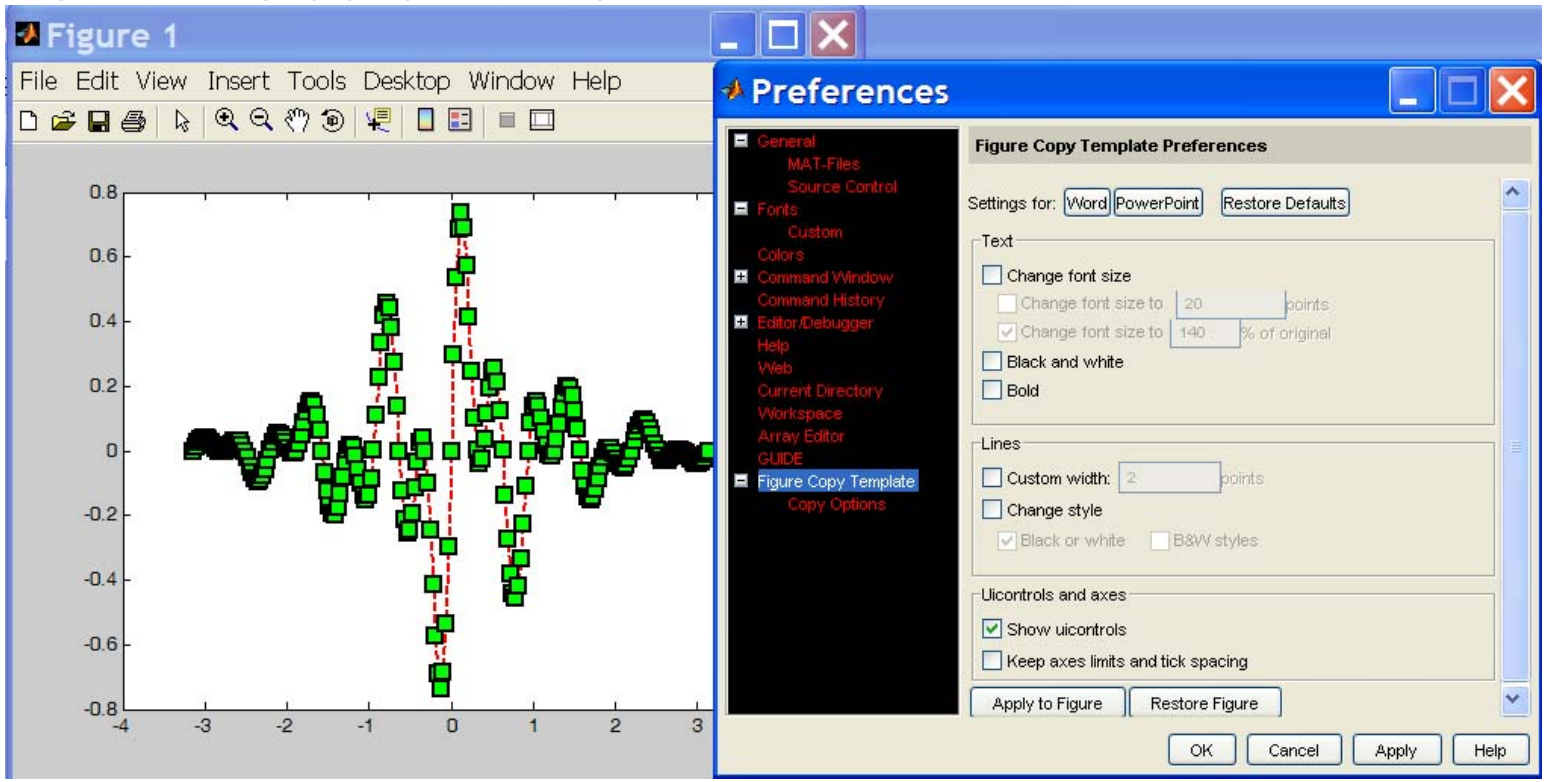
Multiple Plots in one Figure

- To have multiple axes in one figure
  - » `subplot(2,3,1)`
    - ➢ makes a figure with 2 rows and three columns of axes, and activates the first axis for plotting
    - ➢ each axis can have labels, a legend, and a title
  - » `subplot(2,3,4:6)`
    - ➢ activating a range of axes fuses them into one

- To close existing figures
  - » `close([1 3])`
    - ➢ closes figures 1 and 3
  - » `close all`
    - ➢ closes all figures (useful in scripts/functions)

Copy/Paste Figures

- Figures can be pasted into other apps (word, ppt, etc)
- *Edit→ copy options→ figure copy template*
  - Change font sizes, line properties; presets for word and ppt
- *Edit→ copy figure* to copy figure
- Paste into document of interest



Saving Figures

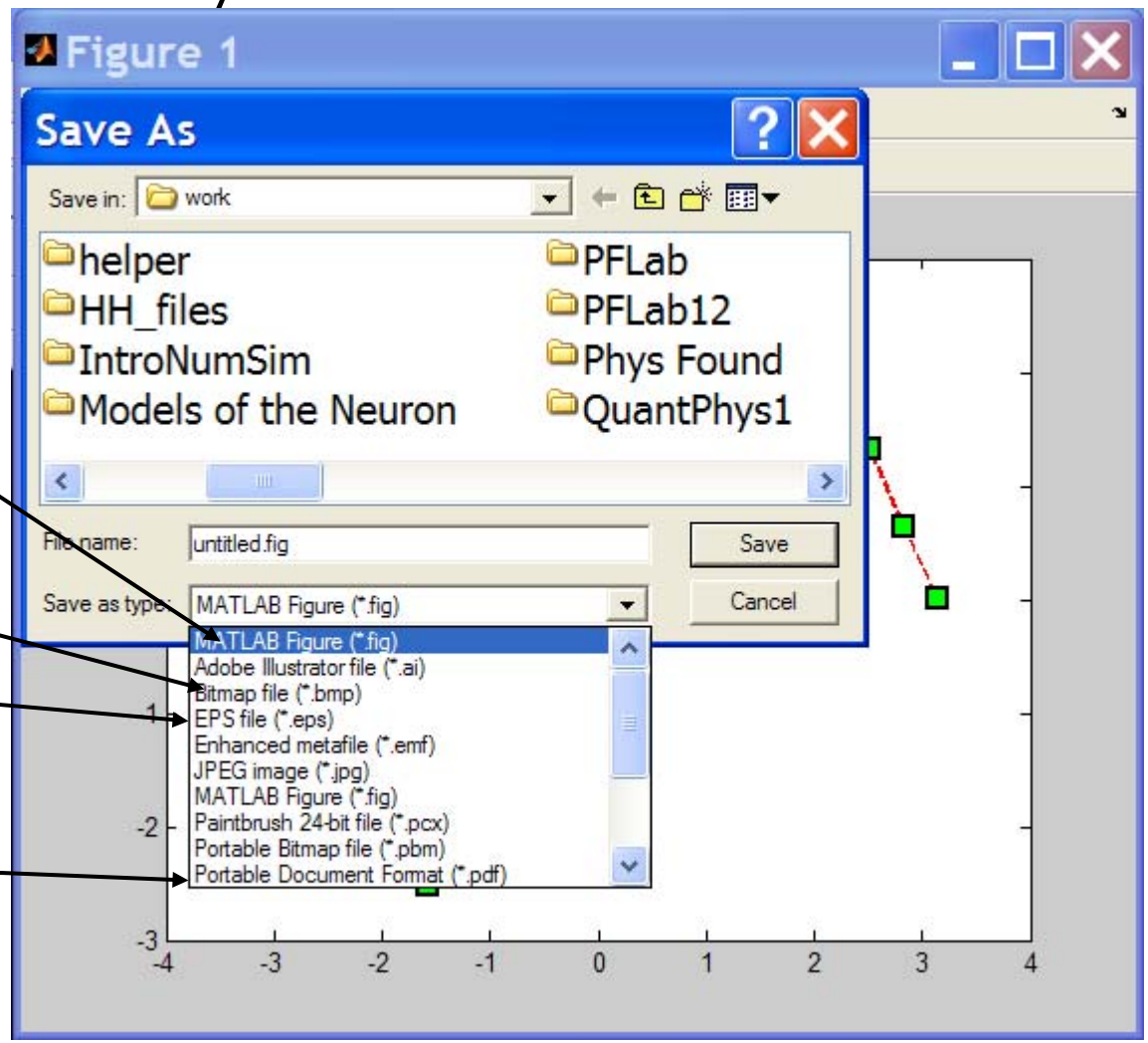
- Figures can be saved in many formats. The common ones are:

.fig preserves all information

.bmp uncompressed image

.eps high-quality scaleable format

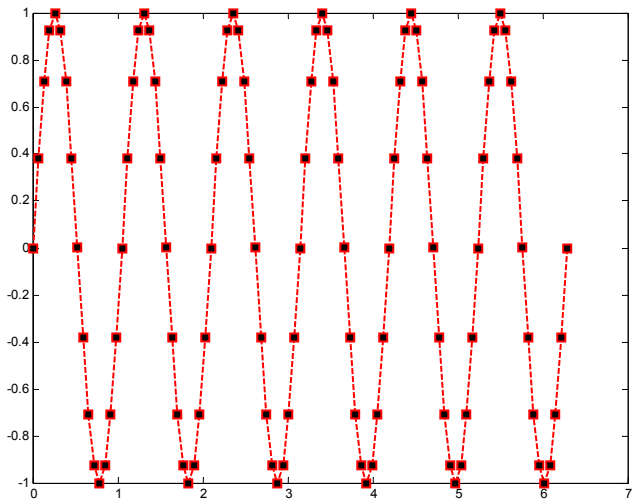
.pdf compressed image



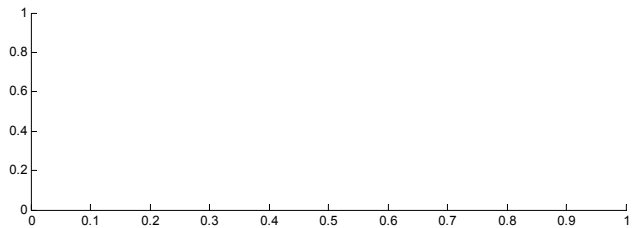
Advanced Plotting: Exercise

- Modify the plot command in your plotSin function to use **squares** as markers and a **dashed red** line of **thickness** 2 as the line. Set the marker face color to be **black** (properties are `LineWidth`, `MarkerFaceColor`)
- If there are 2 inputs, open a new figure with 2 axes, one on top of the other (not side by side), and activate the top one (`subplot`)

`plotSin(6)`



`plotSin(1,2)`



Advanced Plotting: Exercise

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- If there are 2 inputs, open a new figure with 2 axes, one on top of the other (not side by side), and activate the top one (`subplot`)

```
» if nargin == 1
      plot(x,sin(f1*x),'rs--',...
       'LineWidth',2,'MarkerFaceColor','k');
  elseif nargin == 2
      subplot(2,1,1);
  end
```

Outline

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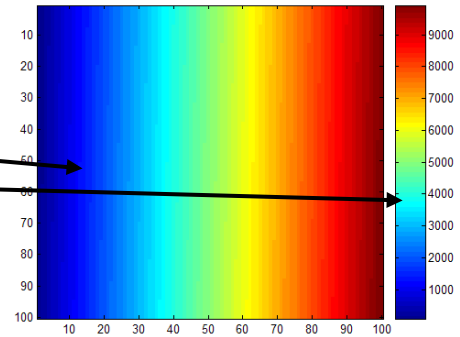
Visualizing matrices

- Any matrix can be visualized as an image

```
» mat=reshape(1:10000,100,100);
» imagesc(mat);
» colorbar
```



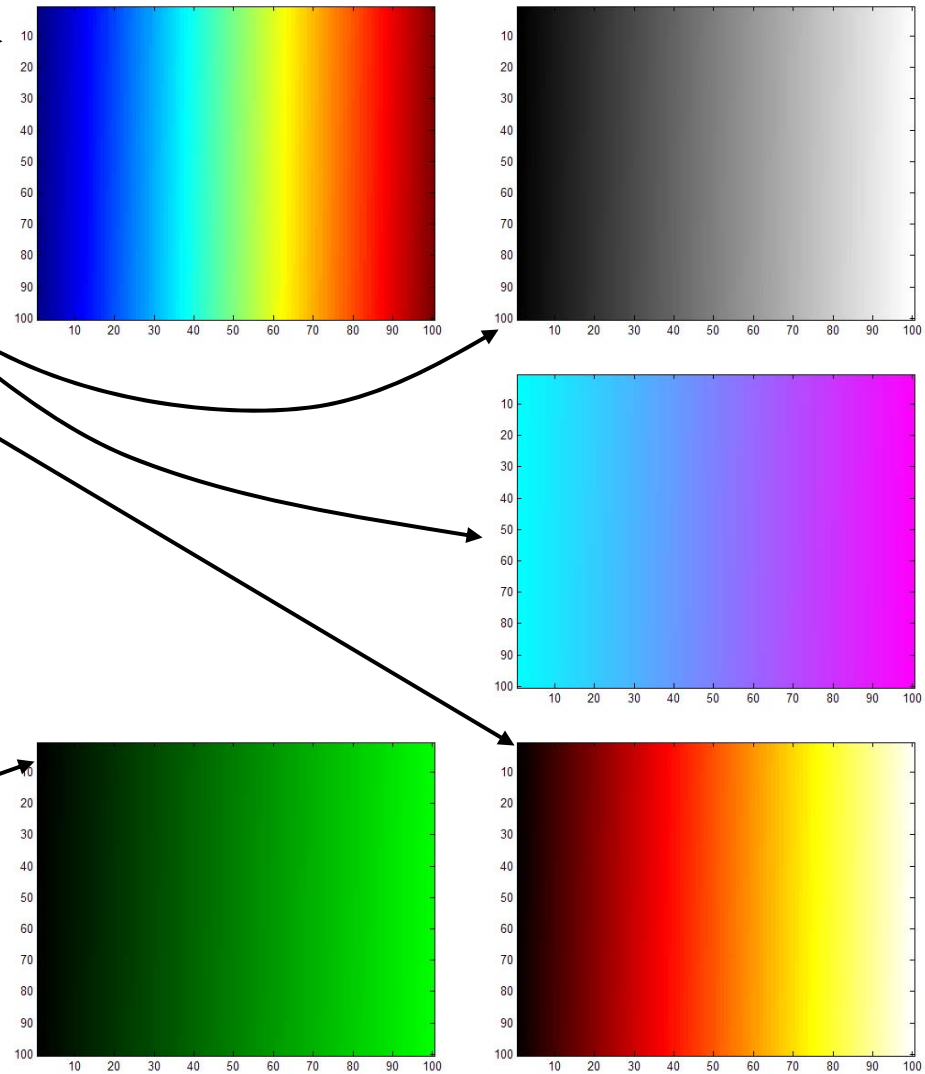
- **imagesc** automatically scales the values to span the entire colormap

- Can set limits for the color axis (analogous to **xlim**, **ylim**)

```
» caxis([3000 7000])
```

Colormaps

- You can change the colormap:
  - » `imagesc(mat)`
    - ➢ default map is jet
  - » `colormap(gray)`
  - » `colormap(cool)`
  - » `colormap(hot(256))`
- See `help hot` for a list
- Can define custom colormap
  - » `map=zeros(256,3);`
  - » `map(:,2)=(0:255)/255;`
  - » `colormap(map);`

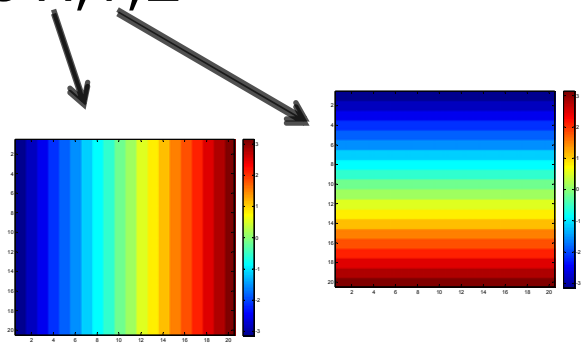


Surface Plots

- It is more common to visualize *surfaces* in 3D
- Example:

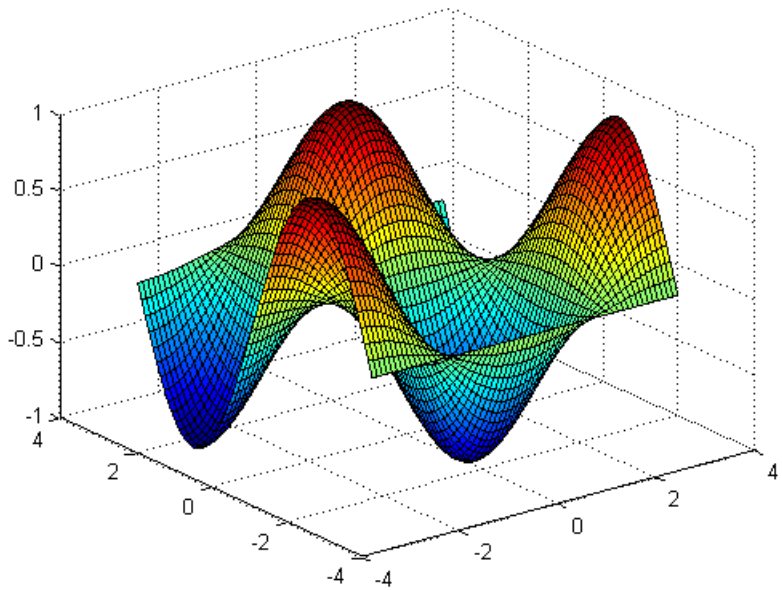
$$f(x,y) = sin(x)cos(y)$$
$$x \in [-\pi,\pi]; y \in [-\pi,\pi]$$

- **surf** puts vertices at specified points in space x,y,z, and connects all the vertices to make a surface
- The vertices can be denoted by matrices X,Y,Z
- How can we make these matrices
  - loop (DUMB)
  - built-in function: **meshgrid**



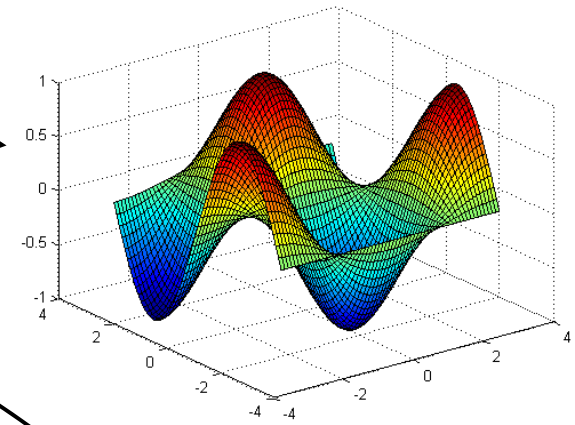
surf

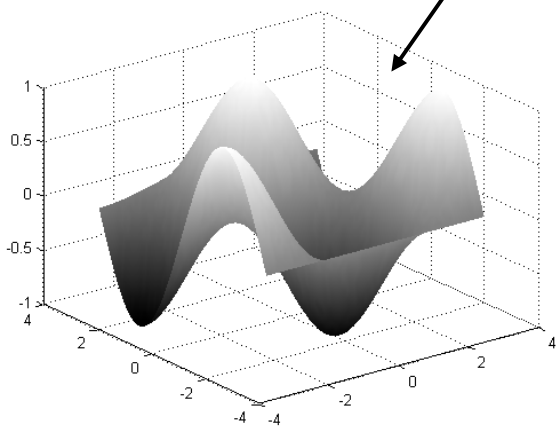
- Make the x and y vectors
  - `» x=-pi:0.1:pi;`
  - `» y=-pi:0.1:pi;`
- Use meshgrid to make matrices (this is the same as loop)
  - `» [X,Y]=meshgrid(x,y);`
- To get function values, evaluate the matrices
  - `» Z =sin(X).*cos(Y);`
- Plot the surface
  - `» surf(X,Y,Z)`
  - `» surf(x,y,Z);`

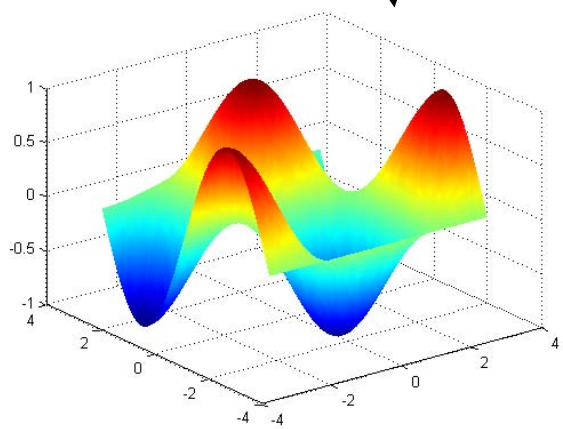


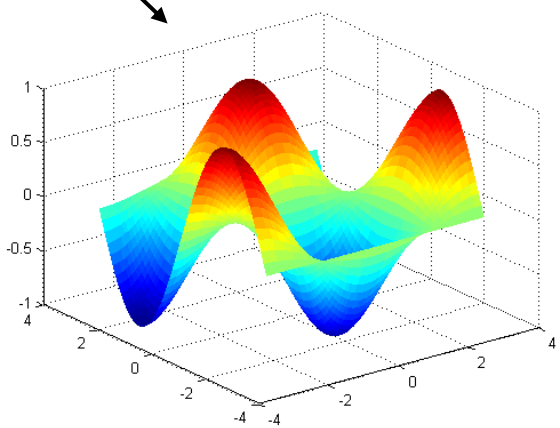
surf Options

- See **help surf** for more options
- There are three types of surface shading
  - » `shading faceted`
  - » `shading flat`
  - » `shading interp`
- You can change colormaps
  - » `colormap(gray)`



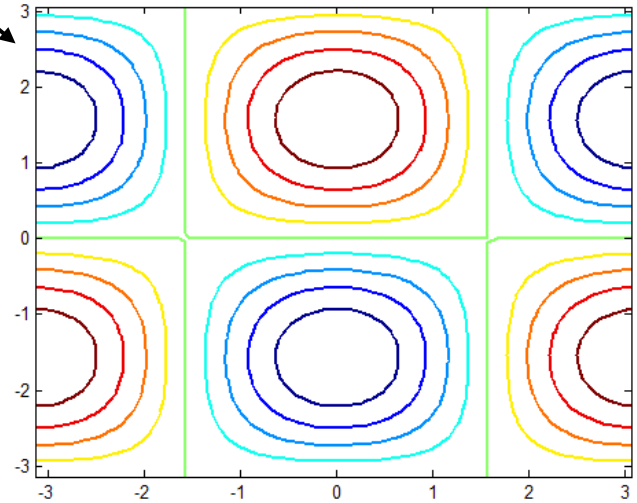


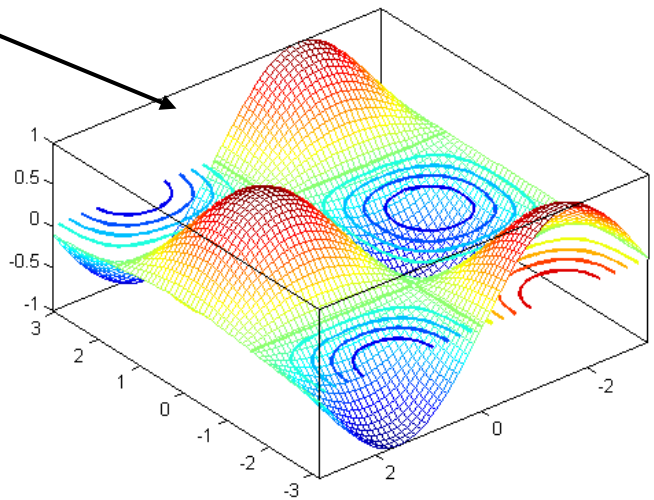




contour

- You can make surfaces two-dimensional by using contour
  - `» contour(X,Y,Z,'LineWidth',2)`
    - takes same arguments as surf
    - color indicates height
    - can modify linestyle properties
    - can set colormap
  - `» hold on`
  - `» mesh(X,Y,Z)`





Exercise: 3-D Plots

- Modify **`plotSin`** to do the following:
- If two inputs are given, evaluate the following function:

$$Z = \sin\left(f_1 x\right) + \sin\left(f_2 y\right)$$

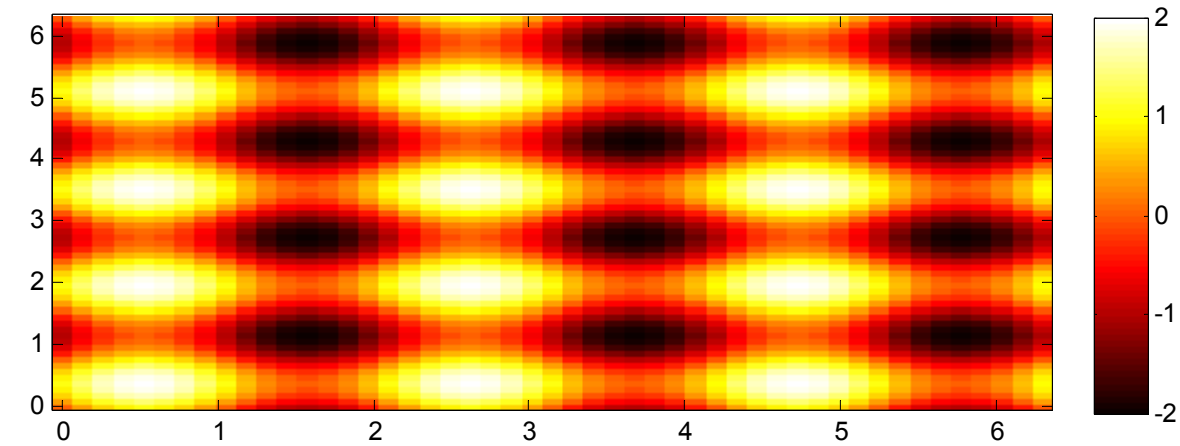
- y should be just like x, but using f2. (use **`meshgrid`** to get the X and Y matrices)
- In the top axis of your subplot, display an image of the Z matrix. Display the colorbar and use a **`hot`** colormap. Set the axis to xy (**`imagesc`**, **`colormap`**, **`colorbar`**, **`axis`**)
- In the bottom axis of the subplot, plot the 3-D surface of Z (**`surf`**)

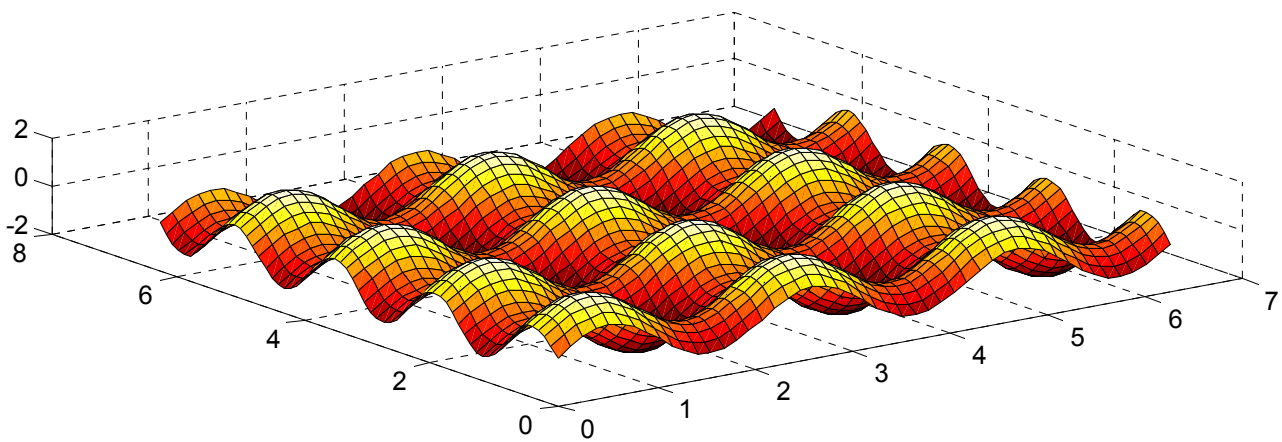
Exercise: 3-D Plots

```
» function plotSin(f1,f2)

  x=linspace(0,2*pi,round(16*f1)+1);
  figure

  if nargin == 1
      plot(x,sin(f1*x),'rs--',...
       'LineWidth',2,'MarkerFaceColor','k');
  elseif nargin == 2
      y=linspace(0,2*pi,round(16*f2)+1);
      [X,Y]=meshgrid(x,y);
      Z=sin(f1*X)+sin(f2*Y);
      subplot(2,1,1); imagesc(x,y,Z); colorbar;
      axis xy; colormap hot
      subplot(2,1,2); surf(X,Y,Z);
  end
```

Exercise: 3-D Plots

`plotSin(3,4)` generates this figure





Specialized Plotting Functions

- MATLAB has a lot of specialized plotting functions
- **polar**-to make polar plots

```
» polar(0:0.01:2*pi,cos((0:0.01:2*pi)*2))
```

- **bar**-to make bar graphs

```
» bar(1:10,rand(1,10));
```

- **quiver**-to add velocity vectors to a plot

```
» [X,Y]=meshgrid(1:10,1:10);
» quiver(X,Y,rand(10),rand(10));
```

- **stairs**-plot piecewise constant functions

```
» stairs(1:10,rand(1,10));
```

- **fill**-draws and fills a polygon with specified vertices

```
» fill([0 1 0.5],[0 0 1],'r');
```

- see help on these functions for syntax
- **doc specgraph** – for a complete list

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Revisiting find

- **find** is a very important function
  - Returns indices of nonzero values
  - Can simplify code and help avoid loops

- Basic syntax: index=find(cond)

```
» x=rand(1,100);
» inds = find(x>0.4 & x<0.6);
```

- **inds** will contain the indices at which x has values between 0.4 and 0.6. This is what happens:
  - x>0.4 returns a vector with 1 where true and 0 where false
  - x<0.6 returns a similar vector
  - The & combines the two vectors using an **and**
  - The find returns the indices of the 1's

Example: Avoiding Loops

- Given x= sin(linspace(0,10*pi,100)), how many of the entries are positive?

Using a loop and if/else

```
count=0;
for n=1:length(x)
    if x(n)>0
        count=count+1;
    end
end
```

Being more clever

```
count=length(find(x>0));
```

length(x)	Loop time	Find time
100	0.01	0
10,000	0.1	0
100,000	0.22	0
1,000,000	1.5	0.04

- Avoid loops!
- Built-in functions will make it faster to write and execute

Efficient Code

- Avoid loops
  - This is referred to as vectorization
- Vectorized code is more efficient for MATLAB
- Use indexing and matrix operations to avoid loops
- For example, to sum up every two consecutive terms:

```
» a=rand(1,100);
» b=zeros(1,100);
» for n=1:100
»     if n==1
»         b(n)=a(n);
»     else
»         b(n)=a(n-1)+a(n);
»     end
» end
```

  - Slow and complicated

```
» a=rand(1,100);
» b=[0 a(1:end-1)]+a;
```

  - Efficient and clean. Can also do this using `conv`

End of Lecture 2

(1) Functions
(2) Flow Control
(3) Line Plots
(4) Image/Surface Plots
(5) Vectorization

Vectorization makes coding fun!

6.094 Introduction to MATLAB®

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